ALTERNATIVE FRUIT CROPS FOR THE NORTHERN ROCKY MOUNTAIN CLIMATE- PRODUCTION AND QUALITY FACTORS OF CULTIVARS

by

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DEDICATION

I have no doubt that this thesis would not have come together without the aid, support, and encouragement of many people. First and foremost, I would like to thank my wife Melisa, who has never let me give up and has been my constant companion and Captain at Arms against life’s endless tirade. She provided the motivation to remember myself, my goals, and the big picture. My son, Sterling, that Melisa provided me, has helped me look to the future and envision how I want to shape myself, my family, and the world around me. Our shared family has provided plentiful support throughout the process, serving as mentors, companions, friends, siblings, grandparents, and the best of neighbors! When life got hard, they were there to push back the weight on my shoulders, pick me up and dust me off. Not to be discounted; my pooches Keats, Loki and Bailey have offered priceless guidance that only an animal can; the constant reminder to always be a puppy at heart, to never hold a grudge, to try new things and to clear your plate, to love with all of your heart and to look forward to each new day like it might be your last, leaving nothing on the table except a trail of paw-prints showing where you’ve been.

ACKNOWLEDGEMENTS

My education advisor Mac Burgess served as my advisor, friend, confidant, and mentor. My experiment advisor Zach Miller provided keen insights into the set-up of experiments, analysis, theory, and orchard management. Tracy Dougher was a supportive voice on my committee. Selena Ahmed was an encouraging mentor and the Food and Health Lab she administers was crucial to my research. Bridgid Jarrett coordinated the berry program at WARC. Ganesh Bala, the manager of the Mass Spectrometry Facility, provided considerable assistance in implementing UPHLC analysis of fruit compounds, analysis, and statistics.

The antioxidant (total phenolic concentration) analysis of the fruit was carried out in the Food and Health Lab at Montana State University under the supervision of Selena Ahmed with support from Lab Managers Debra Kraner and Rocio Rivas. Funding support for the total phenolic concentration analysis was provided by National Science Foundation EPSCoR Research Infrastructure Improvement Program: Track-2 Award (NSF RII Track-2 FEC OIA 1632810). The information provided here does not represent the views of the National Science Foundation.

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ABSTRACT

The demand for healthy foods is large and increasing. There are many high-antioxidant berry and fruit crops that fit this market but not all are suitable for cold climates. This study evaluates six novel fruit crops for Montana: Aronia, Black and Red Currant, Dwarf Sour Cherry, Haskap and Saskatoon. Trials were planted in 2015 in a randomized complete block design with three blocks per site, at three different sites in Montana. Qualities investigated include yield, fruit mass, soluble solids (SS), and total phenolic content (TPC).

The trialed species were generally well suited to Montana. Yields varied among cultivars and yields in Bozeman were smaller than other sites.

The following results incorporate data across sites from 2016 to 2018. Yield results are the most mature year. TPC is reported as milligrams of gallic acid equivalent per 100 grams of fresh fruit.

Aronia yields averaged 4061 grams, mean fruit mass was 0.89 grams. SS averaged 22° brix. TPC averaged 2800 mg. The cultivar McKenzie produced higher TPC than Viking.

Black Currant yields averaged 3784 grams; fruit mass averaged 1.15 grams. Mean SS were 17.5° brix. The cultivar Stikine produced the largest yield, Blackcomb the heaviest fruit, Titania the highest SS.

Red Currant yield in Corvallis averaged 5059 grams and mean fruit mass was 0.79 grams. The cultivar Jonkeer van Tets provided the largest yield and fruit mass.

Dwarf Sour Cherry yield averaged 6435 grams. Mean fruit mass and SS were 4.1 grams and 16.2° brix, respectively. The cultivar Carmine Jewel produced the largest yield, Lutowka Rose the largest fruit, and Romeo the highest SS. Crimson Passion did not flower at any site.

Haskap yield averaged 1364 grams, mean fruit mass was 1.2 grams and mean SS were 15.3° brix. Phenolic content averaged 919 milligrams. The cultivar 85-19 produced the largest yield, Aurora the largest fruit, Indigo Gem the highest SS, and Auroroa and Borealis the highest phenolic contents.

Saskatoon mean yield was 1567 grams. Mean fruit mass and SS were 1.02 grams and 20.1° brix, respectively. Northline produced the largest Saskatoon yield, Martin the heaviest fruit and Smoky the highest SS.

CHAPTER ONE: ALTERNATIVE FRUIT PRODUCTION OPPORTUNITIES IN THE NORTHERN ROCKIES

Fruit Production

There is a growing market for berries and fruits that are perceived to have health benefits. Fruits provide nutrition including fiber, minerals, vitamins, and phytonutrients and such compounds provide antiinflammation and antioxidant roles as well as being implicated with lower incidence of obesity and cardiovascular disease (Slavin and Lloyd, 2012) Recent research of the positive health benefits of berry consumption associates such consumption with benefits including improved neurological and bone health, reduced incidence of hypoglycemia and insulin resistance, and lower incidence of cancer (Celli et al. 2014). Nationally, there has been an observed trend of increased berry consumption. In the USA, overall berry consumption doubled from 5 pounds to 10 pounds per capita in the period from 2000 to 2015, (Statista, 2018). Blueberry consumption quadrupled from 1995 to 2015, to an estimated 1 billion pounds (IBO, 2016).

This growing demand has created a unique potential for domestic production of these types of fruits. Berry production is typically intensive agriculture, with higher economic returns on smaller plots of land than is typical to other conventional agriculture such as hay and cereal crops. Small fruit production has other advantages over tree and trellis production techniques. Such advantages include lower labor and capital requirements due to reduced maintenance and harvest requirements compared to the time intensive practices of trellising grapes or managing tall orchards like cherries and apples.

Recognizing this trend, the Montana Department of Agriculture has sought to identify suitable fruit species and cultivars which might help accomplish the Department's goals of; improving agricultural practices, increasing agricultural businesses success, capturing a higher value per product and land area, aiding start-up businesses, and strengthening communities through the diversification of food systems and economies.

One of many such ventures, the Montana Cold Hardy Fruit Trial, was established in 2015 to evaluate prospective fruit species and their cultivars. This project was conceived with the intention of identifying and assessing alternative fruit crops and cultivars thereof, with inherent value and marketability, suitable to intensive production in the cooler climates of the Northern Rocky Mountains.

Suitability

The environment and climate of Montana and the Northern Rocky Mountains impose numerous restrictions upon prospective crops and cropping systems. High elevations, freezing temperatures, and limited precipitation are common elements among this region. These geographical limitations do not preclude fruit production as crops like apples, which have substantial chilling requirements, succeed in these environments and are often more productive and of higher quality than they are in more temperate environments (Rai et al, 2015). As such, the criteria for species inclusion in the variety trial was conceived around the limiting factors of climate, which required cold hardy species capable of producing marketable crops in a short growing season. Included species were also selected on the basis of tolerance to basic soils, as are found in a majority of Montana. In addition, species were selected based on potential for commercial-scale production weighing factors including marketability and labor required for harvest and plant care.

Hardiness

A primary concern to agriculture in Montana and the surrounding area is hardiness to the cold climate. This geographic area experiences some of the harshest winters in the continental states. Freezing events occur frequently and for extended durations. These conditions preclude many species of fruit that are suited to more temperate climates (Magness and Traub, 1941.). There is variation in the chilling requirements within some species genomes, or among genotypes or typified cultivars, and therefore among their suitable regions of cultivation (Fear and Meyer, 1993). Thusly, species were selected on a basis of cold hardiness based upon their USDA Plant Hardiness Zone, with potential variation among available cultivars which might be assessed and compared within the trial.

Time to maturity

An important element in both perennial agriculture and research trials is time to maturity, both of plants over time and fruit within a season. Scientific research trials are typically conducted over a limited time period, corresponding to their length of funding. For the purposes of the Cold Hardy Fruit Trial, only species which had potential to reach relative maturity within 4 to 5 years were considered. Additionally, it was required that such species achieve fruit maturity successfully within the short growing season available. Time to maturity within a season is an important factor for producers, and quantifying when species and cultivars bear fruit might allow producers to fine tune their operations by targeting yield timing and or diversifying yields throughout the year.

From an agricultural production perspective, this time frame is also relevant as it approaches the maximum wait for a return on investment. Slow-maturing crops represent a considerable and risky investment to producers. Many production costs become recurrent upon planting; tasks such as irrigation, pest and weed control, and maintaining fertility occur regardless of marketable yield or income. For producers to feel secure in such an investment, they require plants which reliably survive and produce an income within a reasonable time frame. As such it is important to quantify the potential returns of such species and to differentiate whether there are cultivars within these species which possess optimal qualities relative to plant and fruit maturity.

Marketability

It is essential for any new crop to have marketable qualities. There are many characteristics which confer fruit and fruit products marketability. The requirements for inclusion in the trial included palatability, visual appeal, and healthful benefits.

Culture

Montana and the surrounding area are largely typified by soils with an annual soil-water deficit. As a result, most soils in agriculturally suitable areas are calcareous in nature. A neutral to acidic soil can be easily corrected to basic with the addition of lime, while acidification of soil is not practical in well-buffered soils. The species selected for trial were therefore chosen based on suitability to neutral to basic soils. This precluded crops like blueberries and other vaccinium species which require acidic soils.

Other cultural considerations for species selection included species which were orchard suitable; notably that the fruit were potentially machine harvestable, and also required that fruit species included be relatively pest tolerant.

Selected Species

Based upon the criteria of suitability to potential Montana fruit production, and of genetic diversity, six species of fruit were chosen. Each of these species is already in production in other agricultural systems and regions. The six species chosen were *Amelanchier alnifolia* (Saskatoon), *Lonicera caerulea* (Haskap), *Prunus fruiticosa x cerasus* (Dwarf Sour Cherry), *Ribes nigrum* (Black Currant), *Ribes rubrum* (Red Currant), and *Sorbaronia mitschurinii* (Aronia).

Aronia

Chokeberry (*Aronia melanocarpa*) is a cold hardy fruiting shrub of the Rosaceae family. Native to North America, the plant has been improved by hybridization with the European Mountain Ash (*Sorbus aucuparia*) and found popularity throughout the northern hemisphere. The hybrid is commonly known as Aronia. The plants are cold hardy (Zones 2-3) and flower in late spring, avoiding bloom-killing low temperatures and ensuring pollinators are active. Growth and maturity are both quick with sizeable yields and plants within five years. Despite sharing the environment with many Rosaceae pathogen co-hosts, minimal pathogen related issues were observed in Aronia plantings.

Aronia fruit is attractive, with red-black coloration and uniform sizes and shapes. The fruit is not commonly utilized for fresh consumption, as it contains high tannin contents that mask the high concentrations of solid solids. Aronia fruit has an extremely high phenolic content, far surpassing any conventional fruit crop. A high proportion of this phenolic content consists of anthocyanins which are valued both for their healthful antioxidant benefit, as well as their commercial use as a natural food colorant (Ochmian et al., 2012).

The majority of Aronia production occurs in Eastern Europe and Russia. Poland produces the majority of European Aronia, with 15,000 acres producing 35-40,000 tons of which 90% is exported as juice (NDSU, 2010). Production in the United States has reached 2100 acres as of 2017 (USDA, 2017). The cultivars McKenzie and Viking are both of Russian origin. According to the Natural Resources Conservation Service, McKenzie was released for primary use as a conservation planting in the USA, while Viking was developed for fruit production (Everhart, 2009). Known variety trials and evaluations have occurred at North Dakota State University (NDSU, 2010), and in Poland (Ochmian et al., 2012).

Currants

Currants are native across the Northern hemisphere, and in parts of South America and Africa. Over 150 species of *Ribes* have been described, and it is believed that no less than 18 of said species have contributed to domesticated germplasm which includes black, red, white, golden, and ornamental Currants, as well as gooseberries. Currant production has been occurring for roughly the last four centuries in Europe and Russia. Currants were a popular crop in North America until the early twentieth century, with over 7000 acres under cultivation in 1919, when white pine blister rust was recognized as a threat to white pine populations and prohibitions were put in place against Currant production, as Currants act as an alternate host to white pine blister rust. Only recently have these legal hurdles been lifted as it has been recognized that native populations of Currant exist in these areas and cannot reasonably be extirpated (Hummer and Barney, 2002).

Black Currant is a medium sized shrub growing to around 6 feet. All parts of the plant contain an aromatic compound, casis. Casis is utilized in liqueurs and perfumes primarily and has a piney scent and taste some people find disagreeable. The sulfurous compound responsible for such scent is known as cat ketone, a compound common to cat urine (Mouhib and Stahl, 2014). Cooking, drying or otherwise processing Black Currant fruit neutralizes the casis. Fruits themselves are sweet and juicy. Black Currants produce attractive fruit on small clusters of peduncles, with some cultivars' fruit nearly the size of small grapes. Advantageously, fruit tends to mature at the same time on a per plant basis.

Red Currant shrubs grow about the same size as Black Currants but have smaller leaves. Fruit are smaller than Black Currants and can occur in the same loose clusters or in longer trailing clusters similar to grapes. Red Currant fruits are high in ascorbic acid and low in soluble solids and are consequently not suitable for fresh consumption due to their tartness. Instead, Red Currants are utilized in a variety of processed food stuffs like jellies and compotes.

Currant cultivars largely originate from breeding programs in Russia and Europe, with Currant breeding programs existing in Poland, Russia, Scotland, New Zealand, Lithuania, and Estonia. Among the cultivars in the trial, Titania was derived from Sweden (Hummer and Barney, 2002) while Jonkheer Van Tets and Rovada originated in Holland (Hancock, 2008). Known Currant variety trials or previous evaluations have occurred at North Dakota State University (NDSU, 2010), Lithuania, Sweden, and Latvia (Sasnauskas et al., 2009), Finland (Zheng et al., 2012) and Serbia (Djordjevic et al., 2012).

Global production of black currant has remained relatively steady over the last three decades, with average production ranging from 500,000 to 700,000 metric tons per year. Nearly 99% of such production occurs in Europe (Faostat, 2019). The majority of this production is used domestically. The USDA reports 533 acres of currants in the USA while Statistics Canada reports 230 acres in Canada.

Dwarf Sour Cherry

Dwarf sour cherries are the result of a breeding program carried out in Canada beginning in the 1940's by Dr. Les Kerr. In 1966 the University of Saskatchewan initiated research of Dwarf Sour Cherries, obtained Dr. Kerr's selections in 1983 and began crossing European Sour Cherry cultivars with hardy hybrid selections (Bors, 2005). Sour cherries, *Prunus cerasus,* were interbred with Mongolian cherries, *Prunus fruiticosa*, with the goal of dwarfing sour cherry germplasm. Dwarf sour cherries lineage consists of 75% sour cherry and 25% Mongolian cherry. Such hybrids have initially been named *Prunus kerrasis* in honor of the original breeder. The University of Saskatchewan has released about half a dozen varieties to date, beginning in 1999. All varieties trialed originated at University of Saskatchewan except the Sour Cherry cultivar Lutowka Rose.

In 2011, nearly 200 commercial entities reported Dwarf Sour Cherry crops in production across Canada (NDSU, 2019). Largely, there is not demographic data or information available about the extent of plantings, production, or markets of Dwarf Sour Cherry. Sour Cherry production in the Americas rose above 140,000 metric tons in 2018, while nearly 1.4 million tonnes were produced in Europe and Asia (FAO, 2020). Variety trials and evaluations have occurred at the University of Saskatchewan and North Dakota State University.

Dwarf Sour Cherry plants are more shrub than tree and tend to have a terminal height around eight to twelve feet. Plantlets are self-rooted and produce many sucker shoots around the base. There are minimal differences in production from other sour cherries, the hybrids share the same pests and pathogens and are similarly vulnerable to abortion of flowers during late spring frosts. Dwarf Sour Cherries are reported to be cold hardy to around USDA Zone 3 by University of Saskatchewan.

One purported advantage over other sour cherries is that fruit have a wide window of harvest and can develop dark coloration, high soluble solids, and potential fresh consumption quality comparable to sweet cherries.

The largest potential advantage over conventional sour cherries is that of any intensive dwarfed crop; more plants per acre, potentially more precocious plants and crops and increased ease of harvest and maintenance (pruning and pest management) due to their smaller stature.

Haskap

Haskap, also commonly known as honeyberry and edible blue honeysuckle, is a fruiting species of honeysuckle that is native to the boreal forests of the northern hemisphere. The cold-hardy plant produces blue cylindrical fruit in early spring, typically small and bitter among native populations, but up to 3 grams and with a favorable flavor commonly described as blue raspberry among domesticated varieties. Traditionally, the fruit has been utilized by indigenous populations in northern Asia.

Modern domestication efforts began in the early 1900’s in Russia and Canada. The first developments in North American occurred in the 1920’s when haskap seeds were grown out at an Agriculture Research Station in Alberta. Two cultivars, Georges Bugnet and Julia Bugnet were released, but were not received well by nurseries or the public as they were low yielding, small in fruit size and unsavory. In Russia, serious domestication efforts began in the 1950's, spawning at least 70 cultivars to date (Hummer, 2006). There has also been extensive Haskap development in Poland and Czechoslovakia. Interest in breeding programs developed in Saskatchewan in the late 1990's (Bors, n.d.) and Oregon in 2000 (Thompson, 2006). Of the cultivars included in the trial; Aurora, Boreal Blizzard, Borealis, and Indigo Gem originated from the University of Saskatchewan's breeding program, Solo, Kawai, Keiko, Tana, Taka, and the numbered lines 79-9,141-75, and 85-19 from Oregon State Universities (OSU) breeding program, Sugar Mountain Blue from the Czech Republic and Blue Corn, Blue Goose, and Wild Treasure were sourced from the company Berries Unlimited.

Little information exists about Haskap production worldwide, but the majority of production and consumption occurs in Japan, Poland, the Czech Republic and Russia. The European Union did not approve Haskap fruit for trade until 2018, so European inter-state trade was limited until the recent legislative change. Statistics Canada reports 1500 acres of Haskap in Canada valued at $2.3 million CAD.

Known variety trials and evaluations have occurred at North Dakota State University, University of Saskatchewan, Oregon State University, in the Czech Republic (Sochor et al., 2014), Poland (Kucharska et al., 2017), and Nova Scotia (Khattab et al., 2016).

Haskap is an early flowering and maturing crop with tremendous cold hardiness (Zone 2-3). The earlier flowering plants can have trouble with adequate pollination due to temperatures being too low for insect pollinators to be active.

According to the University of Saskatchewan, Haskap has few pests or diseases. This was found to be largely true in the trial, though fruit predation by birds could reach extremes if not checked.

Saskatoon

Saskatoons, a fruiting species of the Rosaceae family, are found throughout North America. The plants and fruit are also commonly known as Juneberries or some variation of Serviceberry, depending on geographic locale.

Saskatoon plants can take up to 10 years to reach maximum yields. Saskatoon plants can reach sizes comparable to apple trees at 10 plus feet.

Saskatoon produces large and juicy fruit in early summer that are quite similar to blueberries in most regards. However, the plants do better in neutral to basic soils than blueberries.

The majority of cultivars of Saskatoon have been selected from wild plants based on favorable traits. (Spencer et al., 2013). Most production and consumption occur in Canada, with 2700 acres reported, valued at $2.1 CAD (Statistics Canada, 2020).

Saskatoon plants are cold hardy to USDA zone 3. Saskatoons are somewhat susceptible to both pests and disease, as there are often other wild Saskatoon plants and common Rosaceae pests and pathogens occurring in the local environment. For this reason, Saskatoon might be a poor companion crop to other vulnerable crops of the Rosaceae family like apples (Spencer, et al., 2013, St. Pierre, 1992).

Experiments

Experiment Locations

Cultivar evaluations consisted of a multisite trial of six fruit species, planted at four sites across the state in the late spring of 2015. Sites were located near urban centers (Kalispell, Missoula, Bozeman, and Helena) to evaluate performance in areas with established local-food markets and producers. One site was located at the Montana State University Western Agricultural Research Station (WARC) in Corvallis and was managed by the Superintendent of WARC, Zach Miller, and Bridgid Jarrett. A second site was located at the Flathead Valley Community College Learning Farm (FVCC) in Kalispell and was managed by the farm manager, Julian Cunningham and an ag professor, Heather Estrada, from FVCC. The third site was split between two private properties in Helena, which were managed by the landowners and the Lewis and Clark county extension agent Brent Sarchet. Data from Helena was not included in this document, as the two properties were dissimilar. The fourth site was located on the MSU Bozeman Horticulture Farm and was managed by the author, Durc Setzer and his academic advisor, Mac Burgess.

Experimental Design

At each site, the fruit species were arranged in a Randomized Complete Block Design with three blocks per site. Main plots were species. For each species, the cultivars were treated as a split-plot treatment. The locations of the cultivars were randomly assigned within the area designated for that species. In a block, each cultivar was represented by three plants, with one plant per row in the same position in three adjacent rows.

Across all sites, 26 varieties of six fruit species were evaluated. Cultivars were selected based on potential performance based on previous trials and availability. Fifteen additional cultivars were added at the MSU-WARC site.

Amelanchier alnifolia (Saskatoon) cultivars at all sites included Martin, Smoky, Northline, Lee 3, Lee 8, and JB30.

Ribes nigrum (Black Currant) cultivars at all sites included Titania, Blackcomb, Stikine and Tofino. Additional cultivars at the WARC site included M12, Cheakamus, Tahsis, and Whistler.

Ribes rubrum (Red Currant) cultivars at all sites included Rovada and HRON. Additional cultivars at the WARC site included Jonkeer van Tets.

Sorbaronia mitschurinii (Aronia) cultivars at all sites included Viking and McKenzie. WARC additionally included Autumn Magic.

Prunus fruiticosa x cerasus (Dwarf Sour Cherry) cultivars at all sites included Romeo, Juliet, Carmine Jewel, and Crimson Passion. The additional sour cherry cultivar Lutowoka Rose was included at Corvallis.

Lonicera caerulea (Haskap) cultivars at all sites included Indigo Gem, Aurora, Borealis, Sugar Mountain Blue, Boreal Blizzard, Solo, 41-75, and 85-19. Additional cultivars at the WARC site included Blue Corn, Blue Goose, Wild Treasure, Kawai, Taka, Tana, Keiko, 41-75, and 79-91.

CHAPTER TWO: FRUIT YIELD FACTORS

Summary

Cold hardy berries and small fruits may have potential for production in the N. Rockies. To identify better suited species and varieties, replicated trials were planted in 2015 at three sites in Montana: Bozeman, Corvallis, and Kalispell. 28 varieties of Aronia, Saskatoons, Black and Red Currants, Haskaps, and Dwarf Sour Cherries were planted at all sites with additional varieties included at the Corvallis site. Yields and fruit mass in the third and fourth year were compared among varieties within each fruit species.

All species appeared well adapted to Montana climates and soils, with cold and frost injury observed in one Dwarf Sour Cherry and four, early flowering Haskap varieties.

Yields differed among sites. Yields at the Corvallis site were typically five to ten times greater than Bozeman and 50% to 2 times greater than Kalispell. Management and climate may drive these differences in yield among sites. Yields for all species were continuing to increase annually, suggesting the plants have not reached their maximum mature yields. Differences among varieties in yield and fruit size were generally consistent among sites. Commercial Aronia varieties (Viking and McKenzie) had similar yields that were much greater than an ornamental variety (Autumn Magic). Several Black Currant varieties had yields that exceeded the reference variety, Titania. Most red and Black Currant varieties produced yields that were greater than 3 kg per plant which is relatively high compared to previous trials conducted in different areas. Dwarf sour cherries did not produce consistent crops in Bozeman but did in Kalispell and Corvallis. Carmine Jewel was the most productive Dwarf Sour Cherry (8 to 9 kg per plant in 2018), but Juliet and Romeo, planted one year later, were on track to have similarly high yields.

Haskaps produced as much as 3 kg per plant in the fourth year. Yield differences among varieties were driven by fruit size and when the fruit matured. Early varieties had small fruit and yields compared to mid-season (early-July) and late-season (late July-early August) varieties. Indigo Gem was the most productive early variety. Both mid-season varieties, Aurora and Borealis, produced large crops (1.5-2.5 kg per plant) in the fourth year. Among the late-season varieties, 85-19 and Tana, had greater yields (3 kg per plant in 2018) than the majority of varieties in Kalispell and Corvallis. Saskatoons were prone to crop loss due to an insect pest, the Saskatoon sawfly, at all sites. Management of this pest may be required for increased yields. Maximum yield reached up to 5 kg per bush in Corvallis in Year 4. Northline, Lee 8, and Smoky were often higher yielding than Martin, JB30, and Lee 3.

Introduction

The Montana Cold Hardy Fruit Trial was established in 2015 to evaluate prospective fruit species and their cultivars. This project was conceived with the intention of identifying and assessing alternative fruit crops and cultivars thereof, with inherent value and marketability, suitable to intensive production in the cooler climates of the Northern Rocky Mountains. The trial seeks to identify yield and quality factors of cultivars and of their fruit. Yield factors of interest were total yield and fruit mass. Quantifying yield and fruit mass offer valuable information for growers to make informed decisions about which cultivars should be included in their orchard and is also important feedback for the breeding programs from which novel cultivars originated.

The project is relatively unique in that there have been few such multi-species, and even fewer multi-site, scientific trials in recent times. One such trial at the North Dakota State

University Carrington Research Site has reported on novel fruit crops performance since 2009. While this trial has generated a tremendous about of usable data, such data has been presented as summary statistics and no statistical cultivar comparisons have taken place. Furthermore, the Carrington trial is limited to one location and cannot evaluate cultivars and species over varying climates, elevations, and latitude. As such, there is a tremendous need to observe these novel species performances in a controlled and replicated scientific manner across different environments in order to quantify the traits of species and cultivars. Additionally, there now exist new offerings from breeding programs which have not been evaluated in other cultivar trials.

Based upon the criteria of suitability to potential Montana fruit production, and of genetic diversity, six species of fruit were chosen. Each of these species is already in production in other agricultural systems and regions. The six species chosen were *Amelanchier alnifolia* (Saskatoon), *Lonicera caerulea* (Haskap), *Prunus fruiticosa x cerasus* (Dwarf Sour Cherry), *Ribes nigrum* (Black Currant), *Ribes rubrum* (Red Currant), and *Sorbaronia mitschurinii* (Aronia).

Three different locations in Montana were utilized for research sites: Bozeman, Corvallis and Kalispell. Across all sites, 26 varieties of six fruit species were evaluated. Cultivars were selected based on potential performance based on previous trials and availability. Fifteen additional cultivars were added at the MSU-WARC site.

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Aronia fruit is attractive, with red-black coloration and uniform sizes and shapes. The fruit is not commonly utilized for fresh consumption, as it contains high tannin contents that mask the high concentrations of solid solids. Aronia fruit has an extremely high phenolic content, far surpassing any conventional fruit crop. A high proportion of this phenolic content consists of anthocyanins which are valued both for their healthful antioxidant benefit, as well as their commercial use as a natural food colorant (Ochmian et al., 2012).

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Black Currant is a medium sized shrub growing to around 6 feet. All parts of the plant contain an aromatic compound, casis. Casis is utilized in liqueurs and perfumes primarily and has a piney scent and taste some people find disagreeable. The sulfurous compound responsible for such scent is known as cat ketone, a compound common to cat urine (Mouhib and Stahl, 2014). Cooking, drying or otherwise processing Black Currant fruit neutralizes the casis. Fruits themselves are sweet and juicy. Black Currants produce attractive fruit on small clusters of peduncles, with some cultivars' fruit nearly the size of small grapes. Advantageously, fruit tends to mature at the same time on a per plant basis.

Red Currant shrubs grow about the same size as Black Currants but have smaller leaves. Fruit are smaller than Black Currants and can occur in the same loose clusters or in longer trailing clusters similar to grapes. Red Currant fruits are high in ascorbic acid and low in soluble solids and are consequently not suitable for fresh consumption due to their tartness. Instead, Red Currants are utilized in a variety of processed food stuffs like jellies and compotes.

Currant cultivars largely originate from breeding programs in Russia and Europe, with Currant breeding programs existing in Poland, Russia, Scotland, New Zealand, Lithuania, and Estonia. Among the cultivars in the trial, Titania was derived from Europe while Jonkheer Van Tets and Rovada originated in Holland (Hancock, 2008). Known Currant variety trials or previous evaluations have occurred at North Dakota State University (NDSU, 2010), Lithuania, Sweden, and Latvia (Sasnauskas et al., 2009), Finland (Zheng et al., 2012) and Serbia (Djordjevic et al., 2012).

Global production of Black Currant has remained relatively steady over the last three decades, with average production ranging from 500,000 to 700,000 metric tons per year. Nearly 99% of such production occurs in Europe (Faostat, 2019). The majority of this production is used domestically. The USDA reports 533 acres of currants in the USA while Statistics Canada reports 230 acres in Canada.

Dwarf Sour Cherry

Dwarf Sour Cherries are the result of a breeding program carried out in Canada beginning in the 1940's by Dr. Les Kerr. In 1966 the University of Saskatchewan initiated research of Dwarf Sour Cherries, obtained Dr. Kerr's selections in 1983 and began crossing European Sour Cherry cultivars with hardy hybrid selections (Bors, 2005). Sour Cherries, *Prunus cerasus*, were interbred with Mongolian cherries, *Prunus fruiticosa*, with the goal of dwarfing Sour Cherry germplasm. Dwarf Sour Cherries lineage consists of 75% Sour Cherry and 25% Mongolian Cherry. Such hybrids have initially been named *Prunus kerrasis* in honor of the original breeder. The University of Saskatchewan has released about half a dozen varieties to date, beginning in 1999. All varieties trialed originated at University of Saskatchewan except the Sour Cherry cultivar Lutowka Rose.

In 2011, nearly 200 commercial entities reported Dwarf Sour Cherry crops in production across Canada (NDSU, 2019). Largely, there is not demographic data or information available about the extent of plantings, production, or markets of Dwarf Sour Cherry. Sour Cherry production in the Americas rose above 140,000 metric tons in 2018, while nearly 1.4 million metric ton were produced in Europe and Asia (FAO, 2020). Variety trials and evaluations have occurred at the University of Saskatchewan and North Dakota State University.

Dwarf Sour Cherry plants are more shrub than tree and tend to have a terminal height around eight to twelve feet. Plantlets are self-rooted and produce many sucker shoots around the base. There are minimal differences in production from other sour cherries, the hybrids share the same pests and pathogens and are similarly vulnerable to abortion of flowers during late spring frosts. Dwarf Sour Cherries are reported to be cold hardy to around USDA Zone 3 by University of Saskatchewan.

One purported advantage over other sour cherries is that fruit have a wide window of harvest and can develop dark coloration, high soluble solids, and potential fresh consumption quality comparable to sweet cherries.

The largest potential advantage over conventional sour cherries is that of any intensive dwarfed crop; more plants per acre, potentially more precocious plants and crops and increased ease of harvest and maintenance (pruning and pest management) due to their smaller stature.

<u>Haskap</u>

Haskap, also commonly known as honeyberry and edible blue honeysuckle, is a fruiting species of honeysuckle that is native to the boreal forests of the northern hemisphere. The cold-hardy plant produces blue cylindrical fruit in early spring, typically small and bitter among native populations, but up to 3 grams and with a favorable flavor commonly described as blue raspberry among domesticated varieties. Traditionally, the fruit has been utilized by indigenous populations in northern Asia.

Modern domestication efforts began in the early 1900’s in Russia and Canada. The first developments in North American occurred in the 1920’s when haskap seeds were grown out at an Agriculture Research Station in Alberta. Two cultivars, Georges Bugnet and Julia Bugnet were released, but were not received well by nurseries or the public as they were low yielding, small in fruit size and unsavory. In Russia, serious domestication efforts began in the 1950's, spawning at least 70 cultivars to date (Hummer, 2006). There has also been extensive Haskap development in Poland and Czechoslovakia. Interest in breeding programs developed in Saskatchewan in the late 1990's (Bors, n.d.) and Oregon in 2000 (Thompson, 2006). Of the cultivars included in the trial; Aurora, Boreal Blizzard, Borealis, and Indigo Gem originated from the University of Saskatchewan's breeding program, Solo, Kawai, Keiko, Tana, Taka, and the numbered lines 79-9,141-75, and 85-19 from Oregon State Universities (OSU) breeding program, Sugar Mountain Blue from the Czech Republic and Blue Corn, Blue Goose, and Wild Treasure were sourced from the company Berries Unlimited.

Little information exists about Haskap production worldwide, but the majority of production and consumption occurs in Japan, Poland, the Czech Republic and Russia. The European Union did not approve Haskap fruit for trade until 2018, so European inter-state trade was limited until the recent legislative change. Statistics Canada reports 1500 acres of Haskap in Canada valued at $2.3 million CAD.

Known variety trials and evaluations have occurred at North Dakota State University, University of Saskatchewan, Oregon State University, in the Czech Republic (Sochor et al., 2014), Poland (Kucharska et al., 2017), and Nova Scotia (Khattab et al., 2016).

Haskap is an early flowering and maturing crop with tremendous cold hardiness (Zone 2-3). The earlier flowering plants can have trouble with adequate pollination due to temperatures being too low for insect pollinators to be active.

According to the University of Saskatchewan, Haskap has few pests or diseases. This was found to be largely true in the trial, though fruit predation by birds could reach extremes if not checked.

Saskatoon

Saskatoons, a fruiting species of the Rosaceae family, are found throughout North America. The plants and fruit are also commonly known as Juneberries or some variation of Serviceberry, depending on geographic locale.

Saskatoon plants can take up to 10 years to reach maximum yields. Saskatoon plants can reach sizes comparable to apple trees at 10 plus feet.

Saskatoon produces large and juicy fruit in early summer that are quite similar to blueberries in most regards. However, the plants do better in neutral to basic soils than blueberries.

The majority of cultivars of Saskatoon have been selected from wild plants based on favorable traits. (Spencer et al., 2013). Most production and consumption occur in Canada, with 2700 acres reported, valued at $2.1 CAD (Statistics Canada, 2020).

Saskatoon plants are cold hardy to USDA zone 3. Saskatoons are somewhat susceptible to both pests and disease, as there are often other wild Saskatoon plants and common Rosaceae pests and pathogens occurring in the local environment. For this reason, Saskatoon might be a poor companion crop to other vulnerable crops of the Rosaceae family like apples (Spencer, et al., 2013, St. Pierre, 1992).

Materials, Methods and Hypotheses

Experiment Locations

Cultivar evaluations consisted of a multisite trial of six fruit species, planted at four sites across the state in the late spring of 2015. Sites were located near urban centers (Kalispell, Missoula, Bozeman, and Helena) to evaluate performance in areas with established local-food markets and producers. One site was located at the Montana State University Western Agricultural Research Station (WARC) in Corvallis and was managed by the Superintendent of WARC, Zach Miller, and Bridgid Jarrett. A second site was located at the Flathead Valley Community College Learning Farm (FVCC) in Kalispell and was managed by the farm manager, Julian Cunningham and an ag professor, Heather Estrada, from FVCC. The third site was split between two private properties in Helena, which were managed by the landowners and the Lewis and Clark county extension agent Brent Sarchet. Data from Helena was not included in this document, as the two properties were dissimilar. The fourth site was located on the MSU Bozeman Horticulture Farm and was managed by the author, Durc Setzer and his academic advisor, Mac Burgess.

Experimental Design

At each site, the fruit species were arranged in a Randomized Complete Block Design with three blocks per site. Main plots were species. For each species, the cultivars were treated as a split-plot treatment. The locations of the cultivars were randomly assigned within the area designated for that species. In a block, each cultivar was represented by three plants, with one plant per row in the same position in three adjacent rows.

Orchard Establishment

The majority of cultivars were planted in the spring of 2015. The Haskap cultivar Boreal Blizzard and the Dwarf Sour Cherry cultivars Romeo and Juliet were not planted until spring in 2016. Many Currant varieties were replanted in 2016, as bare-root plants were un-expectedly not available in 2015 and the unrooted cane-cuttings which were planted instead had poor survival rates at the Bozeman and Kalispell sites.

In order to control growth, plants which flowered in 2015 had said flowers manually removed to eliminate reproductive growth in favor of vegetative growth.

Orchards were established with the intent of replicating systems in which mechanized harvesting could occur. To accommodate harvesting equipment, orchard alleys were set up at 12 feet from row centers.

In-row spacing of plants varied per species based on their expected growth habits. Haskaps were spaced three feet apart, Dwarf Sour Cherry was planted three- and one-half feet apart, Currants and Aronia were spaced four feet apart, and Saskatoons were planted with five foot spacing.

Irrigation was accomplished via slow flow drip systems starting in 2015, with all species irrigated equally. Irrigation was supplemental to rainfall and was not operated when site managers determined the plants had adequate water available. Irrigation rates were steadily increased year by year to reflect the plants increased needs. Increased rates were accomplished via larger drip emitters and or longer irrigation runs. The amount of irrigation supplied was approximately two to four gallons per plant per week in 2016, three to eight gallons in 2017 and five to ten gallons in 2018.

Fertilization was accomplished with conventional granular fertilizer in Corvallis and Bozeman, and with organic liquid fertigation at Kalispell. Base line soil fertility was measured initially at all sites. Information about these specific fertility needs was scarce and at times conflicting. Based on available information and fertilization needs of similar orchard crops, base fertility was found adequate to support the plant's needs. Initially a replacement fertility scheme was utilized, in which the plants were only fertilized enough to replace the nutrients which they were expected to utilize. By 2017 this fertility plan had changed somewhat, with site managers applying higher supplemental levels of fertilizer. These fertilizer rates amounted to 1 ounce of 10-10-10 fertilizer per plant in 2016, 2 ounces in 2017 and 4 ounces in 2018.

In order to protect the orchard from various pests including deer, birds and even bears, orchards were fenced, and bird netting was utilized during fruiting periods. Bird netting setups went through several different iterations as it was found that it takes a very robust netting system to exclude birds from such an orchard. Eventually the orchards were netted in entirety which greatly reduced bird predation, reduced manager inputs and improved access to the orchards. Kalispell and Bozeman utilized weed mat to reduce weed pest pressure and the need for herbicide applications, but these weed mats were removed in 2017 as they were found to harbor aphids and rodents and were not as effective at weed control as expected.

Data collection began in earnest in 2016. Data from 2016 was not impactful as plants were quite immature, with miniscule yields (less than 200 grams per plant), and will not be reported here, excepting some total phenolic data given the belief phenolic production is not a result of maturity but is instead affected by genetics, climate, and latitude (Åkerström et al., 2010) .

Yield

In 2017 and 2018, harvest dates of plants and sites were chosen based on a variety of fruit factors, including; coloration, soluble solids progression, fruit drop which varied among sites and cultivars, and outside influences such as pest pressure or a likelihood of fruit-damaging weather. Fruit were either picked by hand or collected by shaking the bushes with a mechanical device. Insects, dirt, and leaves were removed by air cleaning devices and hand separation. Total yield of fruit was recorded in grams on a per plant basis, and fruit were frozen for further analysis.

Fruit Mass

Fruit mass was recorded at the time of harvest, in grams, as an average of 10 fruit which were deemed to be mature and not irregular.

Estimated yield

Estimated yield was an estimated metric produced from observed yields, projected to the scale of an acre of production. This provides a useful element for producers to compare cultivars and species, and to compare the trialed species to other conventional crops.

Hypotheses

1. Yield of different cultivars within a species are not equal.
2. Fruit mass of different cultivars within a species are not equal.
3. Fruit mass and yield are inversely co-related, an increase in one factor results in a decrease in the other.

Statistical Analysis

Statistical analysis was performed at the cultivar level per individual site and year. Experimental units were the group of 3 repeated cultivars per block. Traits which did not depend on maturity such as brix, soluble solids, and total phenolic content were analyzed across years when suitable, while yield was analyzed by year. In instances where there was a large 3rd cohort, i.e. replanted Currants, these plants were analyzed as a separate cohort. Analysis was performed with R Studio, utilizing ANOVA. Data which did not follow a normal distribution, as determined by a Shapiro-Wilkes test, was log transformed via the Box-Cox method and re-analyzed. . Analysis across all sites utilized a mixed model with blocks modeled as random effects, while within individual sites analyses utilized linear models. Pairwise comparisons were accomplished utilizing Least-squares means to generate a compact letter display. There were no adjustments for repeated testing. Significance was held at α=0.05. Descriptive statistics of yield with frequencies of all plants per site can be found in appendix tables 4-1 and 4-2.

Analysis was also performed to determine correlations within yield factors, within quality factors, and between yield and quality factors. Such correlations were based on observations of individual plants for all metrics except phenolic content which was based on block averages. Analysis of correlations were restricted to individual sites to avoid confounding effects of any site-by-factor interactions.

Aronia

Summary

In the pursuit of cold hardy, low pest incidence and low-input fruiting species with inherent market value, Aronia appears a near-perfect candidate. However, Aronia is poorly suited for fresh consumption due to its high tannin content. During the trial there were zero plant casualties, and plant and fruit predation was quite low. The plants were extremely hardy to cold, even when flowering. Birds, the most common predator of small fruit, do not prefer Aronia and avoided the fruit. This is a considerable advantage over other species from a production standpoint, as netting the plants to protect the crop is both capital and labor intensive.

The pest occurrences which were observed in Aronia included predation of fruit by bears, pear sawfly colonization of leaves, and fire-blight infected stem tissue. None of the occurrences were overly detrimental to plant growth or fruit production. However, Aronia may serve as an alternate host of these pathogens to other susceptible plants, which might limit multi-species plantings.

The Aronia cultivar trial included the trade-common hybrid cultivars, McKenzie, and Viking at all sites. Corvallis additionally trialed the ornamental variety Autumn Magic.

Results

Table 2-1, presented below, details Aronia yield factors across sites and years. Data is presented in grams and kilograms, as detailed in the first row. Statistical significance is delineated with different letters, with comparisons made within years. The following results sub-sections will refer to the data in this table.

TABLE 2-1 ARONIA YIELD AND FRUIT MASS

Site	Cultivar	Yield (g/plant) 2017	Yield (g/plant) 2018	Fruit Mass (g) 2017	Fruit Mass (g) 2018	Fruit Mass (g) 2017&18	Estimated yield (kg/acre) 2017	Estimated yield (kg/acre) 2018
Bozeman	Mean	321	486	0.69	0.9	0.82	257	389
	McKenzie	181 a	540 a	0.69 a	0.91 a	0.84 a	87	432
	Viking	497 a	435 a	0.69 a	0.89 a	0.80 a	426	346
Corvallis	Mean	1178	5174	0.83	0.86	0.85	942	4139
	McKenzie	1220 a	7642 a	1.05 a	1.06 a	1.05 a	976	6114
	Viking	1508 a	6807 a	0.95 b	0.92 b	0.94 b	1206	5446
	Autumn Magic	807 b	1074 b	0.49 c	0.60 c	0.55 c	646	859
Kalispell	Mean	175	4470	NA	0.635	NA	140	3576
	McKenzie	272 a	4651 a	NA	0.62 a	NA	218	3721
	Viking	77 a	4289 a	NA	0.65 a	NA	62	3431
All Sites	Mean	633	4061	0.85	0.84	0.85	600	2701
	McKenzie	700 a	4278 a	0.87 a	0.86 a	0.87 a	560	3422
	Viking	1002 a	3843 a	0.82 b	0.82 a	0.82 a	806	3074

Within each site, different letters represent statistically significant differences between cultivars at $\alpha=0.05$. Comparisons are within years.

Yield. The Aronia cultivars Viking and McKenzie had similar yields at all sites. The yields of the ornamental variety Autumn Magic that was included in Corvallis were much less than Viking and McKenzie, yielding 46% and 86% less than the commercial cultivars in 2017 and 2018. The largest differences in yields were among sites. Yields in Bozeman in 2018 were an order of magnitude smaller than those in Kalispell and Corvallis. The lower yields in Bozeman may be due to increased weed pressure and mammal damage in the first two years after planting.

A similar cultivar trial conducted by North Dakota State University reported fourth year Aronia yields ranging from 3.4 to 4.6 kg of fruit among four cultivars (NDSU, 2010). Fruit production in Montana was more variable, with yields well below and above those in North Dakota.

Fruit Mass. The cultivars Viking and McKenzie produced fruit of a similar mass in Kalispell and Bozeman. McKenzie outperformed Viking significantly in Corvallis but not at other sites. Fruit in Kalispell were of a much lower weight compared to other sites. In Corvallis there was a clear divide between cultivars' fruit weights, with a consistent trend of McKenzie being superior to Viking, and both cultivars producing a larger average fruit mass than Autumn Magic. Berry weight in Corvallis was positively correlated with yield (p=0.00, r=0.48) which was affected by including the ornamental cultivar Autumn Magic's small fruit and yields. This correlation did not hold true at or across other sites.

In other trials, Aronia fruit mass was observed to range from 0.8 to 1.4 grams (Kawecki, and Tomaszewska, 2006, NDSU, 2010). Fruit mass in Montana fell towards the lower end of this range.

Estimated yield. Under the parameters of the experimental setup, an acre of Aronia would possess about 800 plants. Based on site averages, an Aronia plant in its fourth year of maturity might yield between 0.5 and 5.0 kg of fruit. A similarly aged Aronia orchard in Montana might expect to produce between 400 to 4000 kg of fruit per acre, averaging 2700 kg.

Conclusions

The Aronia cultivars Viking and McKenzie were quite hardy and suffered minimal incidences of pests and predation. The cultivars produced comparable yields and did not differ substantially on this basis across sites and years. It is believed that a majority of Aronia genotypes exhibit low genetic diversity due to a majority of cultivars being descended from a small population of initial propagules (Smolik et al., 2011). There was little evidence to support hypothesis #1 that Aronia yield differed by cultivar, except when Autumn Magic was included at Corvallis.

Across sites, there was not substantial evidence to support hypothesis #2, that fruit mass differed by cultivar, as the only significant differences occurred in Corvallis with McKenzie slightly superior to Viking.

Hypothesis #3, that yield and fruit mass are inversely co-related, was not supported by data. In fact, in Corvallis, it was found that the two factors were positively correlated, though this was likely due to the inclusion of a small fruited and small yielding ornamental cultivar.
The ornamental variety, Autumn Magic, was only trialed in Corvallis. Autumn Magic produced smaller yields, less than 20% of the other cultivars, and smaller fruit measuring only 60% of the mass of the other two cultivars.

Currants

Summary

There was high mortality in Currants in the first year after planting at some sites due to condition of the nursery stock. In 2015 the contracted nursery who was to supply the black and Red Currant cultivars experienced a catastrophic failure of their cold-storage system, consequently losing their stock of viable dormant plants. In place of bare-root plants, the supplier sent cuttings of dormant Currant canes, approximately six inches in length. While this is a valid method of field propagation used extensively in production of many hard and softwood accessions, and is one of the methods used in the production of Currant nursery stock, the success rate of such propagules is typically much lower than that of bare-root plants. Rooting success is typically improved by application of hormonal rooting agents (Hassanein, 2013), though this was not utilized in the experiment.

Success rates of these cuttings in Corvallis were relatively high (65%) but were dismally low at both Kalispell and Bozeman (11%). Due to the low initial success rate for many of the Currant cultivars, many black and Red Currants were replanted as bare root plants in the spring of 2016. These plants formed their own cohort and were included in data presented here, as conclusions and comparisons would be quite limited without this inclusion.

Rooted orchard stock planted in the 2^{nd} year survived as expected with minimal mortalities.

Red and Black Currant cultivars were relatively well suited for Montana production. Established plants grew quickly, were winter-hardy, and pathogen incidence was relatively low. Pests and pathogens observed included black cherry aphids (*Myzus cerasi)*, white pine blister rust (*Cronartium ribicola*) and Currant cane borers (*Synanthedon tipuliformis*). There are many wild Currant plants in the Montana landscape that might act as vectors in transmittal of pest and disease to those in the orchard. It is an on-going concern in many areas that white pine blister rust susceptible Currants might act as an alternate host and should not be planted in the vicinity of the endangered white pine. As white pine exists at high elevations, this situation is relatively unlikely to occur. Black Currants are particularly susceptible, and while some effort has been undertaken to develop resistant cultivars such as Titania, there is evidence that nurseries sometimes erroneously mislabel non-resistant varieties as resistant, meriting caution for those producers in areas with white pine populations (Burnes et al., 2008).

Results

Tables 2-2 and 2-3, presented below, details Black and Red Currant yield factors across sites and years. Data is presented in grams and kilograms, as detailed in the first row. Statistical significance is delineated with different letters, with comparisons made within years. The regular and juvenile cohorts were analyzed separately, except in multi-year and multi-site comparisons. The following results sub-sections will refer to the data in these tables.

TABLE 2-2 BLACK CURRANT YIELD AND FRUIT MASS

Site	Cultivar	Yield (g/plant) 2017	Yield (g/plant) 2018	Fruit Mass (g) 2017	Fruit Mass (g) 2018	Fruit Mass (g) 2017&18	Estimated yield (kg/acre) 2017	Estimated yield (kg/acre) 2018
Bozeman	Mean	NA	992*	NA	1.12*	NA	NA	794*
	Blackcomb	NA	1649 a*	NA	1.33 a*	NA	NA	1319*
	Stikine	NA	1435 a*	NA	1.04 b*	NA	NA	1148*
	Titania	NA	658 b*	NA	.96 b*	NA	NA	526*
	Tofino	NA	225 c*	NA	1.14 ab*	NA	NA	180*
Corvallis	Mean	1635	4103	1.32	1.24	1.31	1308	3282
			2842*		1.30*			2274*
	Tahsis	2237 abc	5845 a	1.59 a	1.51 a	1.64 a	1790	4676
			3460 a*		1.72 a*			2768*
	Whistler	2478 a	5456 a	1.56 a	1.54 a	1.56 a	1982	4365
	M12	2314 ab	4897 ab	1.42 b	1.21 c	1.32 c	1851	3918
	Stikine	1452 bcd	4486 ab	1.23 cd	1.02 d	1.21 de	1162	3589
			3068 a*		1.15 b*			2454*
	Cheakamus	1519 abcd	3427 bc	1.27 bcd	1.30 bc	1.23 cd	1215	2742
			2873 a*		1.09 b*			2298*
	Blackcomb	1336 cd	3074 c	1.37 bc	1.49 a	1.43 b	1069	2459
			3244 a*		1.33 ab*			2595*
	Titania	706 d	2897 c	1.03 d	.92 d	1.10 ef	565	2318
			1565 b*		1.2 b*			1252*
	Tofino	1038 d	2739 c	1.07 d	.96 d	1.02 f	830	2191
Kalispell	Mean	2276	4641	1.56	1.22	1.22	1821	3713
			1610*		1.31*			1288
	Stikine	4583 a	6659 a	1.28 a	1.40 a	1.39 a	3666	5327
			2222 a*		1.45 a*			1778*
	Blackcomb	491 a	3849 b	0.5 a	1.00 a	1.23 ab	393	3079
			1628 a*		1.39 a*			1302*
	Tofino	1754 a	3415 c	0.83 ab	1.05 a	1.07 b	1403	2732
			750 b*		1.16 b*			600*
	Titania	NA	1839 a*	NA	NA	1.20 ab	NA	1471*
All	Mean	1629	3784	1.07	1.07	1.15	1564	3784
	Blackcomb	914 b	4481 b	1.20 a	1.30 a	1.30 a	731	3584.8
	Stikine	3410 a	5957 a	1.20 a	1.12 ab	1.22 b	2414	4765.3
	Titania	706 b	2320 b	0.91 b	0.96 bc	1.07 c	565	1855.5
	Tofino	1485 b	2376 b	0.97 b	0.91 c	1.02 c	1117	1901.1

Within each site, different letters represent statistically significant differences between cultivars at α=0.05
*= Replanted varieties, 1-year junior to other 2018 cultivars
Comparisons made within year

TABLE 2-3 RED CURRANT YIELD AND FRUIT MASS

Site	Cultivar	Yield (g/plant) 2017	Yield (g/plant) 2018	Fruit Mass (g) 2017	Fruit Mass (g) 2018	Fruit Mass (g) 2017&18	Estimated yield (kg/acre) 2017	Estimated yield (kg/acre) 2018
Bozeman	Mean	NA	43*	NA	0.47*	NA	NA	34*
	Rovada	NA	73 *	NA	0.6 *	NA	NA	58*
	HRON	NA	12*	NA	0.33*	NA	NA	10*
Corvallis	Mean	935	5059	0.91	0.72	0.79	748	4047
	Jonkeer van Tets	1367 a	6366 a	0.99 a	0.73 a	0.84 a	1094	5093
	Rovada	502 b	3752 b	0.83 b	0.70 a	0.74 b	402	3002
	HRON	NA	514*	NA	0.63*	NA	NA	411*
Kalispell	Mean	NA	1534*	NA	0.63	NA	NA	1227*
	Rovada	NA	1883 a*	NA	0.68 a*	NA	NA	1506*
	HRON	NA	1184 a*	NA	0.58 b*	NA	NA	947*
All	Mean	NA	1544	NA	0.60	0.57	748	1777
	Rovada	NA	1903	NA	0.66 a	0.63 a	1094	1522
	HRON	NA	1184	NA	0.53 b	0.51 b	402	947

Within each site, different letters represent statistically significant differences between cultivars at α=0.05
*= Replanted varieties, 1-year junior to other 2018 cultivars
Comparisons are within years

Yield. Among the four core Black Currant cultivars common to all three sites, Stikine produced the largest yields. Blackcomb produced larger yields than Titania and Tofino Currant cultivar performance was relatively similar across sites. In Corvallis, of the additional four cultivars; Tahsis, Whistler and M12 all yielded more than Stikine. Cheakamus yielded less than Stikine, but more than the other three core varieties.

A Lithuanian cultivar evaluation of 20 varieties of Black Currant found a 3rd year average of 2.65 kg per plant, with a range of 1.57 to 3.62 kg. Yields declined in the 4th and 5th year of the

Lithuanian trial (Sasnauskas et al., 2009). Another cultivar trial based out of Serbia found a yield range in the 3rd year of 0.5 to 1.97 kg (Djordjevic et al., 2012). North Dakota State University reported a yield of about 0.5 kg in year three and 0.5 to 1.1 kg in the fourth year of growth (NDSU, 2010). Yields in Montana were largely superior to these other trials. The additional varieties trialed in Corvallis show potential comparable to Blackcomb and Stikine.

Among Red Currant cultivars, production was intermittent, with virtually none in Bozeman and no yield of HRON in Corvallis. In Corvallis, Jonkeer van Tets was superior to Rovada, and in Kalispell, Rovada was superior to HRON. Two-year plants in Corvallis and Kalispell yielded a range of .5 to 1.9 kg, while three-year plants in Corvallis ranged from 3.7 to 6.4 kg, with the largest yield occurring in the extra variety Jonkeer van Tets.

NDSU reported Red Currant yields of 0.5 kg in third year Jonkeer van Tets, and 0.96 to 2.4 kg of fruit in fourth year cultivars (NDSU, 2010). Red Currant production in Kalispell and Corvallis appears considerably higher than in North Dakota.

Fruit Mass. Among the four core Black Currant cultivars, Blackcomb produced the largest average fruit mass, except in Kalispell where Stikine fruit were markedly large. Tofino and Titania tended towards low fruit mass. In Corvallis, the extra varieties Tahsis and Whistler produced modestly larger berries than Blackcomb. The extra varieties M12 and Cheakamus bore larger fruit than Stikine, Tofino, and Titania.

Among other experiments, Black Currant berry weight was found to range from 0.8 to 2.1 grams (Sasnauskas et al., 2009, Djordjevic et al., 2012, NDSU, 2010). Black Currant fruit in Montana did not depart from this range of fruit mass.

Among Red Currant cultivars there was little variation in fruit mass, but the same trend was observed as in yield; in Corvallis, Jonkeer was superior to Rovada and in Kalispell, Rovada was superior to HRON. In Corvallis, fruit mass of Red Currants was negatively correlated with yield (p=0.00, r=-0.47)., indicating that fruit size is likely an important component of Red Currant yields.

North Dakota observed average Red Currant fruit masses ranging from 0.54 to 0.78 grams among five cultivars (NDSU, 2010), which is very comparable to masses observed in Montana.

Estimated yield. Given the field layout utilized in the experiment, 800 Currant plants could be planted per acre. Based off observed Black Currant yields averaged within sites, a Black Currant production system might expect yields of 700 to 2200 kg of fruit in the third year of production and over 3000 kg in the fourth year.

Red Currants did not produce as much data to extrapolate yields, but Corvallis and Kalispell yields would indicate a third-year yield range of 750 to 1200 kg. Corvallis' fourth year average yield would have produced 4000 kg of fruit an acre.

Conclusions

Black Currant production in Montana was quite favorable, with yields surpassing those reported in other trials. The varieties Stikine and Blackcomb produced the highest yields across sites, and Tahsis, Whistler, Cheakamus and M12 produced comparable or larger yields at the Corvallis site. These cultivars should be investigated at other sites across Montana to further investigate their potential in other micro-environments.

All Black Currant cultivars produced large fruit averaging over one gram. Blackcomb and Stikine were again superior to Tofino and Titania. The varieties M12 and Cheakamus produced larger fruit than all varieties excepting Blackcomb.

There was sufficient evidence to conclude that both hypotheses #1 and #2 were true, with significant differences in both yield and fruit mass occurring among cultivars of both red and Black Currants.

Hypothesis #3 that yield and fruit mass are inversely related, only bore true in Corvallis, among Red and Black currants.

Based on the combined metrics of fruit size and yield, the cultivars Stikine, Blackcomb, M12 and Cheakamus were shown to produce large yields of large fruit and are likely most suitable to producers targeting markets comprised of direct consumption of whole fruit.

Red Currant production was not as favorable as black. Production was intermittent among sites with minimal production at Bozeman and with HRON only producing in Kalispell. Rovada did produce larger yields and fruit than HRON at Kalispell. The cultivar Jonkeer van Tets, only trialed at Corvallis, produced superior yields and fruit mass to Rovada. This variety should be trialed at other sites for comparison and considered by Red Currant producers, as it was vastly superior at the Corvallis site.

Dwarf Sour Cherry

Summary

Dwarf Sour Cherry cultivars at all sites consisted of Carmine Jewel, Crimson Passion, Romeo, and Juliet. The sour cherry variety, Lutowka Rose was included at Corvallis.

Romeo and Juliet were not planted until 2016.

Dwarf Sour Cherry was less suitable compared to other species but produced massive yields when it did succeed. The lack of suitability was due to multiple factors. The plants were extremely attractive to both rodents and deer, digging up and pulling plants from the ground while browsing, girdling stems, and chewing through roots. The plants were also very susceptible to black cherry aphid infestations, with associated ant colonies. Pear saw-fly was observed occasionally on the plants, though not at detrimental levels. There were no observed instances of the cherry fruit fly (*Rhagoletis indifferens*) but it is fully expected these hybrids will act as a vector and secondary environmental host, predicating that integrated management be undertaken or that these hybrids not be grown in concert with other cherry species or within vector range of other susceptible orchards which do not manage for fruit fly.

Dwarf Sour Cherry plants were not all winter-hardy, and like most stone-fruit in northern climes, were extremely susceptible to late frosts during flowering, which can result in a complete loss of the crop. In Bozeman, multiple cultivars bore flowers, yet an unknown factor resulted in floral and fruit abortion.

Kalispell did not produce a yield in 2017. The cultivar Crimson Passion was not observed to flower or fruit at any site. Plant mortalities resulted in a third cohort, planted in 2016 and one-year juvenile to other surviving plants.

Results

Table 2-4, presented below, details Dwarf Sour Cherry yield factors across sites and years. Data is presented in grams and kilograms, as detailed in the first row. Data marked with an asterisk was derived from plants which are among a cohort one year younger. Statistical significance is delineated with different letters, with comparisons made within years. The regular and juvenile cohorts were analyzed separately. The following results sub-sections will refer to the data in these tables.

TABLE 2-4 DWARF SOUR CHERRY YIELD AND FRUIT MASS

Site	Cultivar	Yield (g/plant) 2017	Yield (g/plant) 2018	Fruit Mass (g) 2017	Fruit Mass (g) 2018	Estimated yield (kg/acre) 2017	Estimated yield (kg/acre) 2018
Corvallis	Mean	410	5117	3.51	4.47	374	4667
			2096*		3.72*		1912
	Carmine Jewel	318 a	7591 a	3.53 a	3.21 b	290	6923
	Romeo	NA	3120 a*	NA	3.11 b*	NA	2845
	Lutowka Rose	501 a	2643 b	3.48 a	5.73 a	457	2410
	Juliet	NA	1071 b*	NA	4.33 a*	NA	977
Kalispell	Mean	NA	NA	NA	NA	NA	NA
	Carmine Jewel	NA	9071 a	NA	NA	NA	8273
	Juliet	NA	481 a*	NA	NA	NA	439
	Romeo	NA	8 b*	NA	NA	NA	7

Within each site, different letters represent statistically significant differences between cultivars at $\alpha=0.05$.
*= Replanted varieties, 1-year junior to other 2018 cultivars
Comparisons are within years

Yield. Dwarf Sour Cherry did not supply many cultivar comparisons, due to Romeo and Juliet being planted one year late, and the lack of production of Crimson Passion.

Carmine Jewel produced dramatically large yields in its fourth year of growth in Corvallis and Kalispell. In Corvallis, the third year Romeo out yielded its counterpart Juliet, though both plants produced over twice as much fruit as Carmine did in its third year. Romeo failed to produce in Kalispell. The ornamental variety Lutowka Rose in Corvallis only attained 1/3 the yield of Carmine Jewel.

North Dakota reported the first yields in Dwarf Sour Cherry occurred in the plants fourth year of growth with Carmine Jewel producing an average of 1.4 kg of fruit and Crimson Passion producing 0.3 kg (NDSU, 2010). The Montana trials, when plants flowered and yielded, produced considerably larger yields than trials in North Dakota.

Fruit Mass. Corvallis was the only site to record fruit mass. Fruit mass typically ranged from 3 to 3.5 grams, however in 2018, Lutowka Rose averaged almost 6 grams and Juliet attained almost 4.5 grams. NDSU reported average berry weights of 5.5 grams in Crimson Passion in 2010.

In Corvallis, Dwarf Sour Cherry fruit mass tended to be negatively associated with yield ($p=0.09$, $r=-0.31$), implying that there is potentially a trade-off between fruit mass and total fruit production among Dwarf Sour Cherry cultivars.

Estimated yield. Assuming the parameters used in the experimental trial, an acre would contain approximately 912 cherry plants. Based on the observed average range of yields, expected yields in the third year of maturity in western Montana might range from 290 to 450 kg of fruit per acre. In the fourth year of maturity, yields in Carmine Jewel could have produced 6800 to 8200 kg of fruit an acre.

Conclusions

Due to the year late planting of Romeo and Juliet and the lack of production by Crimson Passion, there were no directly comparable mature cultivars, excepting in Corvallis among Carmine Jewel and the sour cherry variety Lutowka Rose. Lutowka Rose produced a much smaller yield than Carmine but did produce larger fruit.

Romeo and Juliet, in Corvallis, produced substantially larger yields in their second year than Carmine Jewel did, and further trial is required to compare these varieties.

There was not sufficient data from any site to adequately confirm hypotheses #1, 2 or 3 among the four core cultivars. Corvallis provided ancillary evidence that Carmine Jewel and Lutowka Rose were not equal in yield or fruit mass, and that yield and fruit mass may be inversely related, however this correlation was not significant and could not be tested across other sites.

Ultimately, Dwarf Sour Cherries do not attain maximal maturity until 5 years or later, so following these cultivar trials through ensuing years will provide more relevant data.

Haskap

Summary

Haskap was a very suitable crop for Montana fruit production. Haskap cultivars were found to flower and fruit at different times of the year, allowing fruit production over a wide yield window of two months. This variation might allow a producer to utilize cultivars to target a harvest or market schedule, or to produce Haskap fruit continuously throughout the early fruit season. Another potential benefit is yield redundancy, as an orchard of only one cultivar might experience a catastrophic crop failure whereas a different cultivar might not experience the same failure.

Haskap was incredibly cold hardy, with both plants and flowers surviving severe cold. However, the extreme cold hardiness might not be a favorable trait in all cultivars or regions, as plants that flowered too early were limited in pollination as pollinators are not active in such extreme cold. Additionally, some cultivars' (Sugar Mountain Blue, Blue Corn, Blue Goose, Wild Treasure) dormancy requirements were satisfied by mid-winter and were observed to start flowering during warming events in January and February. As Haskap fruit occurs on the previous years' fruit buds, the plants likely had reduced fruiting potential compared to other cultivars which maintained dormancy until conditions were satisfactory for fruit production. Cultivars developed in Oregon flowered later in the year and did not suffer premature release of dormancy.

There were no pests or diseases of the plants that were of consequence. However, fruit predation by birds in Haskap was of an extreme nature. The predation necessitated netting of the orchards at the earliest signs of ripening. Despite netting, birds in the orchard were a constant problem, as a single bird will gorge on fruit and can be quite difficult and time-consuming to catch and remove.

Results

Table 2-5, presented below, details Haskap yield factors across sites and years. Data is presented in grams and kilograms, as detailed in the first row. Statistical significance is delineated with different letters, with comparisons made within years. The following results sub-sections will refer to the data in this table.

TABLE 2-5 HASKAP YIELD AND FRUIT MASS

Site	Cultivar	Yield (g/plant) 2017	Yield (g/plant) 2018	Fruit Mass (g) 2017	Fruit Mass (g) 2018	Fruit Mass (g) 2017 &2018	Estimated yield (kg/acre) 2017	Estimated yield (kg/acre) 2018
Bozeman	Mean	240	375	0.88	0.98	0.93	219	342
	85-19	227 b	637 a	0.9 a	1.00 ab	0.96 b	207	581
	Solo	392 a	531 a	0.96 a	0.91 b	0.93 bc	358	484
	41-75	452 a	503 a	0.99 a	1.03 ab	1.00 ab	412	459
	Indigo Gem	168 bc	270 b	0.7 b	0.93 b	0.82 cd	153	246
	Borealis	154 bc	238 b	0.99 a	1.07 ab	1.02 ab	140	217
	Aurora	46 c	72 c	1.07 a	1.15 a	1.12 a	42	66
	Sugar Mtn. Blue	NA	NA	0.49 b	0.79 ab	0.65 d	NA	NA
Corvallis	Mean	886	1805	1.17	1.27	1.21	808	1646
	85-19	1756 a	3511 a	1.24 c	1.39 bc	1.31 cd	1601	3202
	Tana	1717 a	3153 a	1.29 bc	1.4 b	1.40 bc	1566	2876
	Borealis	701 cd	2555 ab	1.37 b	1.47 b	1.42 b	639	2330
	Solo	957 bc	2529 ab	1.25 c	1.29 cd	1.27 d	873	2306
	Keiko	1173 b	2106 bc	1.25 c	1.27 cd	1.26 d	1070	1921
	Taka	1264 ab	2073 bc	1.30 bc	1.50 b	1.42 bc	1153	1891
	Indigo Gem	505 de	2045 bc	1.06 d	1.06 e	1.05 e	461	1865
	Kawai	1413 ab	1817 bc	1.60 a	1.33 cd	1.43 b	1289	1657
	79-91	1147 bc	1683 c	1.38 b	1.49 b	1.44 b	1046	1535
	41-75	1407 ab	1644 c	1.29 bc	1.24 d	1.25 d	1283	1499
	Aurora	397 ef	1694 c	1.53 a	1.82 a	1.70 a	362	1545
	Wild Treasure	191 fg	227 d	0.73 f	0.87 f	0.81 g	174	207
	Sugar Mtn. Blue	214 efg	122 d	0.87 e	1.03 e	0.96 ef	195	111
	Blue Goose	49 g	114 d	0.56 g	0.58 g	0.56 h	45	104
	Blue Corn	395 def	NA	0.83 ef	NA	0.87 fg	360	NA
Kalispell	Mean	684	1757	1.41	1.48	1.41	624	1602
	85-19	1530 a	3018 a	1.49 ab	1.56 c	1.53 bc	1395	2752
	Solo	763 c	1861 b	1.45 ab	1.51 c	1.48 c	696	1697
	41-75	1177 b	1778 b	1.50 ab	1.39 cd	1.45 c	1073	1622
	Aurora	253 d	1762 b	1.66 a	1.95 a	1.81 a	231	1607
	Indigo Gem	113 d	1477 bc	0.91 c	1.31 d	1.11 d	103	1347
	Borealis	268 d	1468 bc	1.44 b	1.75 b	1.64 b	244	1339
	Sugar Mtn. Blue	NA	933 c	NA	0.92 e	0.83 e	NA	851
All	Mean	626	1364	1.15	1.25	1.20	422	972
	85-19	1171a	2389 a	1.21 b	1.32 c	1.27c	1068	2178
	Solo	704 b	1640 b	1.22 b	1.24 c	1.23 c	642	1496
	41-75	1012a	1308 bc	1.26 b	1.22 c	1.24 c	923	1193
	Indigo Gem	262 cd	1264 bc	0.90 c	1.10 d	1.00 d	239	1153
	Borealis	374 c	1420 bc	1.27 b	1.43 b	1.35 b	341	1295
	Aurora	232 cd	1176 c	1.42 a	1.64 a	1.53 a	212	1073
	Sugar Mtn. Blue	NA	352 d	0.79 c	0.82 e	0.80 e	195	481

Within each site, different letters represent statistically significant differences between cultivars at α=0.05.
Comparisons are within years

Yield. Haskap cultivars performed quite similarly across sites regarding comparative yield. As in other species trialed, Bozeman yields were depressed compared to other sites, with little gain in yield from 2017 to 2018.

Haskap cultivars were found to have a broad range of characteristics, with cultivars forming groups with their genetic counterparts. Cultivars that flowered and fruited later in the year, those derived from Oregon germplasm, were observed to produce larger yields.
The cultivar 85-19 dramatically surpassed other cultivars in terms of yield. The other cultivars, except Sugar Mountain Blue, largely formed a broad group with similar fruit yields. Sugar Mountain Blue did not perform well at any site except Kalispell, where it was still the smallest yielder by a large margin.

Haskaps fruit yield among these cultivars are spaced out over a month or two, a longer time period than was seen in other species. Producers might take advantage of this temporal range by targeting early, middle, and late yielding cultivars to extend market opportunities. Such a plan might include Indigo Gem for early yields; Solo, Borealis or Aurora for mid-season yields and 85-19 for late season production.

Among the extra seven cultivars trialed at Corvallis, Tana produced a yield that was superior to Borealis and Solo. The cultivars 79-91, Keiko, Taka and Kawai demonstrated yields comparable to or better than the group of intermediate core Haskap cultivars. These five cultivars demonstrated considerable yield potential. Wild Treasure, Blue Goose and Blue Corn were comparable to Sugar Mountain Blue, producing minimal yields.

In other variety trials, Haskap yields ranged from 0.25 to 1 kg and 0.35 to 2.8 kg of fruit per plant in the third and fourth year of maturity respectively (NDSU, 2018., Małodobry et. al, 2010., Ochmian et al., 2010). The cultivar 85-19 outperformed other cultivars in Montana and in other trials by a large margin in Kalispell and Corvallis, averaging 1.5 to 1.75 kg and 3.0 to 3.5 kg per plant in the third and fourth years of maturity.

Fruit Mass. Across all sites, fruit mass in Haskaps was positively correlated with yield (p=0.00, r=0.29-0.47). Clearly, fruit mass is a significant factor in Haskap yields. This correlation was driven by the cultivars with small yields; notably Sugar Mountain Blue and Indigo Gem, producing low yields and fruit with the least mass. This trend was also observed in Corvallis among the poor yielding extra varieties Blue Goose, Blue Corn and Wild Treasure. Aurora bucked the trend, producing fruit with the highest mass while producing intermediate yields. The cultivar 85-19, Borealis, Solo and 41-75 produced intermediate and comparable average fruit masses, while Sugar Mountain Blue and Indigo Gem produced relatively small fruit.

The other extra varieties in Corvallis displayed considerable merit, with Kawai, Tana, Keiko and Taka producing fruit masses comparable to Borealis, Solo and 41-75.

Among other Haskap trials, average fruit mass was found to range from 0.66 to 1.8 grams (NDSU, 2018., Małodobry et. al, 2010., Ochmian et al. 2010). Haskap fruit in Montana averaged fruit mass between 0.8 and 1.5 grams.

Estimated yield. The Montana variety trial utilized an in-row plant spacing of 3 feet per Haskap plant and 12 feet between rows. This arrangement would allow 912 plants per acre. Basing yields on averages, a Haskap orchard in Montana might expect acre yields between 200 to 1000 kg of fruit in the third year of growth, and 450 to 2000 kg in the fourth year of growth.

Conclusions

There was significant evidence to confirm that hypothesis #1 and 2 bore true; that there are significant differences in both yield and fruit mass among Haskap cultivars. Hypothesis #3, that fruit mass and yield are inversely related was proven not true, as these two factors were found to be positively correlated across all sites. In Haskaps it would appear fruit mass is a substantial component of yield and there is not a trade-off between the two factors.

Among the core cultivars trialed; 85-19, 41-75, Solo and Borealis all achieved high yields and fruit masses. Aurora bore large fruit with intermediate yields.

Among the extra varieties trialed in Corvallis; 79-91, Keiko, Tana, Taka and Kawai all produced comparably large yields and excepting 79-91, comparably large fruit.

A producer would do well to select cultivars from these varieties that are best suited to their individual production system, and or combine multiple varieties for redundancy and to attain a wider yield window.

Saskatoon

Summary

The Saskatoon experiment consisted of six trade-common cultivars at all sites: JB30, Lee3, Lee8, Martin, Northline and Smoky.

Saskatoons appear to require more pest-management than other species trialed to produce successful crops. Saskatoon is vulnerable to a wide range of diseases and pests from a variety of native and domesticated plant species. In these trials, pathogen and pest incidence in Saskatoons were high, relative to personal observations of other species. Rodents were the worst pest, digging up plants and chewing through stems and roots. Deer browsed the plants readily, year-round. Berries were subject to an unknown insect pathogen, likely the Saskatoon sawfly (*hoplocampa spp*.). The disease pathogen, cedar apple rust, appeared frequently on both leaves and fruit.

Results

Table 2-6, presented below, details Saskatoon yield factors across sites and years. Data is presented in grams and kilograms, as detailed in the first row. Statistical significance is delineated with different letters, with comparisons made within years. The following results sub-sections will refer to the data in this table.

TABLE 2-6 SASKATOON YIELD AND FRUIT MASS

Site	Saskatoon	Yield (g/plant) 2017	Yield (g/plant) 2018	Fruit Mass(g) 2017	Fruit Mass(g) 2018	Fruit Mass(g) 2017&18	Estimated yield (kg/acre) 2017	Estimated yield (kg/acre) 2018
Bozeman	Mean	NA	422	NA	1.04	NA	NA	338
	Northline	NA	860 a	NA	1.04 ab	NA	NA	688
	Lee8	NA	517 ab	NA	1.25 a	NA	NA	414
	JB30	NA	412 ab	NA	.84 b	NA	NA	330
	Lee3	NA	308 b	NA	1.07 b	NA	NA	246
	Smoky	NA	307 b	NA	.97 b	NA	NA	246
	Martin	NA	129 b	NA	1.04 ab	NA	NA	103
Corvallis	Mean	153	3011	1.12	1.19	1.16	122.4	2409
	Northline	192 ab	5280 a	1.12 b	1.00 d	1.06 d	154	4224
	Lee8	202 ab	5221 a	1.18 ab	1.08 cd	1.13 cd	162	4177
	Smoky	52 d	3599 b	.70 c	.78 e	0.74 e	42	2879
	Lee3	241 a	1877 c	1.30 a	1.19 c	1.24 bc	193	1502
	Martin	156 bc	1405 cd	1.23 ab	1.65 a	1.44 a	125	1124
	JB30	72 cd	686 d	1.17 ab	1.46 b	1.32 ab	58	549
Kalispell	Mean	60.3	1251	0.7	0.9	0.80	48.24	1001
	Northline	40 a	3063 a	.77 a	.88 b	0.82 ab	32	2450
	Smoky	49 a	1108 b	.54 b	.66 c	0.60 c	39	886
	Lee8	57 a	2705 a	.79 a	.84 b	0.80 ab	46	2164
	Lee3	NA	343 c	.68 a	.85 b	0.75 b	NA	274
	Martin	95 a	183 c	.73 a	1.10 a	0.93 a	76	146
	JB30	NA	102 c	.69 a	1.06 a	0.92 a	NA	82
All	Mean	123	1567	1.03	1.02	1.02	85	1249
	Northline	116	3068 a	1.04 a	0.97 c	0.97 c	93	2454
	Smoky	51	1705 b	0.75 b	0.80 d	0.72 d	101	1826
	Lee8	130	2814 a	1.09 a	1.06 c	1.02 c	44	1791
	Lee3	241	843 c	1.14 a	1.04 c	1.04 bc	193	674
	Martin	126	572 cd	1.09 a	1.26 a	1.21 a	101	505
	JB30	72	400 d	1.05 a	1.12 b	1.13 ab	58	245

Within each site, different letters represent statistically significant differences between cultivars at $\alpha=0.05$.
Comparisons are made within year

Yield. Saskatoon cultivars were slow to produce, with yields of less than one half pound in 2017. In 2018 much larger yields were observed across all sites. As in other species, Bozeman produced smaller and more variable yields than the other two sites.

The cultivar Northline produced the largest yields across all sites. Lee8 had comparable yields to Northline across sites. Across sites, Smoky produced lesser yields than Northline and Lee8 but greater than other cultivars while the varieties Lee3, Martin and JB30 were comparable to each other and produced the smallest yields. A trial in Saskatchewan included all cultivars but

Lee3 and Lee8 and found some similar results in that Martin obtained the lowest yields of this group of cultivars, and that JB30 produced low yields in its early years. In the Canadian orchard Smoky out-yielded the other cultivars (St-Pierre et al., 2005).

Compared to published trials, yields of Saskatoon in Montana were relatively high. Yields in other cultivar trials ranged 314 to 981 grams in fifth year plants in North Dakota, and 1030 to 4700 grams per plant among eight to ten-year-old mature plants in Saskatchewan (NDSU 2010, St-Pierre et al., 2005). In comparison, all sites in Montana produced yields larger than those in one-year more mature plants in North Dakota. Montana yields in the fourth year of production were higher than those in plants in Saskatchewan that were twice as mature.

Fruit Mass. Overall, fruit mass among Saskatoon cultivars did not vary much; however, cultivar fruit mass varied across sites and years, with little uniformity. Kalispell produced lower fruit masses than other sites.

Consistently, the cultivar Martin was among the heaviest fruit, and Smoky was among the lightest. JB30 produced fruit of a lower mass than Martin, but of a higher mass than other cultivars. The varieties Lee3, Lee8, and Northline formed a group of comparable fruit mass. In a trial in Saskatchewan Martin, JB30, Northline and Smoky performed similarly relative to each other, excepting that Montana fruit masses were uniformly lower among all cultivars (Zatylny et al., 2005). In Corvallis, Saskatoon fruit mass was negatively correlated with yield ($p=0.00$, $r=-0.27$). There appeared to be a trade-off between total yield and individual fruit mass in Corvallis. In Kalispell, there was a similar though in-significant trend.

Reports of fruit mass from North Dakota find a range of 1.0 to 1.45 grams per fruit among five cultivars, while a trial in Saskatchewan reports a range of 0.79 to 1.66 grams with an average of 1.14 grams among 16 cultivars (NDSU, 2010., Zatylny et al., 2005). From these comparisons, it appears that Saskatoon production in Montana might produce fruit of lower masses than other locations.

Estimated yield. The Montana cultivar trials employed an in-row spacing of four feet between Saskatoon plants. With 12-foot alley ways, an acre of Saskatoons would contain 800 plants. In the third year of maturity, Saskatoons could be expected to produce small yields of 30 to 190 kilograms of fruit per acre. In the fourth year of maturity yields increase dramatically, with estimated yields ranging from 100 to 4200 kg of fruit per acre.

Saskatoon is a slow maturing fruit crop, with the Canadian government advising that significant yields occur after six to eight years of maturity, and maximum yields taking over a decade to procure. Such mature yields are reported to range from 1000 to 7000 kilograms of fruit per acre. It is also advised that producers expect a crop failure once every five years, due to late frosts causing floral abortion (Ministry of Ag; Manitoba, Saskatchewan). Both Corvallis and Kalispell saw projected production of over 2000 kg per acre among superior cultivars of four years of age, with some plants in Corvallis achieving over 4000 kg. From this early evidence, it appears that some Saskatoon cultivars might yield exceptionally in the Montana environment, compared to reports in other areas.

Conclusions

Saskatoon plants and fruit were beset by more pests (deer, voles, and sawfly) and disease (fire blight, cedar apple rust) than any other species trialed. However, these issues can largely be overcome given a vigorous species-specific integrated pest management plan, as outlined in the

Saskatoon Berry Production Manual (Spencer et al. 2013. Regardless of fruit losses and plant mortalities, Saskatoon fruit production in Montana was very favorable, considerably out-yielding other comparable Saskatoon trials in North Dakota and Saskatchewan.

There was substantial evidence that hypotheses #1 and #2 were true, significant variation in yield and fruit mass existed between cultivars at all sites. Hypothesis #3, that yield and berry mass are inversely correlated, proved true in Corvallis and there was an in-significant trend noticed in Kalispell. Producers of Saskatoon likely must choose between maximal yields and maximal fruit size

The cultivars Northline and Lee8 produced the largest yields across sites. The largest fruit masses were observed in the variety Martin and JB30.

CHAPTER THREE: FRUIT QUALITY FACTORS

Summary

Cold hardy berries and small fruits may have potential for production in the N. Rockies. To identify better suited species and varieties, replicated trials were planted in 2015 at three sites in Montana: Bozeman, Corvallis, and Kalispell. 28 varieties of Aronia, Saskatoons, Black and Red Currants, Haskaps, and Dwarf Sour Cherries were planted at all sites with additional varieties included at the Corvallis site. Comparisons among varieties within each fruit species were made among soluble solids (sugar content measured as ° brix) in the third and fourth year, and total phenolic content (measured as milligrams of gallic acid equivalent per 100 g fresh weight fruit) in the second and or third year.

There were significant differences in soluble solid (SS) content of cultivars found among Haskaps, Black Currants, Saskatoons, Dwarf Sour Cherries and Aronia. There was not enough data accumulated from Red Currant cultivars for meaningful comparisons. Soluble solids varied across years and sites in all species, with the smallest amounts of variation in Haskap. Differences in Aronia SS were only seen in 1 year in Corvallis, in which the ornamental variety Autumn Magic produced 30% higher SS than McKenzie, which produced 9% higher SS than Viking. Soluble solids in Black Currants varied substantially across sites but was similar across years. The reference variety Titania achieved the highest SS concentrations in all sites and years, 20.5° brix across sites and years. Tofino consistently produced low SS in, and 15.6° brix across, sites and years. The extra varieties trialed at Corvallis; M12, Whistler, Tahsis, and Cheakamus largely achieved low SS comparable to Tofino. There were few comparisons which could be made within year of Dwarf Sour Cherry cultivars, but across sites in 2018, Romeo (18.3%)

produced higher SS than Juliet (16.2%) which outperformed Carmine Jewel (14%). In Corvallis, the Sour Cherry variety Lutowka Rose produced higher SS than Carmine Jewel across years. Haskap SS did not vary as much as other species. Across years and sites Indigo Gem, 85-19, Sugar Mountain Blue and Solo and Aurora produced comparably high SS (15.4-16.3%) while Borealis and 41-75 produced lower SS (14-14.7%). Among the extra varieties at Corvallis there was a similar distribution of SS with Keiko, 79-91, and Wild Treasure fruit containing higher SS (15.6-16.2%), while the cultivars Tana, Taka, Kawai, Blue Goose and Blue Corn produced fruit with lower SS (14.1-14.8%). Saskatoon soluble solids varied considerably among year and site. Across sites and years, the cultivars Smoky, Martin and JB30 and Northline formed a group with high SS (20.0-21.2%), while Lee3 and Lee8 achieved lower SS concentrations, 18.4 and 19.5%.

Total phenolic content (TPC) is a measure of potentially healthful plant secondary compounds. It is rare that the TPC of fruit is analyzed at the cultivar level, though such analyses are becoming more commonplace amongst the fruits in this study as they are notably high in phenolic content. Total phenolic content was measured among Aronia, Black Currant, and Haskap cultivars and found to differ significantly among Haskap and Aronia cultivars. Analysis of Aronia was notable as the cultivar McKenzie was absent from other published reports. Analysis of Haskap cultivars was unique as it was among one of the larger scientific variety trials of Haskap and included newly released cultivars which had not been reported on previously. Total phenolic concentrations varied between sites and years in all species. Black Currants produced higher TPC (500 mg) than is found in red raspberries, blueberries, and strawberries. Haskap cultivars produced about twice as much TPC (900 mg) as Black Currants, with cultivars from University of Saskatchewan, Berries Unlimited and Sugar Mountain Blue producing higher

TPC than cultivars from Oregon State University. A dilution affect was observed in Haskap TPC, with yields and TPC negatively correlated, high yielding varieties with low fruit TPC produced net TPC comparable to cultivars with higher fruit TPC. Aronia cultivars achieved seven times as much TPC (2800 mg) as Black Currants, with the variety McKenzie producing 75% higher TPC (3500 mg) than the cultivar Viking (200 mg). A single sample of the Dwarf Sour Cherry cultivar Carmine Jewel indicated TPC (570 mg) comparable to that seen in Sour Cherries.

In order to better understand the many phenolic compounds that make up TPC of Haskap cultivars, Ultra High Performance Liquid Chromatography (UHPLC) analysis was performed on fruit of Haskap cultivars derived from Bozeman and Corvallis in 2017. Six phenolic compounds which are common to Haskap were analyzed. Results of UHPLC provided varying results, with half of the compounds analyzed differing substantially from other published results. Regardless, compounds were compared among cultivars and found to differ substantially, indicating a general ranking of such compounds among the varieties. Results of UHPLC generally mirrored those of TPC, with high TPC cultivars containing the largest proportions of phenolic compounds, while low TPC cultivars measured among the lowest proportions of phenolic compounds.

Introduction

There is a growing market for berries and fruits that are perceived to have health benefits. Fruits provide nutrition including fiber, minerals, vitamins, and phytonutrients and such compounds provide antiinflammation and antioxidant roles as well as being implicated with lower incidence of obesity and cardiovascular disease (Slavin and Lloyd, 2012) Recent research of the positive health benefits of berry consumption associates such consumption with benefits including improved neurological and bone health, reduced incidence of hypoglycemia and insulin resistance, and lower incidence of cancer (Celli et al., 2014). Nationally, there has been an observed trend of increased berry consumption. In the USA, overall berry consumption doubled from 5 pounds to 10 pounds per capita in the period from 2000 to 2015, (Statista, 2018). Blueberry consumption quadrupled from 1995 to 2015, to an estimated 1 billion pounds (IBO, 2016).

This growing demand has created a unique potential for domestic production of these types of fruits. Recognizing this trend, the Montana Department of Agriculture has sought to identify suitable fruit species and cultivars which might help accomplish the Department's goals of; improving agricultural practices, increasing agricultural businesses success, capturing a higher value per product and land area, aiding start-up businesses, and strengthening communities through the diversification of food systems and economies.

The Montana Cold Hardy Fruit Trial was established in 2015 to evaluate prospective fruit species and their cultivars. This project was conceived with the intention of identifying and assessing alternative fruit crops and cultivars thereof, with inherent value and marketability, suitable to intensive production in the cooler climates of the Northern Rocky Mountains. The trial seeks to identify yield and quality factors of cultivars and of their fruit. Fruit quality factors of interest included determination of soluble solids (SS) of fruit for all cultivars, and dry matter and total phenolic content (TPC) for Haskap cultivars, primarily. Soluble solids, measured as °brix, are a common metric of fruit sugar content as sugars make up 80% of SS. Comparing SS of cultivars within a species gives a relative approximation of which cultivars' fruit contain more sugar. Dry matter's inverse, juice content, provides valuable information for manufacturers and growers whose market is juice production. Total phenolic content measures phenols, a broad range of secondary plant compounds, some of which confer health benefits and antioxidants, and others that contribute to taste, aroma and coloration. Comparing TPC among cultivars indicates which cultivars possess high proportions of phenolic compounds. Such cultivars could then be targeted for a more in-depth analysis of individual phenolic compounds, which might elucidate differences in rates of pigmentation, taste, antioxidants, and other health conferring compounds. This in-depth analysis of phenolic compounds was conducted among Haskaps in this trial, however the data did not conform to other such reported analyses of Haskap phenolic compounds.

The project is relatively unique in that there have been few such multi-species, and even fewer multi-site, scientific trials in recent times. One such trial at the North Dakota State University Carrington Research Site has reported on novel fruit crops performance since 2009. While this trial has generated a tremendous about of usable data, such data has been presented as summary statistics and no statistical cultivar comparisons have taken place. Furthermore, the Carrington trial is limited to one location and cannot evaluate cultivars and species over varying climates, elevations, and latitude. TPC has not been assessed in the Carrington trial. As such, there is a tremendous need to observe these novel species performances in a controlled and replicated scientific manner across different environments in order to quantify the traits of species and cultivars. Additionally, there now exist new offerings from breeding programs which have not been evaluated in other cultivar trials.

Based upon the criteria of suitability to potential Montana fruit production, and of genetic diversity, six species of fruit were chosen. Each of these species is already in production in other agricultural systems and regions. The six species chosen were *Amelanchier alnifolia* (Saskatoon), *Lonicera caerulea* (Haskap), *Prunus fruiticosa x cerasus* (Dwarf Sour Cherry), *Ribes nigrum* (Black Currant), *Ribes rubrum* (Red Currant), and *Sorbaronia mitschurinii* (Aronia).

Three different locations in Montana were utilized for research sites: Bozeman, Corvallis and Kalispell. Across all sites, 26 varieties of six fruit species were evaluated. Cultivars were selected based on potential performance based on previous trials and availability. Fifteen additional cultivars were added at the MSU-WARC site.

Amelanchier alnifolia (Saskatoon) cultivars at all sites included Martin, Smoky, Northline, Lee 3, Lee 8, and JB30.

Ribes nigrum (Black Currant) cultivars at all sites included Titania, Blackcomb, Stikine and Tofino. Additional cultivars at the WARC site included M12, Cheakamus, Tahsis, and Whistler.

Ribes rubrum (Red Currant) cultivars at all sites included Rovada and HRON. Additional cultivars at the WARC site included Jonkeer van Tets.

Sorbaronia mitschurinii (Aronia) cultivars at all sites included Viking and McKenzie. WARC additionally included Autumn Magic.

Prunus fruiticosa x cerasus (Dwarf Sour Cherry) cultivars at all sites included Romeo, Juliet, Carmine Jewel, and Crimson Passion. The additional sour cherry cultivar Lutowoka Rose was included at Corvallis.

Lonicera caerulea (Haskap) cultivars at all sites included Indigo Gem, Aurora, Borealis, Sugar Mountain Blue, Boreal Blizzard, Solo, 41-75, and 85-19. Additional cultivars at the

WARC site included Blue Corn, Blue Goose, Wild Treasure, Kawai, Taka, Tana, Keiko, 41-75, and 79-91.

Aronia

Chokeberry (*Aronia melanocarpa*) is a cold hardy fruiting shrub of the Rosaceae family. Native to North America, the plant has been improved by hybridization with the European Mountain Ash (*Sorbus aucuparia*) and found popularity throughout the northern hemisphere. The hybrid is commonly known as Aronia. The plants are cold hardy (Zones 2-3) and flower in late spring, avoiding bloom-killing low temperatures and ensuring pollinators are active. Growth and maturity are both quick with sizeable yields and plants within five years. Despite sharing the environment with many Rosaceae pathogen co-hosts, minimal pathogen related issues were observed in Aronia plantings.

Aronia fruit is attractive, with red-black coloration and uniform sizes and shapes. The fruit is not commonly utilized for fresh consumption, as it contains high tannin contents that mask the high concentrations of solid solids. Aronia fruit has an extremely high phenolic content, far surpassing any conventional fruit crop. A high proportion of this phenolic content consists of anthocyanins which are valued both for their healthful antioxidant benefit, as well as their commercial use as a natural food colorant (Ochmian et al., 2012).

The majority of Aronia production occurs in Eastern Europe and Russia. Poland produces the majority of European Aronia, with 15,000 acres producing 35-40,000 tons of which 90% is exported as juice (NDSU, 2010). Production in the United States has reached 2100 acres as of 2017 (USDA, 2017). The cultivars McKenzie and Viking are both of Russian origin. According to the Natural Resources Conservation Service, McKenzie was released for primary use as a conservation planting in the USA, while Viking was developed for fruit production (Everhart, 2009). Known variety trials and evaluations have occurred at North Dakota State University (NDSU, 2010), and in Poland (Ochmian et al., 2012).

Currants

Currants are native across the Northern hemisphere, and in parts of South America and Africa. Over 150 species of *Ribes* have been described, and it is believed that no less than 18 of said species have contributed to domesticated germplasm which includes black, red, white, golden, and ornamental Currants, as well as gooseberries. Currant production has been occurring for roughly the last four centuries in Europe and Russia. Currants were a popular crop in North America until the early twentieth century, with over 7000 acres under cultivation in 1919, when white pine blister rust was recognized as a threat to white pine populations and prohibitions were put in place against Currant production , as Currants act as an alternate host to white pine blister rust. Only recently have these legal hurdles been lifted as it has been recognized that native populations of Currant exist in these areas and cannot reasonably be extirpated (Hummer and Barney, 2002).

Black Currant is a medium sized shrub growing to around 6 feet. All parts of the plant contain an aromatic compound, casis. Casis is utilized in liqueurs and perfumes primarily and has a piney scent and taste some people find disagreeable. The sulfurous compound responsible for such scent is known as cat ketone, a compound common to cat urine (Mouhib and Stahl, 2014). Cooking, drying or otherwise processing Black Currant fruit neutralizes the casis. Fruits themselves are sweet and juicy. Black Currants produce attractive fruit on small clusters of peduncles, with some cultivars' fruit nearly the size of small grapes. Advantageously, fruit tends to mature at the same time on a per plant basis.

Red Currant shrubs grow about the same size as Black Currants but have smaller leaves. Fruit are smaller than Black Currants and can occur in the same loose clusters or in longer trailing clusters similar to grapes. Red Currant fruits are high in ascorbic acid and low in soluble solids and are consequently not suitable for fresh consumption due to their tartness. Instead, Red Currants are utilized in a variety of processed food stuffs like jellies and compotes.

Currant cultivars largely originate from breeding programs in Russia and Europe, with Currant breeding programs existing in Poland, Russia, Scotland, New Zealand, Lithuania, and Estonia. Among the cultivars in the trial, Titania was derived from Europe while Jonkheer Van Tets and Rovada originated in Holland (Hancock, 2008). Known Currant variety trials or previous evaluations have occurred at North Dakota State University (NDSU, 2010), Lithuania, Sweden, and Latvia (Sasnauskas et al., 2009), Finland (Zheng et al., 2012) and Serbia (Djordjevic et al., 2012).

Global production of black currant has remained relatively steady over the last three decades, with average production ranging from 500,000 to 700,000 metric tons per year. Nearly 99% of such production occurs in Europe (Faostat, 2019). The majority of this production is used domestically. The USDA reports 533 acres of currants in the USA while Statistics Canada reports 230 acres in Canada.

Dwarf Sour Cherry

Dwarf sour cherries are the result of a breeding program carried out in Canada beginning in the 1940's by Dr. Les Kerr. In 1966 the University of Saskatchewan initiated research of

Dwarf Sour Cherries, obtained Dr. Kerr's selections in 1983 and began crossing European Sour Cherry cultivars with hardy hybrid selections (Bors, 2005). Sour cherries, *Prunus cerasus*, were interbred with Mongolian cherries, *Prunus fruiticosa*, with the goal of dwarfing sour cherry germplasm. Dwarf sour cherries lineage consists of 75% sour cherry and 25% Mongolian cherry. Such hybrids have initially been named *Prunus kerrasis* in honor of the original breeder. The University of Saskatchewan has released about half a dozen varieties to date, beginning in 1999. All varieties trialed originated at University of Saskatchewan except the Sour Cherry cultivar Lutowka Rose.

In 2011, nearly 200 commercial entities reported Dwarf Sour Cherry crops in production across Canada (NDSU, 2019). Largely, there is not demographic data or information available about the extent of plantings, production, or markets of Dwarf Sour Cherry. Sour Cherry production in the Americas rose above 140,000 metric tons in 2018, while nearly 1.4 million tonnes were produced in Europe and Asia (FAO, 2020). Variety trials and evaluations have occurred at the University of Saskatchewan and North Dakota State University.

Dwarf Sour Cherry plants are more shrub than tree and tend to have a terminal height around eight to twelve feet. Plantlets are self-rooted and produce many sucker shoots around the base. There are minimal differences in production from other sour cherries, the hybrids share the same pests and pathogens and are similarly vulnerable to abortion of flowers during late spring frosts. Dwarf Sour Cherries are reported to be cold hardy to around USDA Zone 3 by University of Saskatchewan.

One purported advantage over other sour cherries is that fruit have a wide window of harvest and can develop dark coloration, high soluble solids, and potential fresh consumption quality comparable to sweet cherries.

The largest potential advantage over conventional sour cherries is that of any intensive dwarfed crop; more plants per acre, potentially more precocious plants and crops and increased ease of harvest and maintenance (pruning and pest management) due to their smaller stature.

Haskap

Haskap, also commonly known as honeyberry and edible blue honeysuckle, is a fruiting species of honeysuckle that is native to the boreal forests of the northern hemisphere. The cold-hardy plant produces blue cylindrical fruit in early spring, typically small and bitter among native populations, but up to 3 grams and with a favorable flavor commonly described as blue raspberry among domesticated varieties. Traditionally, the fruit has been utilized by indigenous populations in northern Asia.

Modern domestication efforts began in the early 1900’s in Russia and Canada. The first developments in North American occurred in the 1920’s when haskap seeds were grown out at an Agriculture Research Station in Alberta. Two cultivars, Georges Bugnet and Julia Bugnet were released, but were not received well by nurseries or the public as they were low yielding, small in fruit size and unsavory. In Russia, serious domestication efforts began in the 1950’s, spawning at least 70 cultivars to date (Hummer, 2006). There has also been extensive Haskap development in Poland and Czechoslovakia. Interest in breeding programs developed in Saskatchewan in the late 1990’s (Bors, n.d.) and Oregon in 2000 (Thompson, 2006). Of the cultivars included in the trial; Aurora, Boreal Blizzard, Borealis, and Indigo Gem originated from the University of Saskatchewan's breeding program, Solo, Kawai, Keiko, Tana, Taka, and the numbered lines 79-9,141-75, and 85-19 from Oregon State Universities (OSU) breeding program, Sugar Mountain Blue from the Czech Republic and Blue Corn, Blue Goose, and Wild Treasure were sourced from the company Berries Unlimited.

Little information exists about Haskap production worldwide, but the majority of production and consumption occurs in Japan, Poland, the Czech Republic and Russia. The European Union did not approve Haskap fruit for trade until 2018, so European inter-state trade was limited until the recent legislative change. Statistics Canada reports 1500 acres of Haskap in Canada valued at $2.3 million CAD.

Known variety trials and evaluations have occurred at North Dakota State University, University of Saskatchewan, Oregon State University, in the Czech Republic (Sochor et al., 2014), Poland (Kucharska et al., 2017), and Nova Scotia (Khattab et al., 2016).

Haskap is an early flowering and maturing crop with tremendous cold hardiness (Zone 2-3). The earlier flowering plants can have trouble with adequate pollination due to temperatures being too low for insect pollinators to be active.

According to the University of Saskatchewan, Haskap has few pests or diseases. This was found to be largely true in the trial, though fruit predation by birds could reach extremes if not checked.

Saskatoon

Saskatoons, a fruiting species of the Rosaceae family, are found throughout North America. The plants and fruit are also commonly known as Juneberries or some variation of Serviceberry, depending on geographic locale.

Saskatoon plants can take up to 10 years to reach maximum yields. Saskatoon plants can reach sizes comparable to apple trees at 10 plus feet.

Saskatoon produces large and juicy fruit in early summer that are quite similar to blueberries in most regards. However, the plants do better in neutral to basic soils than blueberries.

The majority of cultivars of Saskatoon have been selected from wild plants based on favorable traits. (Spencer et al., 2013). Most production and consumption occur in Canada, with 2700 acres reported, valued at $2.1 CAD (Statistics Canada, 2020).

Saskatoon plants are cold hardy to USDA zone 3. Saskatoons are somewhat susceptible to both pests and disease, as there are often other wild Saskatoon plants and common Rosaceae pests and pathogens occurring in the local environment. For this reason, Saskatoon might be a poor companion crop to other vulnerable crops of the Rosaceae family like apples (Spencer, et al., 2013, St. Pierre, 1992).

Materials, Methods and Hypotheses

Experiment Locations

Cultivar evaluations consisted of a multisite trial of six fruit species, planted at four sites across the state in the late spring of 2015. Sites were located near urban centers (Kalispell, Missoula, Bozeman, and Helena) to evaluate performance in areas with established local-food markets and producers. One site was located at the Montana State University Western Agricultural Research Station (WARC) in Corvallis and was managed by the Superintendent of WARC, Zach Miller, and Bridgid Jarrett. A second site was located at the Flathead Valley Community College Learning Farm (FVCC) in Kalispell and was managed by the farm manager, Julian Cunningham and an ag professor, Heather Estrada, from FVCC. The third site was split between two private properties in Helena, which were managed by the landowners and the Lewis and Clark county extension agent Brent Sarchet. Data from Helena was not included in this document, as the two properties were dissimilar. The fourth site was located on the MSU Bozeman Horticulture Farm and was managed by the author, Durc Setzer and his academic advisor, Mac Burgess.

Experimental Design

At each site, the fruit species were arranged in a Randomized Complete Block Design with three blocks per site. Main plots were species. For each species, the cultivars were treated as a split-plot treatment. The locations of the cultivars were randomly assigned within the area designated for that species. In a block, each cultivar was represented by three plants, with one plant per row in the same position in three adjacent rows.

Data was collected on fruit quality parameters of cultivars starting in 2016 and consisted of soluble solids, average fruit dry matter percentage, and total phenolic content of fruit measured as milligrams of gallic acid equivalent per 100 grams of fresh weight fruit. Soluble solids were measured as °brix by analyzing the conglomerated juices of at least three to five fruit with a handheld analog refractometer.

Dry matter content of fruit was derived from fruit mass by weighing fruit mass of samples before and after freeze drying.

Total Phenolic Content

Samples for TPC consisted of approximately 1 ounce of fresh fruit which had been conglomerated from each cultivar within a block. These samples were subsequently lyophilized (freeze dried) to a minimum moisture content and pulverized to a homogenous dry powder with a hand-held grinder. This ensured that phenolic content of the whole fruit was accounted for, including pomace, liquid contents, and seeds.

TPC of fruit was analyzed utilizing the Folin–Ciocalteau assay (FC) and is reported as Gallic Acid Equivalents of 100 grams of fresh fruit. Fruit was initially frozen in conventional freezers approximately three months, mirroring potential phenolic degradation seen in frozen commercial fruit (Khattab et al., 2015). Samples were then moved to a scientific -50° C freezer, halting further phenolic degradation. The FC method utilized to prepare, extract, and analyze TPC was one previously verified for use in tea cultivar assessments, as published by (Unachukwu et al., 2010). The method was verified for use in small fruit analysis of these species prior to analysis of cultivars.

Phenolic Compounds

In early 2019, 79 Haskap samples were analyzed via UHPLC for phenolic content, targeting six phenolic compounds that were deemed common to Haskap fruit and for which standards were readily sourced.

The samples were the same methanol extracts as were used in TPC analysis, originally from 2017 fruit from Bozeman and Corvallis, conglomerated per block per site. Samples had been stored at -50 C° to minimize phenolic degradation. Liquid samples were filtered prior to UHPLC analysis. This method was verified in-lab twice before analysis progressed.

Standards utilized included: cyanin chloride with molecular mass 595.53, neochlorogenic acid with mass 354.31, callistephin chloride at 433.38, kuromanin chloride at 484.84, quercetin 3 glucoside at 464.38 and rutin trihydrate at 611.1 grams per mole. Standards were sourced from Sigma Aldrich (Atlanta, GA) and Alkemist Labs (Garden Grove, CA).

Solvents used in standard preparation included aceto-nitrile (ACN) and solvent grade water. For all standards except rutin, a ratio of 1:1:1 was utilized, with 1 ml of each solvent liquid to each mg of standard. For rutin trihydrate, solvent ratio was 1:10, one mg standard to ten ml H2O, with no ACN.

Standards and compounds were analyzed over 8 serial dilutions to establish a linear standard curve.

Statistical Analysis

Statistical analysis of brix and TPC was performed across blocks at the cultivar level per individual site and year. Experimental units consisted of were the group of 3 repeated cultivars per block. Where suitable, soluble solids and TPC were analyzed across years. In instances where there was a large 3rd cohort, i.e. replanted Currants, these plants were analyzed separately. Phenolic compounds were not analyzed, due to the lack of validity of the data in comparison to other published reports.

Analysis was performed with R Studio, utilizing ANOVA. Data which did not follow a normal distribution, as determined by a Shapiro-Wilkes test, was log transformed via the Box-Cox method and re-analyzed. . Analysis across sites utilized a mixed model with blocks modeled as random effects, while within individual sites analyses utilized linear models. Pairwise comparisons were accomplished utilizing Least-squares means to generate a compact letter display. There were no adjustments for repeated testing. Significance was held at $\alpha=0.05$. Descriptive statistics of TPC including frequency may be found in appendix table 4-3. Soluble solids frequencies should mirror yield frequencies found in appendix tables 4-1 and 4-2. Analysis was also performed to determine correlations within quality and with yield factors. Such correlations were based on observations of individual plants for all metrics except phenolic content which was based on block averages. Analysis of correlations were restricted to individual sites to avoid confounding effects of any site-by-location interactions.

Hypotheses

1. Soluble solids of different cultivars within a species are not equal.
2. Soluble solids and yield are inversely co-related, an increase in one factor results in a decrease in the other.
3. Soluble solids and fruit mass are inversely co-related, an increase in one factor results in a decrease in the other.

Haskap-only Hypotheses

4. TPC of different cultivars are not equal.
5. Dry matter content of different Haskap cultivars are not equal.
6. Individual phenolic compounds of different Haskap cultivars are not equal.
7. TPC and yield are inversely co-related, an increase in one factor results in a decrease in the other.

8. TPC and fruit mass are inversely co-related, an increase in one factor results in a decrease in the other.
9. TPC and soluble solids are inversely co-related, an increase in one factor results in a decrease in the other.
10. TPC and dry matter content are positively co-related, an increase in one factor results in an increase in the other.

Aronia

Results

Table 3-1, presented below, details Aronia fruit quality factors across sites and years. Data is presented as percent soluble solids (brix), TPC as milligrams of gallic acid equivalent per 100 grams of fresh weight fruit, and percent dry matter, as detailed in the first row. Statistical significance is delineated with different letters, with comparisons made within years. The following results sub-sections will refer to the data in this table.

TABLE 3-1 ARONIA QUALITY FACTORS

Site	Cultivar	Soluble Solids (%) 2017	Soluble Solids (%) 2018	Soluble Solids (%) 2017&18	TPC (mg GAE/100g FW) 2017	Dry Matter (%) 2017
Bozeman	Mean	23.4	22.0	22.5	2804	30.4
	McKenzie	25.2 a	22.0 a	23.3 a	3580 a	30.7
	Viking	21.6 a	21.9 a	21.7 a	2027 b	30.1
Corvallis	Mean	23.5	20.2	21.9	NA	NA
	McKenzie	23.3 a	18.9 b	21.1 b	NA	NA
	Viking	23.8 a	17.4 c	20.6 b	NA	NA
	Autumn Magic	23.4 a	24.3 a	23.9 a	NA	NA
Kalispell	Mean	NA	27.1	NA	NA	NA
	McKenzie	NA	27.8 a	NA	NA	NA
	Viking	NA	26.4 a	NA	NA	NA
All	Mean	23.9	22.5	23.2	NA	NA
	McKenzie	24.2 a	23.0 a	23.5 a	NA	NA
	Viking	23.5 a	21.9 a	22.9 a	NA	NA

Within each site, different letters represent statistically significant differences between cultivars at α=0.05
Comparisons are made within year

Soluble Solids. The soluble solids (SS) content of the Aronia cultivars McKenzie and Viking did consistently vary across sites and years. There were differences in SS between cultivars in Corvallis in 2018 (Table3-1). In the same year, 2018.the ornamental variety Autumn Magic had higher SS than both commercial cultivars. Kalispell produced a considerably higher concentration of SS in 2018, compared to other sites.

Soluble solids concentrations across years were negatively correlated with both yield (p=0.00-0.06, r=-0.37-0.88) and fruit mass (p=0.00-0.02, r=-0.41-0.59), at all sites. This trend was associated with higher SS and lower yields in 2017 than in 2018, as well as the effect of inclusion of Autumn Magic in Corvallis. Regardless, it appears there is a dilution tradeoff between high SS and fruit mass, and possibly yield as well.

Phenolic Content and Dry Matter. Total phenolic content and dry matter were measured for Aronia cultivars in Bozeman in 2017. TPC varied significantly between the two cultivars, in contrast to yield and soluble solid results, McKenzie had 77% higher TPC concentrations than Viking.

Conclusions

Aronia cultivars did not have consistent differences in soluble solids concentrations across sites and years. Thus, it is likely that hypothesis #1, that soluble solids varied between cultivars, would not hold true at any site.

Hypothesis #2 that TPC varied between cultivars bore true. In the one site year it was evaluated there was a dramatic difference between McKenzie and Viking TPC. This should be investigated further. Interestingly, the two cultivars displayed nearly identical yields, SS, and dry matter content.

There was significant evidence that hypotheses #3 and #4 were true, that there is a “yield dilution” trade-off affect in Aronia between soluble solids and both yield and fruit mass, but this is driven by the differences between the Autumn Magic (*Aronia melanocarpa*) and the commercial, hybrid cultivars.

Black Currants

Results

Table 3-2, presented below, details Black Currant fruit quality factors across sites and years. Data is presented as percent soluble solids (°brix), TPC as milligrams of gallic acid equivalent per 100 grams of fresh weight fruit, and percent dry matter, as detailed in the first row. Statistical significance is delineated with different letters, with comparisons made within years. The following results sub-sections will refer to the data in this table.

TABLE 3-2 BLACK CURRANT QUALITY FACTORS

Site	Cultivar	Soluble Solids (%) 2017	Soluble Solids (%) 2018	Soluble Solids (%) 2017&18	TPC (mg GAE/100g FW) 2017	Dry Matter (%) 2017
Bozeman	Mean	NA	18.95*	NA	520	21.8
	Blackcomb	NA	18.0 bc*	NA	627 a	23.3 ab
	Stikine	NA	19.4 b*	NA	497 a	20.1 bc
	Titania	NA	22.0 a*	NA	556 a	26.4 a
	Tofino	NA	16.4 c*	NA	398 a	17.5 c
Corvallis	Mean	16.3	15.4	15.8	NA	NA
			16.0*		NA	NA
	Tahsis	14.9 d	14.0 d	14.5 d	NA	NA
			13.5 b*		NA	NA
	Whistler	14.9 d	14.3 cd	14.6 d	NA	NA
	M12	15.4 cd	14.2 cd	14.8 cd	NA	NA
	Stikine	16.5 bc	14.6 cd	15.5 c	NA	NA
			15.8 b*		NA	NA
	Cheakamus	15.6 bcd	13.5 d	14.6 cd	NA	NA
			14.3 b*		NA	NA
	Blackcomb	16.7 b	17.6 b	17.1 b	NA	NA
			16.4 ab*		NA	NA
	Titania	21.0 a	20.0 a	20.5 a	NA	NA
			19.9 a*		NA	NA
	Tofino	15.2 d	14.9 c	15.1 cd	NA	NA
Kalispell	Mean	15.5	15.2	16.3	NA	NA
			17.1*		NA	NA
	Stikine	15.2 a	14.5 a	14.8 a	NA	NA
			15.9 b*		NA	NA
	Blackcomb	17.2 a	15.5 a	16.3 a	NA	NA
			17.0 b*		NA	NA
	Tofino	14.2 a	15.5 a	14.8 a	NA	NA
			16.2 b*		NA	NA
	Titania	NA	19.2 a*	19.2	NA	NA
All	Mean	17.6	16.9	17.5	NA	NA
	Blackcomb	17.1 b	17.7 b	17.2 b	NA	NA
	Stikine	16.8 b	15.2 c	16.7 b	NA	NA
	Titania	21.0 a	19.3 a	20.5 a	NA	NA
	Tofino	15.3 c	15.3 c	15.6 c	NA	NA

Within each site, different letters represent statistically significant differences between cultivars at α=0.05
*= Replanted varieties, 1-year junior to other 2018 cultivars
Comparisons made within years

Soluble Solids. Across all sites, the cultivar Titania produced the highest concentrations of soluble solids, with all sites reporting 19° brix or more. Blackcomb was ranked second, with Stikine next, and Tofino typically producing the lowest concentrations, though the difference was not large.

All four extra cultivars trialed in Corvallis; Cheakamus, Tahsis, Whistler and M12 were comparable to Tofino with consistently low SS concentrations, and were outperformed by Titania, Blackcomb, and Stikine.

In Corvallis, Black Currant soluble solid levels were negatively correlated with yield ($p \leq 0.001$, $r = -0.45$), and negatively associated with fruit mass ($p = 0.06$, $r = -0.19$). The yield trend appears to hold true among all sites, with higher yielding cultivars producing relatively low levels of soluble solids. The trend with fruit mass does not appear to hold true, even in Corvallis, as there are many instances where high yielding cultivars also produce relatively large fruit.

A Serbian trial of 13 cultivars found SS concentrations ranging from 12.3 to 18.2° brix. The cultivar Titania was included in the study and was among the lower observed concentrations of SS at 13.3° which departed from the trend of high SS observed in Montana (Djordjevic et al., 2012). A Lithuanian experiment consisting of 20 Black Currant cultivars found a range of soluble solids concentration from 13.5 to 17.7, averaging 15° brix (Sasnauskas et al., 2009). Among six Black Currant cultivars at North Dakota State, soluble solids ranged from 16.8 to 20.2, with Titania achieving 20.0° brix (NDSU, 2010). Montana soluble solids concentrations of Black Currant cultivars were considerably higher than those observed in European trials.

Phenolic Content and Dry Matter. In 2017, 11 samples of Black Currant were analyzed for phenolic and dry matter content. There appear to be modest and non-significant differences between cultivars in TPC. Dry matter content did differ significantly, with Titania having the largest value and Tofino the smallest. In general, Black Currant cultivars at Bozeman produced fruit with higher phenolic concentrations than those observed in *Rubus* species, strawberries, and blueberries (Celli et al., 2014).

Conclusions

There was considerable evidence that hypothesis #1 was true, significant differences in soluble solids were found among Black Currant cultivars. There was some evidence found to support hypotheses #2 and #3 in Corvallis, that soluble solids are inversely correlated with yield and fruit mass, but there was not significant evidence of this trend among other sites. In Corvallis, a significant trend of soluble solids being negatively correlated with yield was found, but SS was only negatively associated with fruit mass. While the yield trend appeared to play out in other sites, the trend was not significant.

Dwarf Sour Cherry

Results

Table 3-3, presented below, details Dwarf Sour Cherry fruit soluble solids across sites and years. Data is presented as percent soluble solids (brix) as detailed in the first row. Data marked with an asterisk was derived from plants which are among a cohort one year younger. Statistical significance is delineated with different letters, comparisons made within years. There were not enough observations of TPC or dry matter for inclusion. The following results sub-sections will refer to the data in this table.

TABLE 3-3 DWARF SOUR CHERRY QUALITY FACTORS

Site	Cultivar	Soluble Solids (%) 2017	Soluble Solids (%) 2018
Corvallis	Mean	16.1	15.55
			17.7*
	Carmine Jewel	15.2 b	15.0 b
	Romeo	NA	17.5 a*
	Lutowka Rose	17.0 a	16.1 a
	Juliet	NA	17.8 a*
Kalispell	Mean	NA	16.6*
	Carmine Jewel	NA	11.8
	Juliet	NA	14.6 b*
	Romeo	NA	18.6 a*
All	Mean	NA	16.2
	Carmine Jewel	NA	14.0 c
	Juliet	NA	16.2 b
	Romeo	NA	18.3 a

Within each site, different letters represent statistically significant differences between cultivars at $\alpha=0.05$
*= Replanted varieties, 1-year junior to other 2018 cultivars
Comparisons are made within year

<u>Soluble Solids.</u> Dwarf Sour Cherry cultivars did not provide much data for comparison, due to the lack of yields in the cultivar Crimson Passion and at the Bozeman site, the plants' long maturity requirement and the fact that Romeo and Juliet were planted in 2016.

The cultivars Romeo and Juliet, and the Sour Cherry variety Lutowka Rose trialed in Corvallis, all produced higher concentrations of soluble solids than Carmine Jewel. Soluble solids concentrations in Kalispell Carmine Jewel plants were particularly low, which was likely affected by harvesting on a schedule rather than waiting for a targeted brix level. Among the core varieties, Romeo produced the largest concentration of soluble solids.

The North Dakota cultivar trial reported soluble solids concentrations of 16.4° in Carmine Jewel and 18.6° in Crimson Passion among four-year old plants (NDSU, 2010).

Total Phenolic Content. A single sample of Dwarf Sour Cherry was obtained from the cultivar, Carmine Jewel, in 2017 from the Bozeman site. The single sample measured 570 mg GAE/100g FW. This was higher than most Black Currant varieties sampled in 2017, which largely ranged from 300 to 500 mg GAE/100g FW.

A separate analysis of 34 Sour Cherry (*Prunus cerasus*) cultivars found maximum TPC levels ranging from 600 to 750 mg GAE/100g FW (Khoo et al., 2011), which validates the relatively high TPC level of the single sample.

Haskap

Results

Table 3-4, presented below, details Haskap fruit quality factors across sites and years. Data is presented as percent soluble solids (brix), TPC as milligrams of gallic acid equivalent per 100 grams of fresh weight fruit, net TPC as gallic acid equivalent by fresh weight fruit, and percent dry matter, as detailed in the first row. Statistical significance of soluble solids is delineated with different letters, with comparisons made within years. Net TPC was derived from analyses performed in 2016 and 2017. The following results sub-sections will refer to the data in this table.

TABLE 3-4 HASKAP QUALITY FACTORS

Site	Cultivar	Soluble Solids (% brix)			Total Phenolic Content (mg GAE/100g FW)			Net TPC per Plant (mg GAE FW)		Dry Matter (%)
		2017	2018	2017&18	2016	2017	2016&17	2017	2018*	2017
Bozeman	Mean	15.8	14.4	15.1	632	1129	866	2710	3248	20.0
	85-19	17.3 ab	15.4 ab	16.3 a	531 b	835 c	648 d	1895	4128	20.1 b
	Solo	14.7 c	14.7 bc	14.7 bc	746 a	890 bc	818 bcd	3489	4344	18.9 bc
	41-75	16.1 bc	13.5 c	14.9 bc	590 b	937 bc	760 cd	4235	3823	20.2 abc
	Indigo Gem	17.9 a	14.0 bc	16.1 ab	587 b	1406 a	1041 ab	2362	2811	23.7 a
	Borealis	15.0 c	13.1 c	14.1 c	705 a	1435 a	1166 a	2210	2775	21.1 ab
	Aurora	16.0 bc	13.5 c	14.6 c	NA	1238 ab	1002 abc	569	721	22.5 ab
	Sugar Mtn. Blue	13.4 c	16.8 a	15.1 abc	NA	824 bc	628 bcd	NA	NA	13.6 c
Corvallis	Mean	15.5	15.5	15.5	630	814	797	7212	14386	17.5
	85-19	16.0 abcd	16.7 b	16.5 b	363 d	380 f	376 f	6673	13201	17.7 bcde
	Tana	16.0 abcd	13.8 f	14.8 efg	716 abc	691 de	716 cde	11864	22575	16.7 cdef
	Borealis	14.6 cde	15.4 cde	15.1 defg	1059 a	975 bc	1020 ab	6835	26061	17.1 cde
	Solo	17.0 a	15.8 bcd	16.3 bc	922 ab	1153 ab	1026 ab	11034	25948	19.8 ab
	Keiko	16.7 abc	15.8 bcd	16.2 bcd	476 cd	646 de	554 ef	7578	11667	17.9 bcde
	Taka	14.8 abcde	14.8 def	14.9 efg	596 bcd	650 de	624 de	8216	12936	14.7 fg
	Indigo Gem	16.8 ab	18.8 a	18.0 a	NA	856 cd	839 bcd	4323	17158	20.4 a
	Kawai	14.8 bcde	13.6 f	14.1 gh	586 abcd	503 ef	561 def	7107	10193	15.6 efg
	79-91	15.8 abcd	16.4 bc	16.2 bcd	397 cd	613 def	521 ef	7031	8768	18.3 abcd
	41-75	12.9 e	13.6 f	13.4 h	575 bcd	477 ef	538 ef	6711	8845	16.1 defg
	Aurora	16.5 abc	15.6 bcd	15.9 bcde	NA	1280 a	1263 a	5082	21395	18.6 abc
	Wild Treasure	15.6 abcd	15.5 bcde	15.6 bcdef	NA	963 bc	946 abc	1839	2147	18.6 abc
	Sugar Mtn. Blue	16.2 abc	16.7 bc	16.3 bc	NA	998 bc	977 abc	2136	1192	17.0 cdef
	Blue Goose	14.6 abcde	14.2 ef	14.4 fgh	NA	967 bc	951 abc	473	1084	20.4 a
	Blue Corn	14 de	NA	14.6 cdefgh	NA	1060 abc	1043 ab	4187	NA	14.2 g
Kalispell	Mean	14.7	15.5	15.3	NA	NA	NA	NA	NA	NA
	85-19	15.1 a	15.0 cd	15.0 b	NA	NA	NA	NA	NA	NA
	Solo	16.0 a	15.4 bc	15.7 ab	NA	NA	NA	NA	NA	NA
	41-75	13.8 b	13.8 d	13.8 c	NA	NA	NA	NA	NA	NA
	Aurora	15.1 a	15.6 bc	15.4 ab	NA	NA	NA	NA	NA	NA
	Indigo Gem	12.3 c	17.7 a	15.0 b	NA	NA	NA	NA	NA	NA
	Borealis	15.7 a	14.5 cd	15.3 ab	NA	NA	NA	NA	NA	NA
	Sugar Mtn. Blue	NA	16.6 ab	16.6 a	NA	NA	NA	NA	NA	NA
All	Mean	15.5	15.3	15.3	697	1014	919	6348	12535	19.3
	85-19	16.1 a	15.7 bc	15.9 abc	436 b	648 c	564 d	7588	13474	18.8 bc
	Solo	15.7 a	15.3 bc	15.6 bc	847 a	1021 a	945 b	7188	15498	19.3 abc
	41-75	14.5 b	13.6 e	14.0 e	582 b	720 bc	664 cd	7286	8685	18.2 bc
	Indigo Gem	15.5 a	16.9 a	16.3 a	NA	1165 a	1072 ab	3052	13550	22.1 a
	Borealis	15.2 ab	14.3 de	14.7 de	921 a	1254 a	1143 a	4690	16231	19.5 bc
	Aurora	15.8 a	14.9 cd	15.4 cd	NA	1259 a	1151 ab	2921	13536	20.5 ab
	Sugar Mtn. Blue	15.7 ab	16.2 ab	15.8 ab	NA	1028 ab	891 abc	NA	3136	16.8 c

Within each site, different letters represent statistically significant differences between cultivars at α=0.05.
* Net Average TPC for 2018 is estimated based on TPC mean from 2016 and 2017.
Comparisons are made within years

Total Phenolic Content. Across sites and years, the Haskap variety Borealis produced the highest total phenolic content (TPC) and was closely followed by the cultivars Indigo Gem and Aurora. Sugar Mountain Blue and Solo formed an intermediate group. Both cultivars 41-75 and 85-19 displayed the lowest levels of TPC, achieving approximately only half the phenolic production of the top group.

Among the extra cultivars trialed in Corvallis there were two distinct groups of cultivars based on phenolic content. Blue Corn, Blue Goose and Wild Treasure composed the high phenolic content group, comparable to Borealis, Solo and Aurora. The remaining extra cultivars: Taka, Tana, Keiko, Kawai and 75-19 composed the low phenolic content group, with TPC comparable to 85-19 and 41-75.

A Canadian cultivar trial reported Haskap TPC values of 11 cultivars ranging from 634 to 1154 mg GAE per 100g FW, averaging 832 mg, with Borealis containing the highest concentration (Rupasinghe, et al., 2015). A trial out of the Czech Republic reported on 10 cultivars with a range of 554 to 866 mg GAE per 100g FW, averaging 692 (Sochor et al., 2014). TPC levels in the Montana trial were similar to these other results, averaging a slightly higher 919 mg.

In 2017, total phenolic content in Corvallis and Bozeman was negatively correlated with yield ($p \leq 0.001, 0.05$, $r=-0.35, -0.74$). This trend was not absolute as the lowest yielding varieties did not produce the highest TPC, and the highest TPC was observed in cultivars with intermediate yields.

Net TPC per Plant. Total phenolic content is a good metric of fruit quality from a consumer perspective but does not consider yield potential and total yield of phenolic content from a given crop. Thus, net TPC per plant is derived from the cultivar's fruit yield and observed phenolic content. As phenolic data was obtained from 2016 and 2017, but yield from 2017 and 2018, net TPC in 2018 was obtained from the TPC across 2016 and 2017.

Across sites, Solo, Borealis, Indigo Gem and Aurora produced comparable net phenolic content to the high yielding cultivar 85-19. The cultivars 41-75 and Sugar Mountain Blue produced much lower levels of net phenolic content.

Among the extra cultivars trialed in Corvallis, only Tana stood out. Tana's high yields and intermediate TPC combined to achieve TPC total yields comparable to the other top-group cultivars. Keiko, Taka, and Kawai produced intermediate TPC total yields. Blue Corn achieved lower net TPC levels, while Blue Goose and Wild Treasure produced very low net TPC levels comparable to Sugar Mountain Blue.

Dry Matter. Another metric of fruit quality is that of dry matter content, or its inverse, juice content. Dry matter content was measured in 2017 only. Although this range was typically small, a few percent, there were some differences between cultivars. Across sites, Indigo Gem produced the highest dry matter content. The cultivar Sugar Mountain Blue displayed the lowest dry matter content. Differences in liquid content were not so great as to overcome yield tendencies; with high yielding varieties producing a larger total juice yield than cultivars which had less dry matter content.

Among the extra cultivars trialed at Corvallis, only Blue Goose and Blue Corn stood out, with Blue Goose attaining the same dry matter content as Indigo Gem, while Blue Corn displayed the lowest dry matter content.

Total phenolic content in Bozeman and Corvallis was positively correlated with dry matter ($p \leq 0.001, 0.001$, $r=0.39, 0.52$). This is as expected, as the constituents of TPC in Haskap are primarily found in the fruit pomace and not in liquid contents.

Soluble Solids. Concentrations of soluble solids concentrations in Haskap cultivars did not vary as much as in some other species, with a range of 12.3 to 18.8° brix occurring in the same cultivar; Indigo Gem, which had more year to year variation than other cultivars. Regardless, Indigo Gem produced the highest concentration of soluble solids, achieving over 16° when averaged across sites and years. As soluble solids concentration is not believed to be a maturity factor, averaging results across sites and years provides a clearer picture of the cultivars overall performance and potential. Continuing to average results; the cultivars 85-19, Sugar Mountain Blue, Solo and Aurora, from highest to lowest, grouped between 15 and 16° brix. The cultivar Borealis achieved under 15° and 41-75 produced 14° brix.

Across years, the extra cultivars trialed in Corvallis; Keiko and 79-91 produced over 16° brix. The cultivar Wild Treasure produced over 15° brix, while the rest of the cultivars; Tana, Taka, Blue Goose, Kawai, and Blue Corn, from highest to lowest, were grouped between 14° and 15° brix.

The trial at North Dakota reported soluble solid concentrations for 13 cultivars, ranging from 10.8° to 16.6° brix, with an average of 13.7° brix (NDSU, 2011). By initial appearance, Montana may be better suited to produce high soluble solid concentrations than North Dakota, though this might be a result of many factors including harvest date, yearly climate, and elevation.

Phenolic Compounds. Table 3-5, presented below, details Haskap fruit phenolic compounds. The compounds were derived from fruit harvested in 2018 from Bozeman and Corvallis. Data is presented as milligrams of gallic acid equivalent per 100 grams of fresh weight fruit. No statistical analysis was performed, as results did not correspond to other published data. The following results sub-sections will refer to the data in this table.

TABLE 3-5 HASKAP PHENOLIC COMPOUNDS

Cultivar	Cyanin Chloride	Neochlorogenic Acid	Callistephin	Kuromanin	Quercetin 3 Glucoside	Rutin	Total
Blue Goose	5480	19.2	12.3	2812	50.9	21.5	8396
Wild Treasure	1880	25.2	21.7	3319	79.1	12.5	5337
Blue Corn	1941	25.8	35.1	3236	57.9	9.5	5305
Indigo Gem	1606	17.9	53.8	3356	66.9	16	5116
Sugar Mtn Blue	1654	31.7	45.8	2507	44.8	11.7	4295
Aurora	987	6.0	39.9	3152	91.1	16.9	4292
Borealis	919	7.1	25.6	3198	96.7	12.7	4259
79-91	1329	5.0	44	2656	67.1	8.5	4109
Solo(44-19)	1012	15.4	9	2767	105.8	4.4	3913
Kawai	1970	3.3	9.8	1859	49.9	3.5	3895
Keiko	1111	3.2	15.5	2409	84.9	4	3627
41-75	1254	13.1	28.6	2070	62	4	3432
85-19	570	14.3	19	2415	96.6	6.3	3121
Tana	985	9.6	49	1988	55.7	7.4	3094
Taka	796	10.1	12.2	1961	77	2.9	2859
Mean	1566	13.8	28.1	2647	72.4	9.5	4337

Milligrams of gallic acid equivalent per 100 grams of fresh weight fruit.

In early 2019, 79 Haskap samples were analyzed via UPLC for phenolic content, targeting six phenolic compounds that were deemed common to Haskap fruit and for which standards were readily sourced.

The initial analysis of samples resulted in some values which did not correspond to other reported values, and another analysis of both standards and samples was undertaken. These analyses proved more erroneous and were discarded for the initial analysis. The lab mentioned other phenolic analyses were proving problematic as well, and the source of error was not discovered.

Analysis results of cyanin chloride were clearly erroneous, with other literature reporting a range of 2 to 29, and an average of 12.1 milligrams per 100 grams of fresh weight fruit (mg per 100g FW), results in Montana were two factors higher than reported amounts. Other results which departed from reported values included kuromanin at one factor larger than the reported range of 135 to 649 mg per 100 g FW, and quercetin 3 glucoside with reported values of 1 to 12 mg per 100 g FW. The other compounds analyzed were reasonably similar to reported values, with; neochlorogenic acid reported with a range of 0.35 to 12.6, callistephin at 0.21 to 9 and rutin at 22 to 34 mg per 100 g FW (Kucharska et al., 2017, Khattab et al., 2016).

Cultivars from Oregon and Saskatchewan tended towards lower production of cyanin chloride, neochlorogenic acid, rutin and kuromanin than Sugar Mountain Blue and the Czech cultivars trialed in Corvallis. When compared to yields, it appears these compounds might suffer yield dilution, as the highest values were observed in low yielding cultivars and vice versa. However, this might also be explained and or affected by cultivar harvest date, with early cultivars like Sugar Mountain Blue, Indigo Gem and the Czech cultivars yielding early, versus high yielding Oregon cultivars yielding later in the year. In contrast, quercetin 3 glucoside was more prevalent in high yielding cultivars. Across sites, Indigo Gem produced the highest concentrations of observed compounds, with Sugar Mountain Blue following closely. The lowest total concentrations were observed in the high yielding varieties 85-19, Tana and Taka.

Conclusions

As there are so many hypotheses posited for Haskaps, this section will be organized to address hypotheses by line-item for the sake of cohesiveness.

1. Soluble solids of different cultivars within a species are not equal.

There was substantial and significant evidence at all sites that Haskap cultivars do develop different levels of soluble solids, though the range was narrow, producing 14 to 16° brix when averaged across sites and years.

2. Soluble solids and yield are inversely co-related, an increase in one factor results in a decrease in the other.

The research trial failed to find evidence that soluble solids and yield in Haskap are correlated at all.

3. Soluble solids and fruit mass are inversely co-related, an increase in one factor results in a decrease in the other.

The research trial failed to find evidence that soluble solids and fruit mass in Haskap cultivars are correlated at all.

4. TPC of different cultivars are not equal.

There was considerable and significant evidence from Bozeman and Corvallis that TPC levels are not the same among different Haskap cultivars. Averaged across sites and years there was a two-fold difference between the lowest and highest observed values, ranging 528 to 1047 milligrams of gallic acid equivalent.

5. Dry matter content of different Haskap cultivars are not equal.

There was considerable and significant evidence from Bozeman and Corvallis that dry matter content of Haskap fruit does vary by cultivar. Averaged across sites, there was a four percent difference between the highest and lowest values, ranging from 18 to 22° brix.

6. Individual phenolic compounds of different Haskap cultivars are not equal.

Analyses of individual phenolic compounds were found to be inconsistent with previously published reports and were therefore not analyzed statistically. However there did appear to be trends in the relative amounts of phenolic compounds, primarily that cultivars which possessed low yields and low palatability (palatability based on the author's observations); Blue Goose, Blue Corn and Wild Treasure, contained the highest relative amount of the tested compounds. While these cultivars had relatively high TPC levels, other varieties which possessed high yields and high palatability attained higher TPC concentrations, suggesting that there are other phenolic compounds which were not analyzed that comprise a large portion of total phenolic content in Haskap fruit.

7. TPC and yield are inversely co-related, an increase in one factor results in a decrease in the other.

There was significant evidence from 2017 Bozeman and Corvallis samples that TPC and yield are negatively correlated and that there is likely a yield dilution effect on TPC in high yielding cultivars. This might be an effect of the inclusion of the variety 85-19, which produced dramatically high yields and low TPC, as other varieties with relatively high yields such as Solo, Borealis and Aurora attained high levels of TPC.

8. TPC and fruit mass are inversely co-related, an increase in one factor results in a decrease in the other.

There was a failure to find any evidence that TPC and fruit mass are correlated in any way.

9. TPC and soluble solids are inversely co-related, an increase in one factor results in a decrease in the other.

There was no significant evidence that TPC and soluble solids are correlated in any way.

10. TPC and dry matter content are positively co-related, an increase in one factor results in an increase in the other.

There was significant evidence that TPC and dry matter content are positively correlated in Haskap fruit. This suggests that cultivars with higher dry matter content, ie pomace and seeds, have inherently higher TPC levels. This implication might affect both fresh fruit and juice production systems, as it appears that high TPC fruit are produced with a trade-off towards lower juiciness and increased mealiness.

Saskatoon

Results

Table 3-6, presented below, details Saskatoon fruit soluble solids across sites and years. Data is presented as percent soluble solids (brix), as detailed in the first row. Statistical significance of soluble solids is delineated with different letters, with comparisons made within years. The following results sub-sections will refer to the data in this table.

TABLE 3-6 SASKATOON SOLUBLE SOLIDS

Site	Cultivar	Soluble Solids (%) 2017	Soluble Solids (%) 2018	Soluble Solids (%) 2017&18
Bozeman	Mean	NA	18.5	18.5
	Northline	NA	18.1 a	18.1 a
	Lee8	NA	17.7 a	17.7 a
	JB30	NA	18.8 a	18.8 a
	Lee3	NA	17.1 a	17.0 a
	Smoky	NA	19.7 a	19.7 a
	Martin	NA	19.8 a	19.8 a
Corvallis	Mean	19.6	16.8	18.2
	Northline	22.4 a	15.6 c	18.8 ab
	Lee8	22.2 a	15.1 bc	18.7 ab
	Smoky	21.9 a	19.2 a	20.3 a
	Lee3	15.4 c	14.8 c	15.1 c
	Martin	17.1 bc	17.5 bc	17.2 b
	JB30	18.8 b	18.8 ab	18.8 ab
Kalispell	Mean	24.5	19.4	22.0
	Northline	26.2 a	16.3 c	20.9 ab
	Smoky	24.1 a	19.6 ab	21.8 ab
	Lee8	22.7 a	17.7 bc	19.6 b
	Lee3	23.8 a	20.9 a	21.9 ab
	Martin	26.1 a	21.0 a	22.8 a
	JB30	24.0 a	20.8 a	21.6 ab
All	Mean	21.0	18.2	20.1
	Northline	23.5 a	16.4 b	20.0 ab
	Smoky	21.9 ab	19.5 a	21.2 a
	Lee8	22.0 ab	16.8 b	19.5 bc
	Lee3	18.0 c	17.5 b	18.4 c
	Martin	20.3 bc	19.4 a	20.4 ab
	JB30	20.4 bc	19.8 a	20.8 ab

Within each site, different letters represent statistically significant differences between cultivars at α=0.05
Comparisons are made within years

Soluble Solids. Saskatoon cultivars displayed a large variation in soluble solids, with an observed range from 14.8° to 26.2° brix. Across sites and years, the Saskatoon cultivars which displayed the highest concentration of soluble solids was Smoky at over 21° brix. The cultivars JB30, Martin, and Northline achieved over 20° brix. Lee8 produced over 19° brix while Lee3 had the lowest soluble solids concentration of over 18°.

A trial in Saskatchewan of 16 Saskatoon cultivars reported a range of 14° to 20.1° brix, with a mean of 16.1° brix (Zatylny et al., 2005). Mean concentrations observed in Montana were considerably higher than those in Saskatchewan.

At all sites, soluble solid concentrations were negatively correlated with yield ($p \leq 0.001$-0.03, r=-0.39-0.68). This trend was affected by high SS and low yields in 2017 and low SS and increasing yields in 2018. Regardless, it appears the trend has some substance to it, as high yielding varieties tended towards lower SS while low yielding varieties tended towards high SS.

Conclusions

1. Soluble solids of different cultivars within a species are not equal.

There was significant evidence from Corvallis and Kalispell in 2018 that different cultivars of Saskatoon do produce differing levels of soluble solids.

2. Soluble solids and yield are inversely co-related, an increase in one factor results in a decrease in the other.

At all sites there was significant evidence that soluble solids and yield of Saskatoons are negatively correlated, it appears that there is a yield dilution effect on soluble solids as yield increases.

3. Soluble solids and fruit mass are inversely co-related, an increase in one factor results in a decrease in the other.

The research trial failed to produce evidence that soluble solids and fruit mass of Saskatoons are correlated in any way.

PERSONAL CONCLUSIONS

The following informal conclusions are personal, and opinions expressed are those of the author and should not be construed as scientifically tested, qualified or quantified viewpoints.

At the inception of this project I was a recent undergraduate who still maintained dreams of utilizing a beginning farmer loan from the USDA to operate a commercial perennial fruit orchard. Along the way this dream has waned, but as I exit this project the dream is renewed afresh. These fruit species are at least as viable in our harsh climates and in our under-utilized markets as the raspberries, blueberries and strawberries which now ubiquitously dominate our supermarket selection.

Following are my opinions, observations, and recommendations of some aspects of this project and of fruit production of this nature.

- Infrastructure matters
    - Infrastructure is a make or break early decision in fruit production
    - Netting, irrigation, fertilization, harvest, weed control
        - Can and should be mechanized/optimized from beginning of orchard
        - I'm of the opinion that if specific infrastructure is required, it should be designed intelligently with the future in mind.
            - Repetitious renovation of orchard's infrastructure is waste of time, capital, labor, and motivation
    - Infrastructure improves outcomes
        - Plant damage can reduce yields for 1, 2, or multiple years

        - Plant competition can reduce yields for multiple years
        - Stress from inadequate irrigation and fertilization can reduce yields for multiple years
        - Predation of fruit can devastate entire or multiple years efforts

- Costs of establishment
    - Plant material
        - The cost of plant material is likely the single largest capital expenditure of any large-scale orchard. Choosing cultivars with impropriety to the bottom line would be foolish of anyone hoping to take profits. The cost of plant materials is reduced by the age of the orchard, excepting mortalities
    - Infrastructure
        - The cost of infrastructure is significant, depending on scale and orchard design
        - The ability to scale an agronomic business relies heavily on specialized infrastructure
            - Ideally, the majority of infrastructure is a one-time commitment followed by maintenance of such assets. As such, the cost of infrastructure is reduced per the age of the orchard.
    - Labor
        - Cost of labor is on-going and increases yearly until fruit plants are mature
        - Minimizing labor by increasing infrastructure will increase long term profits

- Species/Cultivar matters
    - All species were viable, but some species are “bullet-proof” compared to others
        - Dwarf Sour Cherry & Saskatoon suffer more damage, pathogens and pests
            - Can be managed, but is it worthwhile?
                - May be worthwhile for diversification depending on farm organization
    - Aronia and Haskap are nearly pest free, which is hugely advantageous
        - Aronia does not need netted
            - A stand-alone Aronia orchard would require considerably less infrastructure than other species
- Is TPC useful to grower?
    - Yes, for cultivar selection. Knowledge that a cultivar is high in TPC is similar to knowledge that it is high in Soluble Solids and is a metric for decision making
        - Broadly:
            - High TPC more suitable for processing
                - Further analysis of anthocyanin content might relate whether one cultivar is more valuable than another to producers.
            - Low TPC more suitable for fresh consumption
- Was this a useful or novel trial which produced valuable information?
    - Without a doubt this trial was novel, useful and provided valuable insights.

        - Such scientifically designed and replicated trials with multiple novel species are rare
            - It is even more rare that such information is published
        - The results indicate that there is much potential for these crops and such a production system has inherently desirable traits
            - High value
            - Low intensity production systems
            - High quality fruit
            - Un-developed market is both advantage and disadvantage
                - Market could be quickly monopolized
                - Largely a ground up approach, no existing markets
- Recommendations
    - A wider adoption of such trials of novel crops
        - Occurring in more areas, ideally in every State
        - A wider array of novel species and cultivars
            - Continue to add novel species and cultivars
    - A more rigorous site design with 4 blocks or 4 replicates per block per site
    - Design a method to compare cultivars by pigment content
    - Test cultivars for machine harvestability

REFERENCES CITED

1. Åkerström, A., Jaakola, L., Bång, U., & Jäderlund, A., 2010. Effects of Latitude-Related Factors and Geographical Origin on Anthocyanidin Concentrations in Fruits of Vaccinium myrtillus L. (Bilberries). J. Agric. Food chem. 58, 11939–11945. https://doi.org/10.1021/jf102407n

2. Amelanchier alnifolia (Saskatoon berry) – a new berry crop with good perspectives for commercial cultivation in Europe, Stanisław Pluta Research Institute of Horticulture Skierniewice, Poland. Accessed 2019. HTTPS://WWW.EUBERRY.UNIVPM.IT/SITES/WWW.EUBERRY.UNIVPM.IT/FILES/EUBERRY/DOCUMENTI/BERRY%20SCHOOL%20BORDEAUX/PRESENTATIONS/PLUTA%20SASKATOON%20BERRY_S.PDF

3. Bors, R.H. (2005). DWARF SOUR CHERRY BREEDING AT THE UNIVERSITY OF SASKATCHEWAN. Acta Hortic. 667, 135-140
DOI: 10.17660/ActaHortic.2005.667.19
https://doi.org/10.17660/ActaHortic.2005.667.19

4. Bors, B., n.d. Haskap Breeding at the University of Saskatchewan. University of Saskatchewan, SK

5. Burnes, T.A., Blanchette, R.A., Smith, J.A., & Luby, J.J., 2008. Black Currant Clonal Identity and White Pine Blister Rust Resistance. HortScience 43, 200–202. https://doi.org/10.21273/HORTSCI.43.1.200

6. Canadian Dwarf Sour Cherries – Prunus x kerrasis. North Dakota State University. Accessed 2019. https://www.ag.ndsu.edu/CarringtonREC/northern-hardy-fruit-evaluation-project/fruit-index/dwarf-sour-cherry/canadian-dwarf-sour-cherries-2013-prunus-x-kerrasis

7. Celli, G.B., Ghanem, A., & Brooks, M.S.L., 2014. Haskap Berries (Lonicera caerulea L.)—a Critical Review of Antioxidant Capacity and Health-Related Studies for Potential Value-Added Products. Food Bioprocess Technol 7, 1541–1554. https://doi.org/10.1007/s11947-014-1301-2

8. CENSUS OF AGRICULTURE, TABLE 39. SPECIFIED FRUITS AND NUTS BY ACRES: 2017 AND 2012 AND 2007
TABLE 40. BERRIES: 2017 AND 2012 AND 2007.
Https://www.nass.usda.gov/publications/agcensus/2012/full_report/volume_1,_chapter_1_state_level/montana/st30_1_039_040.pdf

9. Djordjevic, B., Savikin, K., Zdunić, G., Janković, T., Vulić, T., Pljevljakusic, D., & Oparnica, C., 2012. Biochemical Properties of the Fresh and Frozen Black Currants and Juices. Journal of Medicinal Food, Vol. 16, No. 1. https://doi.org/10.1089/jmf.2011.0256

10. Everhart, E., 2009. Aronia – A New Crop for Iowa. Acreage Living, Iowa State Extension.
HTTP://PUBLICATIONS.IOWA.GOV/16643/1/MAR09.PDF

11. FAOSTAT World Currant Production 1994 to 2017. Accessed 2019.
http://www.fao.org/faostat/en/#data/QC/visualize

12. Fear,C., & Meyer, M. (1993). BREEDING AND VARIATION IN RUBUS GERMPLASM FOR LOW WINTER CHILL REQUIREMENT. Acta Hortic. 352, 295-304
DOI: 10.17660/ActaHortic.1993.352.42
HTTPS://DOI.ORG/10.17660/ACTAHORTIC.1993.352.42

13. Hancock, J.F. (Ed.), 2008. Temperate fruit crop breeding: germsplasm to genomics. Springer, S.l.

14. Hassanein, A.M.A., 2013. Factors Influencing Plant Propagation Efficiency Via Stem Cuttings. Journal of Horticultural Science & Ornamental Plants 5 (3): 171-176, 2013

15. Hummer, K. E. (2006). Blue honeysuckle: A new berry crop for north america. Journal of the American Pomological Society, 60(1), 3-8

16. Hummer, Kim E. & Barney, Danny L., Crop Reports. Journal of HortTechnology, July-Septemember 2002 12(3)

17. Khattab, R., Brooks, & M.S.-L., Ghanem, A., 2016. Phenolic Analyses of Haskap Berries (Lonicera caerulea L.): Spectrophotometry Versus High Performance Liquid Chromatography. International Journal of Food Properties 19, 1708–1725.
https://doi.org/10.1080/10942912.2015.1084316

18. Khoo, G.M., Clausen, M.R., Pedersen, B.H., & Larsen, E., 2011. Bioactivity and total phenolic content of 34 sour cherry cultivars. Journal of Food Composition and Analysis, 6th International Congress on Pigments in Food—Chemical, Biological and Technological Aspects 24, 772–776.
https://doi.org/10.1016/j.jfca.2011.03.004

19. Kucharska, A.Z., Sokół-Łętowska, A., Oszmiański, J., Piórecki, N., & Fecka, I., 2017. Iridoids, Phenolic Compounds and Antioxidant Activity of Edible Honeysuckle Berries (Lonicera caerulea var. kamtschatica Sevast.). Molecules 22, 405
https://doi.org/10.3390/molecules22030405

20. Magness, J.R. & Traub, H.P., 1941. Climatic Adaptation of Fruit and Nut Crops. Climates and Man

21. Małodobry, M., Bieniasz, M., & Dziedzic, E., 2010. Evaluation of the yield and some components in the fruit of blue honeysuckle (Lonicera caerulea var. edulis Turcz. Freyn.). Folia Horticulturae 22. https://doi.org/10.2478/fhort-2013-0150

22. Mouhib, H., & Stahl, W., 2014. From Cats and Blackcurrants: Structure and Dynamics of the Sulfur-Containing Cassis Odorant Cat Ketone. Chemistry & Biodiversity 11, 1554–1566. https://doi.org/10.1002/cbdv.201400027

23. Northern Hardy Fruit Evaluation Project - 2010 Report of Progress - Plant Data. North Dakota State University. https://www.ag.ndsu.edu/carringtonrec/documents/northernhardyfruitevaluationprojectrd/docs2010/2010%20Fruit%20Project%20Data.pdf

24. Northern Hardy Fruit Evaluation Project - 2011 Report of Progress - Plant Data. North Dakota State University. https://www.ag.ndsu.edu/CarringtonREC/documents/northernhardyfruitevaluationprojectrd/docs2011/2011%20Fruit%20Project%20Data.pdf

25. Ochmian, I.D., Grajkowski, J., & Smolik, M., 2012. Comparison of Some Morphological Features, Quality and Chemical Content of Four Cultivars of Chokeberry Fruits (Aronia melanocarpa). Notulae Botanicae Horti Agrobotanici Cluj-Napoca 40, 253–260. https://doi.org/10.15835/nbha4017181

26. Ochmian, I., Grajkowski, J., & Skupie, K., 2010. Yield and Chemical Composition of Blue Honeysuckle Fruit Depending on Ripening Time. https://doi.org/10.15835/buasvmcn-hort:4921

27. Production Statistics – Crops, Crops Proces… https://knoema.com/FAOPRDSC2020/production-statistics-crops-crops-processed#

28. Rai, R., Joshi, S., Roy, S., Singh, O., Samir, M., & Chandra, A. 2015. Implications of Changing Climate on Productivity of Temperate Fruit Crops with Special Reference to Apple. Horticulture 02.https://doi.org/10.4172/2376-0354.1000135

29. Rupasinghe, H.P.V., & Boehm, M.M.A., Sekhon-Loodu, S., Parmar, I., Bors, B., Jamieson, A.R., 2015. Anti-Inflammatory Activity of Haskap Cultivars is Polyphenols-Dependent. Biomolecules 5, 1079–1098. https://doi.org/10.3390/biom5021079

30. Saskatoon area by census division (CD), 2016 Canada. Statistics Canada https://www150.statcan.gc.ca/n1/pub/95-634-x/2017001/article/54905/catm-ctra-207-eng.htm

31. Saskatoon Berries | Manitoba Agriculture | Province of Manitoba. Accessed 2019 https://www.gov.mb.ca/agriculture/crops/production/fruit-crops/Saskatoon-berries.html

32. Sasnauskas, A., Trajkovski, V., Strautiņa, S., Tikhonova, O.V., Šikšnianas, T., Rubinskienė, M., Viškelis, P., Lanauskas, J., Valiuškaitė, A., Rugienius, R., Bobinas, & Č., Metspalu, L., 2009. Evaluation of black Currant cultivars and perspective hybrids in Lithuania.

33. Slavin. J, & Lloyd, B. Health Benefits of Fruits and Vegetables. Adv Nutr. 2012 Jul; 3(4): 506–516

34. Smolik, M., Ochmian, I.D., & Smolik, B., 2011. RAPD and ISSR Methods Used for Fingerprinting Selected, Closely Related Cultivars of Aronia melanocarpa. Not Bot Hort Agrobot Cluj 39, 276. https://doi.org/10.15835/nbha3926268

35. Sochor, J., Jurikova, T., Pohanka, M., Skutkova, H., Baron, M., Tomaskova, L., Balla, S., Klejdus, B., Pokluda, R., Mlcek, J., Trojakova, Z., & Saloun, J., 2014. Evaluation of Antioxidant Activity, Polyphenolic Compounds, Amino Acids and Mineral Elements of Representative Genotypes of Lonicera edulis. Molecules 19, 6504–6523. https://doi.org/10.3390/molecules19056504

36. Spencer, R., Alberta, Alberta Agriculture and Rural Development, 2013. Saskatoon berry production manual. Alberta Agriculture and Rural Development, Edmonton.

37. St. Pierre, & Richard G., The Development of Native Fruit Species as Horticultural Crops in Saskatchewan. HORTSCIENCE, VOL. 27(8), AUGUST 1992

38. St-Pierre, R.G., Zatylny, A.M., & Tulloch, H.P., 2005. Evaluation of growth and fruit production characteristics of 15 saskatoon (*Amelanchier alnifolia* Nutt.) cultivars at maturity. Can. J. Plant Sci. 85, 929–932. https://doi.org/10.4141/P04-066

39. THOMPSON, M. M. (2006). INTRODUCING HASKAP, JAPANESE BLUE HONEYSUCKLE. Journal of the American Pomological Society, *60*(4), 164-168

40. Unachukwu, U.J., Ahmed, S., Kavalier, A., Lyles, J.T., & Kennelly, E.J., 2010. White and Green Teas (Camellia sinensis var. sinensis): Variation in Phenolic, Methylxanthine, and Antioxidant Profiles. Journal of Food Science 75, C541–C548. HTTPS://DOI.ORG/10.1111/J.1750-3841.2010.01705.X

41. U.S. consumption of fresh blueberries is growing. IBO. Accessed 2019 http://www.internationalblueberry.org/2016/04/18/u-s-consumption-of-fresh-blueberries-is-growing/

42. U.S. fresh berries consumption per capita, 2015. Statista. Accessed 2018 https://www.statista.com/statistics/257200/per-capita-consumption-of-fresh-berries-in-the-us/

43. Zatylny, A.M., Ziehl, W.D., & St-Pierre, R.G., 2005. Physicochemical properties of fruit of 16 saskatoon (*Amelanchier alnifolia* Nutt.) cultivars. Can. J. Plant Sci. 85, 933–938. https://doi.org/10.4141/P04-065

44. Zdzisław Kawecki & Zofia Tomaszewska., THE EFFECT OF VARIOUS SOIL MANAGEMENT TECHNIQUES ON GROWTH AND YIELD IN THE BLACK CHOKEBERRY (Aronia melanocarpa Elliot). Journal of Fruit and Ornamental Plant Research Vol. 14, 2006: 67-73

45. Zheng, J., Yang, B., Ruusunen, V., Laaksonen, O., Tahvonen, R., Hellsten, J., & Kallio, H., 2012. Compositional Differences of Phenolic Compounds between Black Currant (Ribes nigrum L.) Cultivars and Their Response to Latitude and Weather Conditions. J. Agric. Food Chem. 60, 6581–6593. https://doi.org/10.1021/jf3012739

APPENDIX A

YIELD AND TPC DESCRIPTIVE STATISTICS

Note- TPC frequencies are based on experimental unit, while all other frequencies are at sub-sample levels.

TABLE 4-1 YIELD DESCRIPTIVE STATISTICS ACROSS SITES

Year	Species	Cultivar	n	mean	sd	median	min	max	range	se
17	Aronia	Autumn magic	9	806.5	318.1	844.0	206.4	1257.7	1051.3	106.0
17	Aronia	McKenzie	24	605.5	584.5	442.5	4.0	2060.8	2056.8	119.3
17	Aronia	Viking	25	731.5	740.1	391.0	1.0	2584.5	2583.5	148.0
18	Aronia	Autumn magic	9	1073.6	525.1	925.4	410.7	1898.8	1488.1	175.0
18	Aronia	McKenzie	27	4277.8	3305.7	4684.2	10.0	9001.2	8991.2	636.2
18	Aronia	Viking	26	3984.7	2987.1	4345.2	42.0	8901.5	8859.5	585.8
17	B Currant	Blackcomb	8	928.1	660.0	893.9	66.0	1760.5	1694.5	233.3
17	B Currant	Cheakamus	3	1463.9	1304.8	1649.8	76.1	2665.7	2589.6	753.3
17	B Currant	M12	9	2314.5	857.3	2264.1	1019.4	3468.6	2449.2	285.8
17	B Currant	Stikine	9	2500.1	1963.3	1667.4	212.0	5384.6	5172.6	654.4
17	B Currant	Tahsis	6	2164.9	1243.4	1940.2	615.8	3726.9	3111.1	507.6
17	B Currant	Titania	4	546.4	542.1	443.2	67.5	1231.6	1164.1	271.1
17	B Currant	Tofino	12	1030.4	570.1	973.9	14.3	2037.5	2023.2	164.6
17	B Currant	Whistler	10	2444.0	847.9	2549.2	1027.2	3818.9	2791.7	268.1
18	B Currant	Blackcomb	8	2916.1	997.6	2958.0	1722.0	4347.0	2625.0	352.7
18	B Currant	Cheakamus	3	3235.0	498.1	3513.0	2659.9	3532.0	872.1	287.6
18	B Currant	M12	9	4897.2	1155.2	4726.1	2971.8	7156.3	4184.5	385.1
18	B Currant	Stikine	9	6272.0	2540.1	5549.1	2139.5	9946.0	7806.5	846.7
18	B Currant	Tahsis	6	5772.6	1798.1	6150.9	3050.5	7665.0	4614.5	734.1
18	B Currant	Titania	4	3019.8	948.2	3368.0	1620.0	3723.0	2103.0	474.1

18	B Currant	Tofino	12	2381.2	960.2	2514.6	206.0	3636.9	3430.9	277.2
18	B Currant	Whistler	9	5455.7	1283.6	5877.0	3055.7	6833.0	3777.3	427.9
*17	B Currant	Blackcomb	14	462.6	920.6	212.0	28.0	3592.9	3564.9	246.0
*17	B Currant	Cheakamus	5	451.4	622.3	174.5	42.9	1525.5	1482.6	278.3
*17	B Currant	Stikine	15	294.4	348.5	231.2	2.0	1212.6	1210.6	90.0
*17	B Currant	Tahsis	1	124.7		124.7	124.7	124.7	0.0	
*17	B Currant	Titania	18	133.1	177.2	68.0	2.4	645.0	642.6	41.8
*17	B Currant	Tofino	11	206.4	279.4	90.2	3.3	930.9	927.6	84.2
*18	B Currant	Blackcomb	17	1909.7	892.5	1958.0	499.0	3983.0	3484.0	216.5
*18	B Currant	Cheakamus	5	3135.7	624.5	3206.0	2544.0	4095.9	1551.9	279.3
*18	B Currant	Stikine	17	2028.4	1059.0	2174.0	182.0	3661.7	3479.7	256.8
*18	B Currant	Tahsis	1	3629.0		3629.0	3629.0	3629.0	0.0	
*18	B Currant	Titania	21	1340.9	1071.4	1186.0	52.0	3445.0	3393.0	233.8
*18	B Currant	Tofino	14	558.3	385.9	440.0	68.0	1172.0	1104.0	103.1
17	DSC	Carmine Jewel	21	671.0	1180.5	215.0	7.6	4757.1	4749.5	257.6
17	DSC	Lutowka Rose	4	602.8	614.0	393.5	125.8	1498.4	1372.6	307.0
18	DSC	Carmine Jewel	13	7932.3	3630.2	8264.1	120.2	15053.5	14933.3	1006.8
18	DSC	Crimson Passion	1	24.6		24.6	24.6	24.6	0.0	
18	DSC	Lutowka Rose	9	2643.3	2131.5	1682.2	561.4	6569.1	6007.7	710.5
*17	DSC	Juliet	2	4.2	2.3	4.2	2.5	5.8	3.3	1.7
*17	DSC	Romeo	11	20.9	17.7	11.9	2.5	51.2	48.7	5.3
*18	DSC	Juliet	18	776.1	962.1	514.5	25.5	3335.1	3309.6	226.8
*18	DSC	Romeo	15	1876.0	2318.6	764.0	2.8	6494.0	6491.3	598.7
17	Haskap	41-75	27	1012.1	536.4	1118.3	59.3	1873.9	1814.6	103.2
17	Haskap	79-91	9	1147.4	594.0	1201.7	212.5	2086.2	1873.7	198.0

17	Haskap	85-19	27	1170.9	798.3	1345.3	77.4	2455.6	2378.2	153.6
17	Haskap	Aurora	22	278.2	232.6	186.7	9.9	814.8	804.9	49.6
17	Haskap	Blue Corn	4	390.0	249.3	284.0	233.9	758.3	524.4	124.6
17	Haskap	Blue Goose	4	44.3	19.8	47.8	17.3	64.5	47.2	9.9
17	Haskap	Borealis	25	390.8	321.3	285.1	18.9	1008.3	989.4	64.3
17	Haskap	Indigo Gem	24	231.3	247.5	190.4	8.2	1151.1	1142.9	50.5
17	Haskap	Kawai (108-42)	9	1413.0	770.8	1420.6	415.3	2729.7	2314.4	256.9
17	Haskap	Keiko (22-26)	8	1179.1	341.2	1170.6	586.2	1720.9	1134.7	120.6
17	Haskap	Solo (44-19)	26	699.6	290.1	725.2	66.0	1335.0	1269.0	56.9
17	Haskap	Sugar Mtn. Blue	5	195.5	147.6	171.6	51.0	434.0	383.0	66.0
17	Haskap	Taka (91-95)	7	1260.5	500.3	1420.0	413.1	1758.2	1345.1	189.1
17	Haskap	Tana (67-95)	9	1717.0	382.1	1637.1	1085.4	2294.8	1209.4	127.4
17	Haskap	Wild Treasure	5	200.7	181.3	174.0	6.0	460.0	454.0	81.1
18	Haskap	41-75	26	1335.8	759.4	1387.5	66.0	3004.0	2938.0	148.9
18	Haskap	79-91	9	1683.5	395.6	1616.7	1282.8	2594.1	1311.3	131.9
18	Haskap	85-19	27	2388.6	1564.2	2715.6	40.0	4716.6	4676.6	301.0
18	Haskap	Aurora	27	1176.4	1002.8	1131.7	36.0	2867.9	2831.9	193.0
18	Haskap	Blue Goose	6	113.7	73.6	90.6	32.5	224.6	192.1	30.0
18	Haskap	Borealis	25	1414.4	1163.8	1495.4	46.0	4172.9	4126.9	232.8
18	Haskap	Indigo Gem	27	1264.4	882.2	1441.8	28.0	2697.4	2669.4	169.8
18	Haskap	Kawai (108-42)	9	1817.4	545.0	2107.0	955.5	2332.5	1377.0	181.7
18	Haskap	Keiko (22-26)	8	2102.7	634.1	2326.7	1032.7	2883.2	1850.5	224.2
18	Haskap	Solo (44-19)	27	1640.2	1108.0	1753.1	58.0	5699.8	5641.8	213.2
18	Haskap	Sugar Mtn. Blue	18	520.5	565.1	197.7	11.4	1866.8	1855.4	133.2
18	Haskap	Taka (91-95)	7	2062.3	686.7	1873.2	1365.7	3384.8	2019.1	259.5

18	Haskap	Tana (67-95)	9	3153.4	1085.9	3085.5	1830.0	5373.6	3543.6	362.0
18	Haskap	Wild Treasure	8	224.2	144.2	184.3	77.5	532.5	455.0	51.0
*18	Haskap	Boreal Blizzard	11	199.6	171.6	102.9	1.1	468.0	466.9	51.7
17	R Currant	Jonkeer van Tets	9	1367.0	624.5	1374.6	54.2	2419.6	2365.4	208.2
17	R Currant	Rovada	8	486.5	276.4	409.3	268.2	1102.8	834.6	97.7
18	R Currant	Jonkeer van Tets	9	6366.2	1627.5	6546.2	3179.4	8394.3	5214.9	542.5
18	R Currant	Rovada	8	3762.7	1005.0	3455.8	2733.4	5355.6	2622.2	355.3
*17	R Currant	HRON	15	29.9	24.1	30.2	1.0	70.8	69.8	6.2
*17	R Currant	Rovada	16	31.3	45.2	10.3	1.9	151.9	150.0	11.3
*18	R Currant	HRON	21	729.4	605.5	596.0	6.0	2059.0	2053.0	132.1
*18	R Currant	Rovada	17	1027.1	1286.8	320.0	12.0	3841.0	3829.0	312.1
17	Saskatoon	JB30	11	47.9	52.1	28.9	3.7	145.5	141.8	15.7
17	Saskatoon	Lee3	15	151.3	135.8	114.0	1.0	417.4	416.4	35.1
17	Saskatoon	Lee8	15	144.8	161.1	102.9	10.0	636.5	626.5	41.6
17	Saskatoon	Martin	13	131.9	167.5	33.2	5.5	433.2	427.7	46.5
17	Saskatoon	Northline	17	121.1	133.7	36.7	5.8	462.5	456.7	32.4
17	Saskatoon	Smoky	14	50.0	48.4	31.3	6.4	173.2	166.8	12.9
18	Saskatoon	JB30	19	368.8	389.0	234.4	29.0	1366.0	1337.0	89.2
18	Saskatoon	Lee3	25	870.3	904.2	548.0	5.7	3634.0	3628.3	180.8
18	Saskatoon	Lee8	24	3010.6	2192.4	3581.5	74.0	6458.0	6384.0	447.5
18	Saskatoon	Martin	20	725.9	816.4	342.9	31.8	2934.2	2902.4	182.6
18	Saskatoon	Northline	22	3566.9	1954.1	4195.8	130.0	6804.2	6674.2	416.6
18	Saskatoon	Smoky	22	1938.1	1830.6	1152.5	58.0	6790.8	6732.8	390.3
*17	Saskatoon	JB30	1	41.6		41.6	41.6	41.6	0.0	
*18	Saskatoon	JB30	1	204.7		204.7	204.7	204.7	0.0	

*18	Saskatoon	Lee8	1	74.0		74.0	74.0	74.0	0.0	
*18	Saskatoon	Smoky	1	55.0		55.0	55.0	55.0	0.0	

*Replanted cohort

TABLE 4-2YIELD DESCRIPTIVE STATISTICS BY SITE

Site	Year	Species	Cultivar	n	mean	sd	median	min	max	range	se
Bozeman	17	Aronia	McKenzie	6	184.1	118.5	156.8	28.5	374	345.5	48.4
Bozeman	17	Aronia	Viking	7	574.4	495.3	293.0	123	1365.5	1242.5	187.2
Bozeman	18	Aronia	McKenzie	9	540.3	629.5	322.0	10	2020	2010	209.8
Bozeman	18	Aronia	Viking	8	467.5	284.7	535.0	42	906	864	100.7
Bozeman	17	Black Currant	Blackcomb	2	201.5	191.6	201.5	66	337	271	135.5
Bozeman	17	Black Currant	Stikine	1	212.0		212.0	212	212	0	
Bozeman	17	Black Currant	Titania	1	67.5		67.5	67.5	67.5	0	
Bozeman	17	Black Currant	Tofino	1	14.3		14.3	14.3	14.3	0	
Bozeman	18	Black Currant	Blackcomb	2	3001.0	544.5	3001.0	2616	3386	770	385.0
Bozeman	18	Black Currant	Stikine	1	7473.0		7473.0	7473	7473	0	
Bozeman	18	Black Currant	Titania	1	3386.0		3386.0	3386	3386	0	
Bozeman	18	Black Currant	Tofino	1	206.0		206.0	206	206	0	
Bozeman	*	Black Currant	Blackcomb	7	1669.3	725.0	1958.0	521	2550	2029	274.0
Bozeman	*	Black Currant	Stikine	8	1417.3	871.5	1383.0	182	2504	2322	308.1
Bozeman	*	Black Currant	Titania	7	587.1	350.0	564.0	52	1186	1134	132.3
Bozeman	*	Black Currant	Tofino	7	275.4	155.2	280.0	68	552	484	58.7
Bozeman	17	DSC	Carmine Jewel	2	19.0	0.7	19.0	18.5	19.5	1	0.5
Bozeman	17	Haskap	41-75	9	452.5	294.2	430.0	59.3	860	800.7	98.1

Bozeman	17	Haskap	85-19	9	227.0	307.8	102.5	77.4	1033.2	955.8	102.6
Bozeman	17	Haskap	Aurora	6	86.2	67.4	69.5	9.9	188	178.1	27.5
Bozeman	17	Haskap	Borealis	8	148.1	179.3	73.9	44.7	580.5	535.8	63.4
Bozeman	17	Haskap	Indigo Gem	9	167.7	119.4	162.5	8.2	392	383.8	39.8
Bozeman	17	Haskap	Solo (44-19)	9	392.1	175.1	399.5	66	645.5	579.5	58.4
Bozeman	17	Haskap	Sugar Mtn. Blue	1	51.0		51.0	51	51	0	
Bozeman	18	Haskap	41-75	8	491.8	288.8	433.0	66	876	810	102.1
Bozeman	18	Haskap	85-19	9	637.3	469.5	652.0	40	1550	1510	156.5
Bozeman	18	Haskap	Aurora	9	72.4	39.4	50.0	36	140	104	13.1
Bozeman	18	Haskap	Borealis	9	237.6	186.6	130.0	46	542	496	62.2
Bozeman	18	Haskap	Indigo Gem	9	270.4	186.8	228.0	28	558	530	62.3
Bozeman	18	Haskap	Solo (44-19)	9	530.9	261.6	644.0	58	812	754	87.2
Bozeman	18	Haskap	Sugar Mtn. Blue	1	18.0		18.0	18	18	0	
Bozeman	*	R Currant	HRON	3	12.0	6.0	12.0	6	18	12	3.5
Bozeman	*	R Currant	Rovada	8	64.5	63.5	58.0	12	208	196	22.4
Bozeman	17	Saskatoon	Lee3	1	39.5		39.5	39.5	39.5	0	
Bozeman	18	Saskatoon	JB30	2	399.0	199.4	399.0	258	540	282	141.0
Bozeman	18	Saskatoon	Lee3	9	308.2	172.4	310.0	80	554	474	57.5
Bozeman	18	Saskatoon	Lee8	7	518.9	379.8	612.0	74	1156	1082	143.6
Bozeman	18	Saskatoon	Martin	2	116.0	11.3	116.0	108	124	16	8.0
Bozeman	18	Saskatoon	Northline	4	847.0	727.0	779.0	130	1700	1570	363.5
Bozeman	18	Saskatoon	Smoky	5	308.4	251.5	182.0	58	656	598	112.5
Bozeman	*	Saskatoon	Lee8	1	74.0		74.0	74	74	0	
Corvallis	17	Aronia	Autumn magic	9	806.5	318.1	844.0	206.4	1257.7	1051.3	106.0
Corvallis	17	Aronia	McKenzie	9	1219.7	481.7	1156.4	608	2060.8	1452.8	160.6
Corvallis	17	Aronia	Viking	9	1508.4	511.0	1529.3	807.2	2584.5	1777.3	170.3

Corvallis	18	Aronia	Autumn magic	9	1073.6	525.1	925.4	410.7	1898.8	1488.1	175.0
Corvallis	18	Aronia	McKenzie	9	7642.3	967.4	7114.8	6589.9	9001.2	2411.3	322.5
Corvallis	18	Aronia	Viking	9	6806.9	1367.7	6823.4	4539.8	8901.5	4361.7	455.9
Corvallis	17	B Currant	Blackcomb	5	1318.4	486.5	1411.2	517.3	1760.5	1243.2	217.6
Corvallis	17	B Currant	Cheakamus	3	1463.9	1304.8	1649.8	76.1	2665.7	2589.6	753.3
Corvallis	17	B Currant	M12	9	2314.5	857.3	2264.1	1019.4	3468.6	2449.2	285.8
Corvallis	17	B Currant	Stikine	5	1520.9	896.0	1388.9	636	2958.7	2322.7	400.7
Corvallis	17	B Currant	Tahsis	6	2164.9	1243.4	1940.2	615.8	3726.9	3111.1	507.6
Corvallis	17	B Currant	Titania	3	706.0	536.6	727.3	159	1231.6	1072.6	309.8
Corvallis	17	B Currant	Tofino	9	1037.7	502.5	824.2	453.5	2037.5	1584	167.5
Corvallis	17	B Currant	Whistler	10	2444.0	847.9	2549.2	1027.2	3818.9	2791.7	268.1
Corvallis	18	B Currant	Blackcomb	5	3083.3	1172.9	3300.0	1722	4347	2625	524.5
Corvallis	18	B Currant	Cheakamus	3	3235.0	498.1	3513.0	2659.9	3532	872.1	287.6
Corvallis	18	B Currant	M12	9	4897.2	1155.2	4726.1	2971.8	7156.3	4184.5	385.1
Corvallis	18	B Currant	Stikine	5	4942.9	1897.0	5377.8	2139.5	7311.6	5172.1	848.4
Corvallis	18	B Currant	Tahsis	6	5772.6	1798.1	6150.9	3050.5	7665	4614.5	734.1
Corvallis	18	B Currant	Titania	3	2897.7	1122.1	3350.0	1620	3723	2103	647.8
Corvallis	18	B Currant	Tofino	9	2739.0	653.7	2775.0	1589.4	3636.9	2047.5	217.9
Corvallis	18	B Currant	Whistler	9	5455.7	1283.6	5877.0	3055.7	6833	3777.3	427.9
Corvallis	*	B Currant	Blackcomb	2	3530.9	639.4	3530.9	3078.7	3983	904.3	452.2
Corvallis	*	B Currant	Cheakamus	5	3135.7	624.5	3206.0	2544	4095.9	1551.9	279.3
Corvallis	*	B Currant	Stikine	4	3169.5	501.7	3189.9	2636.6	3661.7	1025.1	250.8
Corvallis	*	B Currant	Tahsis	1	3629.0		3629.0	3629	3629	0	
Corvallis	*	B Currant	Titania	6	1565.3	755.4	1695.6	195	2368.1	2173.1	308.4
Corvallis	17	DSC	Carmine Jewel	11	292.7	357.8	153.9	7.6	1087.6	1080	107.9
Corvallis	17	DSC	Lutowka Rose	4	602.8	614.0	393.5	125.8	1498.4	1372.6	307.0

Corvallis	18	DSC	Carmine Jewel	9	7591.3	2132.6	8197.6	3004.1	9606	6601.9	710.9
Corvallis	18	DSC	Lutowka Rose	9	2643.3	2131.5	1682.2	561.4	6569.1	6007.7	710.5
Corvallis	*	DSC	Juliet	9	1071.1	973.3	611.2	398.5	3335.1	2936.6	324.4
Corvallis	*	DSC	Romeo	9	3119.8	2248.7	2427.0	260.2	6494	6233.8	749.6
Corvallis	17	Haskap	41-75	9	1406.6	362.4	1309.5	865.5	1873.9	1008.4	120.8
Corvallis	17	Haskap	79-91	9	1147.4	594.0	1201.7	212.5	2086.2	1873.7	198.0
Corvallis	17	Haskap	85-19	9	1756.2	532.7	1809.6	822.1	2455.6	1633.5	177.6
Corvallis	17	Haskap	Aurora	9	396.8	257.2	412.0	74.4	814.8	740.4	85.7
Corvallis	17	Haskap	Blue Corn	4	390.0	249.3	284.0	233.9	758.3	524.4	124.6
Corvallis	17	Haskap	Blue Goose	4	44.3	19.8	47.8	17.3	64.5	47.2	9.9
Corvallis	17	Haskap	Borealis	9	701.4	217.7	652.7	398.8	1008.3	609.5	72.6
Corvallis	17	Haskap	Indigo Gem	6	504.6	341.2	410.1	200.1	1151.1	951	139.3
Corvallis	17	Haskap	Kawai (108-42)	9	1413.0	770.8	1420.6	415.3	2729.7	2314.4	256.9
Corvallis	17	Haskap	Keiko (22-26)	8	1179.1	341.2	1170.6	586.2	1720.9	1134.7	120.6
Corvallis	17	Haskap	Solo (44-19)	9	957.1	212.5	971.9	547.7	1335	787.3	70.8
Corvallis	17	Haskap	Sugar Mtn. Blue	4	231.6	142.7	194.3	103.8	434	330.2	71.4
Corvallis	17	Haskap	Taka (91-95)	7	1260.5	500.3	1420.0	413.1	1758.2	1345.1	189.1
Corvallis	17	Haskap	Tana (67-95)	9	1717.0	382.1	1637.1	1085.4	2294.8	1209.4	127.4
Corvallis	17	Haskap	Wild Treasure	5	200.7	181.3	174.0	6	460	454	81.1
Corvallis	18	Haskap	41-75	9	1643.6	457.4	1566.3	902.2	2353.4	1451.2	152.5
Corvallis	18	Haskap	79-91	9	1683.5	395.6	1616.7	1282.8	2594.1	1311.3	131.9
Corvallis	18	Haskap	85-19	9	3510.9	1353.1	3851.3	62.3	4716.6	4654.3	451.0
Corvallis	18	Haskap	Aurora	9	1694.4	605.9	1431.7	1035.6	2864.5	1828.9	202.0
Corvallis	18	Haskap	Blue Goose	6	113.7	73.6	90.6	32.5	224.6	192.1	30.0
Corvallis	18	Haskap	Borealis	9	2555.3	807.2	2397.6	1733.9	4172.9	2439	269.1
Corvallis	18	Haskap	Indigo Gem	9	2045.4	638.2	2294.1	614.9	2697.4	2082.5	212.7

Corvallis	18	Haskap	Kawai (108-42)	9	1817.4	545.0	2107.0	955.5	2332.5	1377	181.7
Corvallis	18	Haskap	Keiko (22-26)	8	2102.7	634.1	2326.7	1032.7	2883.2	1850.5	224.2
Corvallis	18	Haskap	Solo (44-19)	9	2528.9	1252.6	2145.0	1535.2	5699.8	4164.6	417.5
Corvallis	18	Haskap	Sugar Mtn. Blue	8	119.4	66.6	119.1	11.4	233.4	222	23.5
Corvallis	18	Haskap	Taka (91-95)	7	2062.3	686.7	1873.2	1365.7	3384.8	2019.1	259.5
Corvallis	18	Haskap	Tana (67-95)	9	3153.4	1085.9	3085.5	1830	5373.6	3543.6	362.0
Corvallis	18	Haskap	Wild Treasure	8	224.2	144.2	184.3	77.5	532.5	455	51.0
Corvallis	*	Haskap	Boreal Blizzard	4	85.9	25.3	96.1	48.6	102.9	54.3	12.6
Corvallis	17	R Currant	Jonkeer van Tets	9	1367.0	624.5	1374.6	54.2	2419.6	2365.4	208.2
Corvallis	17	R Currant	Rovada	8	486.5	276.4	409.3	268.2	1102.8	834.6	97.7
Corvallis	18	R Currant	Jonkeer van Tets	9	6366.2	1627.5	6546.2	3179.4	8394.3	5214.9	542.5
Corvallis	18	R Currant	Rovada	8	3762.7	1005.0	3455.8	2733.4	5355.6	2622.2	355.3
Corvallis	*	R Currant	HRON	9	513.8	266.8	475.6	60.6	906.9	846.3	88.9
Corvallis	17	Saskatoon	JB30	7	71.5	52.3	61.6	15	145.5	130.5	19.8
Corvallis	17	Saskatoon	Lee3	9	241.4	96.5	234.1	101.4	417.4	316	32.2
Corvallis	17	Saskatoon	Lee8	9	201.8	178.9	129.6	77.1	636.5	559.4	59.6
Corvallis	17	Saskatoon	Martin	8	154.5	162.0	88.4	22.9	408.9	386	57.3
Corvallis	17	Saskatoon	Northline	9	191.8	141.3	210.6	30.9	462.5	431.6	47.1
Corvallis	17	Saskatoon	Smoky	6	49.2	45.8	27.5	10.7	107.3	96.6	18.7
Corvallis	18	Saskatoon	JB30	8	661.7	433.8	493.0	186.2	1366	1179.8	153.4
Corvallis	18	Saskatoon	Lee3	9	1876.9	762.7	1647.0	1180.2	3634	2453.8	254.2
Corvallis	18	Saskatoon	Lee8	9	5221.0	825.8	5519.7	4240.3	6458	2217.7	275.3
Corvallis	18	Saskatoon	Martin	9	1404.6	788.6	1335.7	361.4	2934.2	2572.8	262.9
Corvallis	18	Saskatoon	Northline	9	5279.5	961.0	5037.6	4319.7	6804.2	2484.5	320.3
Corvallis	18	Saskatoon	Smoky	9	3598.8	1773.5	3086.9	615.5	6790.8	6175.3	591.2
Corvallis		Saskatoon	JB30	1	204.7		204.7	204.7	204.7	0	

Kalispell	17	Aronia	McKenzie	9	272.1	242.5	271.0	4	647	643	80.8
Kalispell	17	Aronia	Viking	9	76.9	125.2	41.0	1	391	390	41.7
Kalispell	18	Aronia	McKenzie	9	4650.7	2361.4	4684.2	35.4	7712.5	7677.1	787.1
Kalispell	18	Aronia	Viking	9	4288.9	2122.7	4150.5	76.8	7379	7302.2	707.6
Kalispell	17	B Currant	Blackcomb	1	430.0		430.0	430	430	0	
Kalispell	17	B Currant	Stikine	3	4894.7	442.8	4776.7	4522.9	5384.6	861.7	255.7
Kalispell	17	B Currant	Tofino	2	1505.8	265.9	1505.8	1317.8	1693.8	376	188.0
Kalispell	18	B Currant	Blackcomb	1	1910.0		1910.0	1910	1910	0	
Kalispell	18	B Currant	Stikine	3	8087.0	2921.2	9595.0	4720	9946	5226	1686.5
Kalispell	18	B Currant	Tofino	2	1859.0	541.6	1859.0	1476	2242	766	383.0
Kalispell	*	B Currant	Blackcomb	8	1714.9	678.0	1837.0	499	2532	2033	239.7
Kalispell	*	B Currant	Stikine	5	2093.4	955.8	2044.0	1089	3578	2489	427.4
Kalispell	*	B Currant	Titania	8	1832.1	1371.2	1516.5	67	3445	3378	484.8
Kalispell	*	B Currant	Tofino	7	841.1	334.6	940.0	247	1172	925	126.5
Kalispell	17	DSC	Carmine Jewel	8	1354.3	1708.5	482.5	33.5	4757.1	4723.6	604.1
Kalispell	18	DSC	Carmine Jewel	4	8699.7	6281.1	9812.6	120.2	15053.5	14933.3	3140.5
Kalispell	18	DSC	Crimson Passion	1	24.6		24.6	24.6	24.6	0	
Kalispell	*	DSC	Juliet	9	481.1	907.7	138.4	25.5	2792.3	2766.8	302.6
Kalispell	*	DSC	Romeo	6	10.2	14.4	5.3	2.75	39.5	36.75	5.9
Kalispell	17	Haskap	41-75	9	1177.3	399.1	1242.4	462.9	1632	1169.1	133.0
Kalispell	17	Haskap	85-19	9	1529.6	400.3	1515.4	802.6	2271.8	1469.2	133.4
Kalispell	17	Haskap	Aurora	7	290.2	198.1	360.3	28.7	528.7	500	74.9
Kalispell	17	Haskap	Borealis	8	284.2	251.8	244.2	18.9	754.4	735.5	89.0
Kalispell	17	Haskap	Indigo Gem	9	112.6	112.3	29.6	16.1	290.8	274.7	37.4
Kalispell	17	Haskap	Solo (44-19)	8	755.9	58.3	747.3	678.3	836.9	158.6	20.6
Kalispell	18	Haskap	41-75	9	1778.3	693.4	1923.5	541	3004	2463	231.1

Kalispell	18	Haskap	85-19	9	3017.7	766.6	2907.6	1651.4	4300.9	2649.5	255.5
Kalispell	18	Haskap	Aurora	9	1762.3	916.6	1404.9	797.6	2867.9	2070.3	305.5
Kalispell	18	Haskap	Borealis	7	1460.8	685.9	1495.4	369.7	2418.2	2048.5	259.3
Kalispell	18	Haskap	Indigo Gem	9	1477.5	488.1	1509.3	695.2	2176.3	1481.1	162.7
Kalispell	18	Haskap	Solo (44-19)	9	1860.9	157.9	1870.8	1671.1	2179.6	508.5	52.6
Kalispell	18	Haskap	Sugar Mtn. Blue	9	932.8	539.4	939.3	47.8	1866.8	1819	179.8
Kalispell	*	Haskap	Boreal Blizzard	7	264.5	187.7	322.5	1.1	468	466.9	71.0
Kalispell	*	R Currant	HRON	9	1184.2	606.1	1269.0	418	2059	1641	202.0
Kalispell	*	R Currant	Rovada	9	1882.7	1248.3	1988.0	320	3841	3521	416.1
Kalispell	17	Saskatoon	JB30	4	6.6	4.2	5.0	3.7	12.8	9.1	2.1
Kalispell	17	Saskatoon	Lee3	5	11.4	8.0	14.2	1	20	19	3.6
Kalispell	17	Saskatoon	Lee8	6	59.2	82.8	25.8	10	225	215	33.8
Kalispell	17	Saskatoon	Martin	5	95.7	188.8	10.0	5.5	433.2	427.7	84.4
Kalispell	17	Saskatoon	Northline	8	41.6	66.2	24.0	5.8	203.5	197.7	23.4
Kalispell	17	Saskatoon	Smoky	8	50.7	53.3	40.0	6.4	173.2	166.8	18.9
Kalispell	18	Saskatoon	JB30	9	101.9	68.0	84.9	29	234.4	205.4	22.7
Kalispell	18	Saskatoon	Lee3	7	298.9	284.2	168.8	5.7	696.6	690.9	107.4
Kalispell	18	Saskatoon	Lee8	8	2704.1	1513.9	2944.7	527	4536.9	4009.9	535.3
Kalispell	18	Saskatoon	Martin	9	182.8	134.4	181.7	31.8	451	419.2	44.8
Kalispell	18	Saskatoon	Northline	9	3063.1	1271.8	3025.6	1017.4	4820.2	3802.8	423.9
Kalispell	18	Saskatoon	Smoky	8	1088.5	392.4	1029.7	516.7	1781.8	1265.1	138.7
Kalispell	*	Saskatoon	Smoky	1	55.0		55.0	55	55	0	

*Replanted cohort

TABLE 4-3 TPC DESCRIPTIVE STATISTICS BY SITE

Site	Year	Cultivar	n	mean	sd	median	min	max	range	se
Bozeman	2016	41-75	3	590.1	15.5	591.7	573.8	604.8	31.0	9.0
Bozeman	2016	85-19	3	530.7	25.2	530.0	505.8	556.2	50.4	14.6
Bozeman	2016	Borealis	2	711.6	76.8	711.6	657.3	766.0	108.7	54.3
Bozeman	2016	Indigo	3	587.5	23.9	574.4	573.0	615.0	42.0	13.8
Bozeman	2016	Solo	3	746.0	43.7	727.7	714.5	795.9	81.4	25.2
Bozeman	2017	41-75	4	937.1	127.0	909.3	828.6	1101.3	272.7	63.5
Bozeman	2017	85-19	8	835.1	278.3	794.8	463.2	1375.6	912.5	98.4
Bozeman	2017	Aurora	3	1238.2	185.3	1310.1	1027.8	1376.8	349.0	107.0
Bozeman	2017	Borealis	10	1435.2	228.1	1366.2	1157.6	1782.1	624.4	72.1
Bozeman	2017	Indigo Gem	5	1406.2	144.2	1415.0	1241.3	1575.8	334.6	64.5
Bozeman	2017	Solo	3	889.7	315.3	781.1	643.1	1244.9	601.8	182.0
Bozeman	2017	Sugar Mtn. Blue	1	824.3		824.3	824.3	824.3	0.0	
Corvallis	2016	41-75	5	560.8	224.5	463.8	434.4	961.3	526.8	100.4
Corvallis	2016	79-91	4	458.5	117.9	456.5	316.1	604.8	288.8	59.0
Corvallis	2016	85-19	5	372.2	27.1	366.2	353.6	419.5	65.9	12.1
Corvallis	2016	Borealis	2	1131.2	169.8	1131.2	1011.2	1251.3	240.2	120.1
Corvallis	2016	Kawai	4	675.9	304.3	759.2	239.1	946.3	707.2	152.1
Corvallis	2016	Keiko	5	468.4	168.8	395.1	363.8	768.3	404.5	75.5
Corvallis	2016	Solo	4	931.9	419.2	857.9	582.5	1429.6	847.1	209.6
Corvallis	2016	Taka	5	588.2	220.4	515.8	444.7	978.9	534.2	98.5
Corvallis	2016	Tana	6	694.2	243.6	585.4	499.0	1002.0	503.0	99.5
Corvallis	2017	41-75	3	477.3	51.0	480.4	424.8	526.7	101.8	29.4
Corvallis	2017	79-91	3	613.1	4.5	611.2	610.0	618.2	8.3	2.6

Corvallis	2017	85-19	3	380.0	88.8	422.2	278.0	439.8	161.8	51.3
Corvallis	2017	Aurora	3	1279.8	104.5	1266.6	1182.5	1390.2	207.7	60.3
Corvallis	2017	Blue Corn	3	1060.1	77.4	1069.1	978.6	1132.6	154.0	44.7
Corvallis	2017	Blue Goose	3	967.4	18.6	959.0	954.5	988.8	34.3	10.8
Corvallis	2017	Borealis	3	975.4	164.6	891.4	869.7	1165.0	295.3	95.0
Corvallis	2017	Indigo Gem	3	856.1	79.3	814.3	806.5	947.6	141.1	45.8
Corvallis	2017	Kawai	3	503.1	232.2	492.3	276.5	740.5	464.0	134.1
Corvallis	2017	Keiko	3	645.9	129.3	584.7	558.6	794.4	235.8	74.6
Corvallis	2017	Solo	3	1152.6	219.3	1052.4	1001.3	1404.2	402.9	126.6
Corvallis	2017	Sugar Mtn. Blue	3	1003.0	299.9	834.8	825.0	1349.2	524.1	173.1
Corvallis	2017	Taka	3	649.8	179.5	633.2	479.2	837.1	357.9	103.7
Corvallis	2017	Tana	3	691.3	110.4	680.3	586.9	806.8	219.9	63.7
Corvallis	2017	Wild Treasure	3	963.1	88.9	915.0	908.4	1065.7	157.2	51.3
		Aronia								
Bozeman	2017	Viking	4	1936.8	205.0	1986.9	1666.6	2107.0	440.3	102.5
Bozeman	2017	McKenzie	3	3579.7	430.4	3599.3	3139.8	3999.9	860.1	248.5
		Black Currant								
Bozeman	2017	Blackcomb	3	626.5	293.3	575.6	361.9	941.9	580.0	169.4
Bozeman	2017	Tofino	3	397.8	84.4	362.9	336.5	494.0	157.5	48.7
Bozeman	2017	Titania	3	556.1	301.9	492.2	291.2	884.8	593.6	174.3
Bozeman	2017	Stikine	2	497.1	259.9	497.1	313.3	680.8	367.5	183.8
		Red Currant								

Bozeman	2017	Rovada	4	1599.9	108.4	1625.4	1448.7	1700.3	251.6	54.2
		DSC								
Bozeman	2017	Carmine Jewel	1	570.0		570.0	570.0	570.0	0.0	
		Saskatoon								
Bozeman	2017	Lee 3	1	1231.6		1231.6	1231.6	1231.6	0.0	