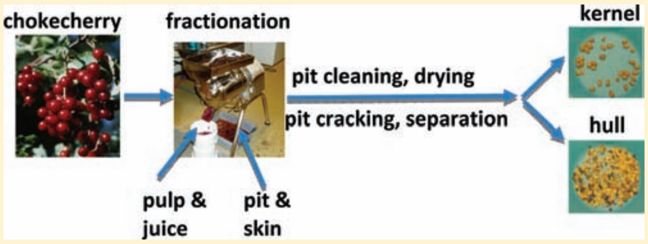
JOURNAL OF
AGRICULTURAL AND
FOOD CHEMISTRY

Food and Biomass Potential of *Prunus virginiana* L. (Chokecherry)

Sunmin Wang,[*,†] Lester Young,[†] Amberly Faye,[‡] Bonnie Li,[§] Johanna Clancy,[†] Bob Bors,[†] and Martin Reaney[*,†]

[†]Department of Plant Sciences, University of Saskatchewan, 51 Campus Drive, Saskatoon, Saskatchewan, S7N 5A8, Canada
[‡]Milligan Biotech Incorporated, Box 130, 907 Highway 16 East, Foam Lake, Saskatchewan, S0A 1A0, Canada
[§]Novozymes Biologicals Limited, 3935 Thatcher Avenue, Saskatoon, Saskatchewan, S7R 1A3



ABSTRACT: *Prunus virginiana* L. (chokecherry) fruit has potential to provide both food and energy and as annual yield of biomass and energy are much greater than annual crops such as canola and wheat. We determined chokecherry fruit weight fractions as well as pit and extracted seed oil concentrations and fatty acid composition. Gross energy for each of the fractions was determined, as were carbon and nitrogen content. Extrapolation of these data suggests that gross energy from pits alone over a 24-year period (890 GJ·ha^{-1}) is equivalent to that from an entire canola/wheat rotation (850 GJ·ha^{-1}). After maturity, pulp contributes an additional 1130 GJ·ha^{-1} over 21 years from ~3.4 t·ha^{-1}·year^{-1} (dw), while wood from pruning could add another 60 GJ·ha^{-1}·year^{-1}. Over this time period, chokecherry would produce 1.5–2.5 times the amount of oil produced by a canola/wheat rotation.

KEYWORDS: *Prunus virginiana, chokecherry, seed oil, fruit, gross energy*

INTRODUCTION

Prunus virginiana L. (Chokecherry) is a highly productive fruit crop that simultaneously has both food and bioenergy potential. It is widely distributed across North America and with the recent release of new cultivars for the Canadian Prairies is being grown in increased amounts.[1,2] Examples of cultivars grown on the Canadian Prairies include Boughen Yellow (yellow fruit), Goertz (black), Lee (red), and Garrington (red).

Chokecherry yields from established orchards are large compared to the volumes produced by an equivalent area of annual crops. Depending on cultivar, location, and plant age, a single tree may produce 2.5–9 kg fruit, with as many as 3400 trees per hectare possible.[3,4] That is 8.5–30 t of fruit per hectare, depending on cultivar and conditions. This large volume of biomass combined with low inputs required for growth, maintenance, and harvesting mean that chokecherries are a good potential source of both food and biomass.

As with most cherries, chokecherries are primarily produced for the mesocarp (pulp), which is utilized for juice and pulp. The pits are considered a low-value byproduct and generally burned for heat or disposed of in landfills. Fruit mass collected from different chokecherry cultivars grown in Saskatchewan ranged from 0.69 to 0.92 g, of which 9.4–25% of the mass was pit, depending on harvesting time.[4,5] An ecological study of wild chokecherry plants observed pulp to pit ratios ranging from 0.86 to 1.74.[6] Given the high potential fruit yields, a large mass of seed (kernel) and pericarp (hull) is produced per hectare. Currently, most pits from commercial sweet cherry, sour cherry, and chokecherry processing are burnt for heat or disposed of in landfills. Utilization of cherry pits could increase the value of the fruit substantially. For example, pyrolysis of pits could be used to produce fuel or chemicals.[7]

Pits of *Prunus* species contain 10–15% oil, corresponding to approximately 33–49% dw of the kernel alone.[8−10] In cherries the percent oil ranges from 10.4% (fw) in wild chokecherry[8] to 14.5% (dw) in *P. avium.*[11] Seed oil is primarily triacylglycerides.[10] Stearic, oleic, and linoleic acids are the primary fatty acids present in *Prunus,* comprising approximately 5–15%, 32–63%, and 28–48%, respectively, in cherries.[8,10−13] Interestingly, eleostearic acid ranged from 9.9% to 13.2% in cherry seed oil.[11,12]

The hulls could also be used as a source of antioxidants[14] or soilless growing media. In the 1930s cherry seed oil was extracted commercially for the cosmetics industry.[15] Seed meal remaining after oil extraction could be used for animal feed if the cyanogenic amygdalin is removed or its glycosidases deactivated.[1,16]

In this paper we examine the composition and gross energy content of different chokecherry fruit fractions to highlight the dual-use (food and biomass) potential of chokecherries.

MATERIALS AND METHODS

Plant Material. Two different stands of chokecherry trees, all grown at the University of Saskatchewan horticulture farm, were used in this study. Stand One consisted of mature, named chokecherry varieties grown on the Canadian Prairies, including Boughen Yellow,

Received: October 17, 2011
Revised: February 16, 2012
Accepted: February 20, 2012
Published: February 21, 2012

Table 1. Mechanical Fractionation of Named Chokecherry Lines Using the Juicer C120[a]

	fruit total	first juice	second juice	third juice (1:1 water)	total juice (1/2 third juice)	pits	total recovered mass
Boughen Yellow	23.7 (100)	15.1 (63.7)	2.1 (8.9)	6.1 (12.9)	20.25 (85.4)	4.7 (19.8)	24.95 (105.3)
Garrington	139.9 (100)	59 (42.2)	28.2 (20.2)	64.1 (22.9)	119.25 (85.2)	27.8 (19.9)	147.05 (105.1)
Goertz	18.5 (100)	13.9 (75.1)	0.8 (4.3)	3.9 (10.5)	16.65 (90.0)	2.4 (13.0)	19.05 (103)
Lee Red	23.5 (100)	16.1 (68.5)	2.0 (8.5)	5.0 (10.6)	20.6 (87.7)	3.6 (15.3)	24.2 (103)

[a]Fraction mass, in kg, and percent, relative to initial mass of fruit, in brackets. Data for 20 (Boughen, Goetrz and Lee) or 140 kg (Garrington) of fruit collected from Stand One.

Copper Schubert, Esperant, Garrington, Goertz, Lee Red, Mission Red, and Robert. Five trees of each variety were planted in 1994 in each of three replicates in a randomized complete block design. The plants were irrigated with drip irrigation (see St-Pierre et al.[3] and Zatylny et al.[4] for more details of the trees and plots used). Stand Two consisted of 17 half-sibling lines derived from open-pollinated accessions collected from across Saskatchewan. Each of the 17 half-sibling lines had 9−168 trees. The individuals from each line were planted adjacent to one another in 13 rows on the University of Saskatchewan horticulture farm. This stand was originally planted to capture some of the genetic diversity of chokecherries grown across Saskatchewan with the aim of identifying germplasm for introduction into the chokecherry breeding program.

Bulk Fruit Fractionation Process. A process for fractionation of chokecherries into pulp, juice, and pit and subsequently from pit to hull and kernel was developed using nine high-yielding and improved chokecherry cultivars grown at the University of Saskatchewan horticulture farm (Stand One). Approximately 20 kg of ripe chokecherries was collected from Boughen Yellow (yellow fruit), Goertz (black), and Lee (red) trees and 140 kg for Garrington (black). These four lines were picked as they are the varieties most commonly grown in Saskatchewan. The fruit were washed with tap water to remove dirt and small stems and passed through a juicer (Model C120, Robot Coupe USA, Inc., Jackson, MS) to obtain a combined juice and pulp fraction and a pit fraction (with a significant amount of fruit skins attached). A second passage through the juicer followed by a third wash diluted 1:1 (w/w) with water were required to clean the pits free from the skins.

Pit and Kernel Production. Fruit were harvested from Stand One to more precisely determine hull and kernel ratios and examine oil content and fatty acid composition. Pits were manually collected and dried at 45 °C in a large drying chamber. A portion of the dry pits was passed through a custom-made roller-cracking mill (Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Saskatoon, SK). The gap between the two rollers was carefully adjusted to crack the endocarp without crushing the kernel inside. Cracked hulls and mostly intact kernels were subsequently separated on an air and screen machine (model 180, Crippen Manufacturing Company, St. Louis, MI) and mass balances of the hulls and kernels calculated.

Determination of Oil Contents and Fatty Acid Compositions. Pit kernels were ground, followed by hexane extraction on a Labconco Goldfisch Apparatus. Solvent-free kernel oils were analyzed to determine fatty acid composition (AOCS Method Ce 1b-89, GC method).

Whole pit oil content was determined using ^{1}H nuclear magnetic resonance at 10 MHz (Bruker miniSpec,Bruker Optik GmbH, Am Silberstreifen, Germany) following AOCS Method Ak4-95. Chokecherry whole pit samples (used in NMR calibration) were ground using a coffee grinder. The oil content of ground samples was determined by hexane extraction using a Labconco Goldfisch Apparatus. A calibration curve was prepared by analyzing chokecherry pit samples of known oil content. Subsequently, pit oil content was determined using the calibration curve. Potential correlations between pit mass and pit oil content were explored. Pit samples with the highest oil content were manually fractionated into endocarps (hulls) and seeds (kernels). Fatty acid compositions were determined on solvent-extracted seed oil (AOCS Method Ce 1b-89).

Pit weight and oil content were determined for Stand Two to examine the variability of these factors in noncultivated chokecherries from across Saskatchewan.

Gross Energy Content. Gross energy content for fractionated fruit was determined using a Parr 1281 Bomb Calorimeter. Fresh fruit harvested on September 17, 2010 were depitted and the pits cracked manually before lyophylization and homogenization into a powder. Atomic absorption spectroscopy was used to determine the carbon and nitrogen content of the fractions. Fatty acid composition was determined using gas chromatography and the presence of eleosteric acid confirmed using NMR.

RESULTS AND DISCUSSION

Bulk Fruit Fractionation. Commercial fruit processors mechanically process bulk fruit to remove the pits. We fractionated bulk fruit from the most common varieties of chokecherry grown in Saskatchewan in to give an indication of the yields of each expected by a commercial outfit.

Mechanical processing of the fruit greatly simplified pit extraction compared with manual processing at the cost of less clean pits. Mechanical fractionation of Garrington, Bought, Lee, and Goertz fruit from Stand One yielded 85−90% juice (Table 1). The pits were almost completely clean of skin and pulp only after the third pass through the juicer. Pits represented 13−20% of the mass of the fruit when processed this way. The pit fraction of Garrington, Lee, and Goertz fruit cleaned manually is lower than that prepared mechanically (Table 2) due in part to the presence of small pieces of skin and pulp in the latter preparations. Pit mass in the open-pollinated lines (Stand Two) ranged from 47.8 to 148.6 mg, with a mean of 90.5 ± 16.79 mg (Table 3). The differences in pit mass between half-sibling lines were highly significant ($F = 7.95$, df = 16/929, $p \ll 0.0001$). When fractionated, 32% of the mass of the pits was kernel, the remaining portion being hulls.

Table 2. One Hundred Fruit Weight, Seed Weight, and Oil Content in Four Lines of Manually Depitted Chokecherry Fruit Grown in Stand One at the University of Saskatchewan Horticulture Farm[a]

	100 berry mass (g)	100 pit mass (g)	pit (% fruit fw)	oil (% pit dw)	oil (% fruit fw)
Garrington	61.9	8.6	13.9	11.9	1.7
Goertz	89.6	8.6	9.6	11.1	1.2
Lee Red	90.0	12.4	13.8	14.8	2.3
Robert	76.6	12.5	16.3	11.3	2.4

[a]NMR of whole pits was used to determine oil content.

A significant biomass is obtained from chokecherries grown in the Prairies, ∼7 kg per tree, or 24.5 t·ha^{-1}, assuming 3400 trees per hectare (St-Pierre et al., 2005).[3] A more conservative value of 16.5 t· ha^{-1}[5] is used in calculations throughout the rest of this work. This high level of productivity indicates that this

Table 3. Mean Oil Content, Range, and Number of Individuals in the 17 Half-Sibling Lines from Stand Two[a]

open-pollinated line	no. of trees	mean oil content % dw pit (std dev)	mean pit mass mg (std dev)
19	59	11.3 (1.89)	91.1 (17.75)
23	31	10.7 (1.38)	97.7 (16.29)
33	47	10.3 (1.81)	98.9 (16.10)
34	10	11.1 (1.80)	97.8 (15.06)
35	9	12.1 (1.81)	81.8 (12.42)
36	9	11.1 (1.51)	88.8 (8.41)
45	143	10.9 (1.89)	87.5 (14.76)
46	11	12.0 (1.27)	88.8 (12.98)
47	8	12.2 (1.65)	88.2 (15.73)
48	55	8.9 (1.59)	105.0 (16.90)
51	11	9.6 (1.86)	98.4 (17.38)
52	40	11.9 (2.11)	92.9 (15.82)
53	148	12.0 (1.76)	86.0 (14.63)
56	90	10.0 (1.81)	88.2 (16.15)
58	73	11.0 (1.56)	87.5 (18.24)
60	67	10.5 (1.58)	88.5 (15.22)
66	27	11.0 (1.97)	83.0 (14.45)

[a] Mean oil content of the pits was determined using NMR. Oil content and mean pit mass are significantly different between lines ($F = 13.6$, $p \ll 0.0001$ for oil and $F = 7.95$, $p \ll 0.0001$ for mass).

crop has significant potential as a sustainable food and biomass crop.

At 16.5 t·.ha^{-1} fruit, chokecherry is significantly more productive than wheat or canola in terms of biomass produced. Approximately 3.4, 1.4, and 0.55 t·ha^{-1} (dw) of pulp, hulls, and kernels, respectively, is produced by chokecherry, compared to the 10-year Saskatchewan average for canola (1.46 t·ha^{-1}) or wheat (2.11 t·ha^{-1}) recorded by the Canadian Grains Commission. An additional advantage of using perennial crops, such as chokecherries, is that yields are typically more consistent than annual crops.[6] Reduced yield variability has the advantage of reducing drastic changes in the price of both food and biomass.

Pit and Kernel Oil Content. The oil contents of manually collected pits from Garrington, Goertz, and Robert were ~11% (dry weight) oil, while Lee Red was closer to 15% (Table 2). The mean oil content of the 17 half-sibling lines from Stand Two was 10.9% ± 1.93, with a range from 4.9% to 17.6% (Table 3). Oil contents were significantly different between half-sibling lines in Stand Two (ANOVA: $F = 13.6$, df = 16/929, $p \ll 0.0001$), suggesting some genetic determination in this factor. Given the degree of variability in oil content, selection for high oil content kernels should be possible.

Oil content in the kernels alone (as determined by NMR) was approximately 45.5%, while the moisture content was 5.9%, similar to that observed by Duman et al.[7] This data suggests an alternative method of gaining higher oil yields in the pits could be to select varieties for larger kernel: hull ratios, assuming actual oil content in the kernel remains constant.

Estimating 3400 plants/ha, with a maximum of 0.94 kg pits/plant and 12% oil, yields 383 kg·ha^{-1} oil (based on numbers from St-Pierre et al.[3] and Zatylny et al.[4]). If based on 16.5 t·ha^{-1} fruit, of which 13% is pits, an oil yield of 257 kg·ha^{-1} would be expected. This is 40−60% of the estimated yield of canola oil at 626 kg·ha^{-1} (assuming 1455 kg·ha^{-1} seed (1999−2009 Saskatchewan average) and 43% oil). However, if considered over a 24-year period, chokecherries would produce 6170−9190 kg·ha^{-1} oil while canola, grown in rotation once every 4 years with wheat, would produce 3760 kg·ha^{-1}.

Fatty Acid Composition. Oleic and linoleic acids were the primary fatty acids present in the seeds of the nine cultivars from Stand One with a similar pattern of fatty acid composition observed in selected high-oil individuals from Stand Two (Table 4). The next most abundant fatty acid after oleate and linoleate was eleostearate.

The pattern of fatty acid composition for the chokecherry lines grown in both Stand One and Stand Two were similar to those observed in wild fruit collected in Alberta.[8] Chokecherries had lower concentrations of palmitate, stearate, linoleate, and eleostearate and higher levels of oleate than *P. avium* and *P. cerasus*.[8,10,11,13] Further differences are observed when comparing chokecherry fatty acid composition to other stone fruit.[8,9] The consistent pattern of fatty acid composition between cultivars and lines plus the differences on fatty acid composition between *P. virginiana*, *P. avium*, and *P cerasus* suggests that a strong genetic component controls accumulation of these seed

Table 4. Fatty Acid Composition of Chokecherry Seed Oil from Different Cultivars Harvested from Stand One at the University of Saskatchewan Horticulture Farm in 2003[a]

cultivar	C16:0	C18:0	C18:1	C18:2	C18:3 $n-3$	C18:3 $n-5$
Boughen Yellow	2.5	1.2	55.4	33.9	0.5	6.5
Copper Schubert	2.3	1.2	57.1	32.7	0.4	6.4
Esperant	2.4	1.1	46.8	40.9	trace	8.9
Garrington	2.3	1.3	51.2	38.0	0.1	7.1
Goertz	2.5	1.2	60.5	31.3	trace	4.5
Lee Red	2.0	1.1	55.4	34.6	0.1	6.8
Maxi	1.5	0.9	49.3	40.8	0.5	7.1
Mission Red	2.8	1.3	61.2	28.2	0.1	6.4
Robert	2.4	1.1	54.8	34.5	0.3	7.0
mean	2.3	1.2	54.6	35.0	0.2	6.8
std dev	0.37	0.12	4.82	4.23	0.18	1.12
open pollinated mean	2.4	1.3	58.3	33.3	0.28	4.5
open pollinated range	1.9−2.8	1.0−19	52.2−66.3	26.3−41.2	0.0−0.94	3.4−6.6
open pollinated std dev	0.22	0.20	4.36	4.22	0.30	0.82

[a] Data for the open-pollinated half-sibling lines (Stand Two) are presented as well. Percent fatty acid composition shown, as determined by gas chromatography.

reserves. Breeding to select lines of plants with maximal concentrations of a desired fatty acid may be possible.

Total Chokecherry Energy Production Compared with Wheat and Canola. We examined total energy and carbon and nitrogen composition for pulp, hulls, and kernels as a measure of chokecherry productivity (Table 5). Gross energy for pulp, hull, and kernel was approximately 16, 20, and 27 kJ·g^{-1}, respectively. The differences in gross energy from pulp was significantly different between cultivars ($F = 13.6$, df = 6/14, $p = 0.00004$). The differences in hull and kernal gross energy were not significant between cultivars however ($p = 0.64$ and 0.090 for hulls and kernels, respectively).

The total amount of energy committed to each of the fruit fractions showed a different trend, however, due to the different proportions of each fraction within the fruit (Table 5). Fraction energy per 100 berries was significantly different between cultivars ($p \ll 0.0001$ for all three fractions). The total amount of energy in the pit was approximately 22 kJ·g^{-1}, based on 187 kJ/100 pits and 8.64 g/100 pits.

On a per hectare basis, total fruit energy was approximately 96 GJ·ha^{-1}, of which 42 GJ·ha^{-1} was from the pits. Per unit mass, pits have 45% more energy than wood, assuming 15 kJ·g^{-1} for the latter. Similar gross energy values were observed for pits resulting from cherry processing in Turkey.[7] The relatively high energy content of the hulls means they could possibly be used as a biomass fuel. Alternatively, hulls could be used as a source of antioxidant phenolics[14] or other compounds,[7] although further examination is required.

Chokecherry productivity is much higher than annual cropping in terms of total biomass harvested and energy output. Mature chokecherries produce an estimated 16.5 (fw) or 5.36 t·ha^{-1} (dw) compared with 1.46 or 2.11 t.ha^{-1} for canola and wheat (1999−2010 means for Saskatchewan, Canadian Grains Commission), respectively. Over a 24-year period, assuming only 25% and 75% productivity in years 3 and 4, total energy from pits and pulp is 890 and 1130 GJ·ha^{-1}, respectively. Total energy output for annual grain crops over a 24-year period is estimated to be approximately 850 GJ·ha^{-1}, assuming six rotations of 1 year of canola and three of wheat, producing 1.34 and 1.84 t·ha^{-1}·year^{-1} dw of seed at 28.4 and 18.7 GJ·t^{-1}, respectively.[17,18] Energy inputs for chokecherry production have not been determined but are likely to be lower than that for annual crops as fewer equipment passages are required.

An additional biomass output from chokecherries is wood. Total woody biomass from chokecherries grown in a shelterbelt is estimated to be 40 t·ha^{-1} [19] (or 600 GJ·ha^{-1} assuming 15 kJ·g for wood). This value is higher than what would be expected from an orchard and would occur just once at the end of the useful life of an orchard. Annual production of wood from chokecherries also produces biomass. Good orchard practice suggests pruning 10−20% of above ground biomass per year, amounting to the lower range of wood produced by willow (4−12 oven dry tons per hectare).[20] Offcuts from pruning mature trees (years 5−23) would equate to 60 GJ·ha^{-1}, at 4 t harvested and 15 kJ·g^{-1} for wood, or an additional 1140 GJ·ha^{-1}.

Carbon and Nitrogen Content of Pulp, Hulls, and Kernels. The mean carbon content of pulp, hulls, and kernels was 42%, 49%, and 59%, respectively, while the mean nitrogen content was 0.69%, 0.18%, and 5.7% (Table 6). Carbon and nitrogen content for pulp and kernel were significantly different between cultivars; however, this was not the case for hulls. These data are similar to that observed previously.[7]

Table 5. Gross Energy of Different Chokecherry Fruit Fractions from Named Cultivars, Harvested September 2010[a]

cultivar	pulp moisture content (%)	pit (% fruit fw)	pit (% fruit dw)	hull (% fruit dw)	kernel (%fruit dw)	100 kernel mass (g dw)	100 berry mass (g fw)	pulp energy/100 berries (kJ)	hull energy/100 berries (kJ)	kernel energy/100 berries (kJ)
Boughen Yellow	74.7 (0.68)	16.6 (0.43)	42.1 (1.47)	30.9 (1.33)	11.3 (0.19)	2.4 (0.02)	58.4 (0.10)	197.8 (8.21)	127.5 (5.89)	65.8 (0.90)
Copper Schubert	74.9 (0.63)	12.5 (0.08)	34.2 (0.39)	24.3 (0.41)	9.9 (0.20)	2.6 (0.05)	78.6 (0.10)	273.2 (9.26)	124.7 (5.22)	69.7 (2.22)
Garrington	75.7 (0.02)	14.7 (0.41)	39.2 (0.84)	29.8 (0.64)	9.4 (0.20)	2.2 (0.02)	68.8 (0.10)	235.4 (6.77)	137.8 (1.78)	58.6 (0.63)
Goertz	79.5 (0.33)	11.0 (0.81)	34.9 (1.84)	23.8 (1.15)	68.3 (0.69)	2.3 (0.14)	73.3 (0.03)	214.5 (6.82)	96.3 (4.41)	60.3 (4.76)
Lee Red	80.6 (0.40)	10.6 (0.30)	35.7 (1.42)	23.8 (1.07)	12 (0.36)	3.0 (0.08)	92.1 (0.09)	255.0 (8.89)	116.48 (4.47)	81.2 (1.77)
Mission Red	74.8 (0.30)	11.9 (0.38)	33.0 (0.92)	23.7 (0.65)	9.3 (0.37)	2.0 (0.12)	65.2 (0.66)	231.5 (3.91)	199.23 (4.79)	53.2 (3.20)
Robert	75.8 (0.67)	13.9 (0.14)	37.8 (0.13)	27.3 (0.27)	10.5 (0.25)	2.8 (0.05)	80.7 (0.12)	269.6 (3.34)	142.9 (2.02)	76.1 (1.05)
F value								47.0	49.9	48.1
p								1.75×10^{-8}	1.18×10^{-8}	1.50×10^{-8}

[a] Mean and standard deviation (in brackets) indicated ($n = 3$). Single-factor ANOVAs showed significant differences in energy content per 100 berries between cultivars (df = 6/14).

Table 6. Carbon and Nitrogen Content for Different Chokecherry Fruit Fractions[a]

cultivar	C pulp	N pulp	C hull	N hull	C kernel	N kernel
Boughen Yellow	41.53 (0.026)	0.44 (0.031)	49.65 (0.540)	0.15 (0.031)	58.83 (0.566)	5.53 (0.093)
Copper Schubert	40.94 (0.116)	0.40 (0.015)	49.18 (0.764)	0.15 (0.015)	58.95 (1.266)	6.25 (0.575)
Garrington	42.77 (0.023)	1.33 (0.081)	49.15 (0.255)	0.18 (0.010)	57.37 (1.032)	6.05 (0.403)
Goertz	41.27 (0.260)	0.68 (0.081)	47.78 (3.256)	0.19 (0.127)	57.74 (1.114)	5.33 (0.306)
Lee Red	41.36 (0.254)	0.63 (0.010)	50.27 (0.178)	0.18 (0.023)	61.54 (0.220)	5.50 (0.716)
Mission Red	41.48 (0.140)	0.39 (0.032)	49.04 (0.484)	0.17 (0.044)	57.14 (0.551)	4.92 (0.285)
Robert	41.35 (0.465)	0.95 (0.012)	49.79 (0.679)	0.22 (0.031)	58.03 (0.757)	6.06 (0.207)
overall mean %	41.53 (0.583)	0.69 (0.332)	49.26 (1.336)	0.18 (0.050)	58.51 (1.594)	5.66 (0.572)
mass element (t/ha)	1.394	0.023	0.692	0.002	0.324	0.031
F value	18.4	161.8	1.06	0.506	9.17	3.85
p	≪0.0001	≪0.0001	0.429	0.794	0.0003	0.018

[a] Mean % dw and standard deviations (in brackets) shown ($n = 3$). Mass per hectare of each element based on overall mean, dry weight % of each fraction, and 16.5 t·ha^{-1} fruit. Significant differences between cultivars were observed for pulp and kernel but not for hulls (df = 6/14).

On a per area basis, chokecherries contain approximately 1395, 692, and 324 kg·ha^{-1} carbon and 23, 2, and 31 kg·ha^{-1} nitrogen for pulp, hulls, and kernels, respectively. In contrast, canola and hard red spring wheat seed contain 580 and 1600 kg·ha^{-1} carbon and 43 and 92 kg·ha^{-1} nitrogen, respectively. These data demonstrate the potential of chokecherries and likely perennial crops in general, for both food and biomass production.

Together, these results demonstrate that chokecherry is a good dual-purpose food and bioenergy crop, particularly for conditions similar to the Northern Prairies. Chokecherries are more productive than winter-sown annuals and warm-season perennial grasses in terms of biomass produced. Although C4 grasses, such as switch grass, are able to grow in Saskatchewan, biomass yields may be lower and take longer to establish than at more southern latitudes. Coharvesting grain and straw from annually grown crops is still less productive than growing chokecherry fruit.[21]

In conclusion, we have shown that chokecherries are a candidate dual-purpose crop producing food in the form of juice and pulp and biomass energy in the form of pits and wood. Total productivity of chokecherry fruit exceeds that of a canola/wheat rotation over a 24-year period in Saskatchewan in terms of biomass, gross energy, and oil produced. Offcuts from chokecherry pruning will add significantly to total biomass and gross energy yields. Selection of lines to obtain the optimal proportions of pulp, hull, and kernel may be desirable and may be possible as some genetic variability in these traits was observed in the open-pollenated half-sibling lines used in the work.

■ AUTHOR INFORMATION

Corresponding Author

*Phone: (306) 966 2071 (S.W.); (306) 966 5027 (M.R.). Fax: (306) 966 5015 (S.W. and M.R.). E-mail: suw425@mail.usask.ca (S.W.); martin.reaney@usask.ca (M.R.).

Funding

This research was funded by the Saskatchewan Agriculture Development Fund.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors thank Rick Sawatzky for technical assistance.

■ ABBREVIATIONS USED

dw, dry weight; fw, fresh weight

■ REFERENCES

(1) Crowder W., Geyer W. A., Broyles P. J. USDA Plant Guide: Chokecherry [Online] 2003, http://www.plant-materials.nrcs.usda.gov/pubs/wapmcpg4750.pdf

(2) Montgomery A. Canadian Agriculture at a glance. [Online] 2007, http://www.statcan.gc.ca/pub/96-325-x/2007000/article/10775-eng.htm#cherries

(3) St-Pierre, R. G.; Zatylny, A. M.; Tulloch, H. P. Evaluation of growth, yield, and fruit size of chokecherry, pincherry, highbush cranberry, and black currant cultivars in Saskatchewan. *Can. J. Plant Sci.* **2005**, *85*, 659−64.

(4) Zatylny, A. M.; Ziehl, W. D.; St-Pierre, R,G. Physicochemical properties of fruit of chokecherry (*Prunus virginiana* L.), highbush cranberry (*Viburnum trilobum* Marsh.), and black currant (*Ribes nigrum* L.) cultivars grown in Saskatchewan. *Can. J. Plant Sci.* **2005**, *85*, 425−9.

(5) Manitoba Agriculture Chokecherry production in Manitoba [Online] Available at http://www.gov.mb.ca/agriculture/crops/fruit/bla01s00.html

(6) Parciak, W. Environmental variation in seed number, size and dispersal of a fleshy-fruited plant. *Ecology* **2002**, *83*, 780−93.

(7) Duman G.; Okutucu C.; Ucar S.; Stahl R.; Yanik J. The slow and fast pyrolysis of cherry seed. *Bioresource Technol.* **2010**, doi: 10.1016/j.biortech.2010.07.051

(8) Anwar, F.; Prybylski, R.; Rudzinska, M.; Gruczynska, E.; Bain, J. Fatty acid, tocopherol and sterol compositions of Canadian prairie fruit seed lipids. *J. Am. Oil Chem. Soc.* **2000**, *85*, 953−9.

(9) Kamel, B. S.; Kakuda, Y. Characterization of the Seed Oil and Meal from Apricot, Cherry, Nectarine, Peach and Plum. *J. Am. Oil Chem. Soc.* **1992**, *69*, 492−4.

(10) Zlatanov, M.; Janakieva, I. J. Phospholipid composition of some fruit-stone oils of Rosaceae species. *Fett/Lipid* **1988**, *100*, 312−5.

(11) Comes, F.; Farines, M.; Aumelas, A.; Sulier, J. Fatty acids and triacylglycerols of cherry seed oil. *J. Am. Oil Chem. Soc.* **1992**, *69*, 1224−27.

(12) Bernardo-Gil, G.; Oneto, C.; Antunes, P.; Rodrigues, M. F.; Empis, J. M. Extraction of lipids from cherry seed oil using supercritical carbon dioxide. *Eur. Food Res. Technol.* **2001**, *212*, 170−4.

(13) Chandra, A.; Nair, M. G. Characterization of Pit Oil from Montmorency Cherry (*Prunus cerasus* L). *J. Agric. Food Chem.* **1993**, *41*, 879−81.

(14) Pinelo, M.; Rubilar, M.; Sineiro, J.; Nunez, M. J. Extraction of antioxidant phenolics from almond hulls (*Prunus amygdalus*) and pine sawdust (*Pinus pinaster*). *Food Chem.* **2004**, *85*, 267−73.

(15) Rabak, F. Cherry kernel oil − production and utilization. *J. Am. Oil Chem. Soc.* **1932**, *9*, 210−3.

(16) Zagrobelny, M.; Bak, S.; Moller, B. L. Cyanogenesis in plants and arthropods. *Phytochemistry* **2008**, *69*, 1457−68.

(17) Chung, T. Y.; Nwokolo, E. N.; Sim, J. S. Compositional and digestibility changes in sprouted barley and canola seeds. *Plant Foods Human Nutr.* **1989**, *39*, 267−78.

(18) Zentner, R. P.; Lafond, G. P.; Derksen, D. A.; Nagy, C. N.; Wall, D. D.; May, W. E. Effects of tillage method and crop rotation on non-renewable energy use efficiency for a thin Black Chernozem in the Canadian Prairies. *Soil Tillage Res.* **2004**, *77*, 125−36.

(19) Kort, J.; Turnock, R. Carbon reservoir and biomass in Canadian prairie shelterbelts. *Agroforest Syst.* **1999**, *44*, 175−86.

(20) Keoleian, G. A.; Volk, T. A. Renewable energy from willow biomass crops: Life cycle energy, environmental and economic performance. *Crit. Rev. Plant Sci.* **2005**, *24*, 385−406.

(21) Malhi, S. S.; Lemke, R.; Wang, Z. H.; Chhabra, B. S. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. *Soil Tillage* **2006**, *90*, 171−83.