On-farm blast freezing of saskatoon berries

N.G. Stephenson[1], S. Cenkowski[1], W.E. Muir[1], M. Izydorczyk[2] and S. Tessier[3]

[1]Department of Biosystems Engineering and [2]Department of Food Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 5V6; and [3]Manitoba Agriculture and Food, Winnipeg, Manitoba, Canada R3T 5S6.

Stephenson, N.G., Cenkowski, S., Muir, W.E., Izydorczyk, M. and Tessier, S. 2002. **On-farm blast freezing of saskatoon berries**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **44**:3.1-3.6. In Canada, saskatoon berries (*Amelanchier alnifolia*) are grown primarily in the Prairie Provinces. Freezing of saskatoons extends the time period of availability of saskatoons for more than the short harvest length of approximately 1 to 4 weeks and increases market flexibility. A 2.2 kW prototype freezer was designed, constructed, and tested on a saskatoon farm in the 1999 and 2000 harvest years. At the beginning of a harvest day, the temperature of the prototype freezer was below –20˚C, the initial temperature of berries was approximately 5˚C, and the berries reached a temperature of –10˚C within 1 h. At the end of a harvest day, the chamber temperature had risen to –12˚C, the initial temperature of the berries was approximately 20˚C, and the time for the berries to reach –10˚C was greater than 4 h. Freezing caused: small change in colour lightness; up to a 30% loss of anthocyanin content; approximately a 23 to 80% loss of benzaldehyde content; no recognizable pattern in changes to total acidity (malic acid); and statistically insignificant change in soluble solids (sugars). For a 2 ha producer, the cost to purchase and operate the prototype freezer was estimated at $0.45/kg of berries and an additional expense of $0.40/kg was required to cover the cost and operation of a storage freezer. On-farm blast freezing of saskatoons is a viable option for value-added processing at the farm. **Keywords**: berry, fruit, blast freezing, cost, colour, acidity, soluble solids.

Au Canada, les baies d'amélanchier (*Amelanchier alnifolia*) sont surtout cultivées dans les provinces des Prairies. La congélation des baies permet d'en augmenter la disponibilité au-delà de la période des récoltes qui dure de 1 à 4 semaines. Un congélateur prototype de 2.2 kW fut conçu, construit et testé durant les périodes de récolte 1999 et 2000. Au début de la journée de récolte, la température du congélateur était à − 20°C alors que la température initiale des baies était d'environ 5°C. Dans ces conditions, il a fallu 1 heure pour que la température des baies atteigne − 10°C. A la fin d'une journée de récolte, la température de la chambre atteignait − 12°C, la température initiale des baies était approximativement de 20°C. Il a fallu plus de 4 heures pour que la température des baies s'abaisse à − 10°C. La congélation a entraîné un léger changement dans l'éclat de la couleur, une perte jusqu'à 30% de la teneur en anthocyane, une perte approximative de 23 à 80% de la teneur en benzaldéhyde, pas de tendance observable dans les variations de l'acidité totale (acide malique) et des changements non statistiquement significatifs de la teneur en solides solubles (sucres). Le coût pour l'achat et l'opération du congélateur prototype, pour un producteur cultivant 2 ha, a été estimé à 0.45 $ par kilogramme de baies. A cela on doit ajouter 0.40 $ par kilogramme pour couvrir les coûts et l'opération d'un entrepôt frigorifique. La congélation par air pulsé à la ferme des baies d'amélanchier est une option viable qui ajoute de la valeur au produit. **Mots-clés**: baie, fruit, congélation par air pulsé, coût, couleur, acidité, solides solubles.

INTRODUCTION

Saskatoons (*Amelanchier alnifolia*), also known as June berries, are grown primarily in the Prairie Provinces of Canada and the Plains of the United States. Saskatoon berries grow on bushes, are spherical in shape, have a diameter of approximately 12 mm, and have a purple colour when ripe. In the Prairie Provinces of Canada, saskatoon berries are harvested in July (St-Pierre et al. 1997).

The area of saskatoon production in Alberta, Saskatchewan, and Manitoba is approximately 500 to 800 ha (St-Pierre et al. 1997). With ideal growing conditions, saskatoon yields range between 3250 and 8750 kg/ha. The length of the saskatoon harvest ranges from 1 to 4 wk. Many producers are not able to harvest and sell their entire crop during the short harvest season.

Freezing of saskatoons on the farm will increase market flexibility for producers, processors, and consumers by extending the length of time saskatoons are available. Frozen saskatoons are marketed for both table use and for processed products such as pies, sauces, and yogurts.

The rate at which a food product is frozen affects the quality. The expansion of water as it freezes causes an increase of pressure within cells, causing the cell walls to break (Mogens 1984). The purpose of freezing saskatoons at a fast rate is to preserve the quality of the berries. If the saskatoons are frozen fast enough, structural damage to the berries can be prevented.

The objective of this research was to design and evaluate the performance of an air-blast freezing system. The air-blast freezing system was evaluated by analysing time-temperature data of saskatoons frozen in the prototype freezer, by performing quality analyses on fresh and frozen saskatoons to determine the effect of freezing, and by analysing the economics of the freezing system.

MATERIALS and METHODS

Design of the prototype freezer

The main criteria considered during the design of the prototype freezer were cost and power requirements. We designed an air-blast freezer that had a capital and installation cost of less than $25 000 and required only single phase electricity. The chamber of the prototype freezer (2.4 m wide x 2.4 m long x 3.1 m high) was built on a farm at Petersfield, approximately 80 km North from the University of Manitoba in Winnipeg, MB. The floor, walls, and ceiling were insulated with 100 mm thick polyurethane. Two insulated doors, 0.97 m wide by 1.98 m high, were located on opposite sides of the chamber.

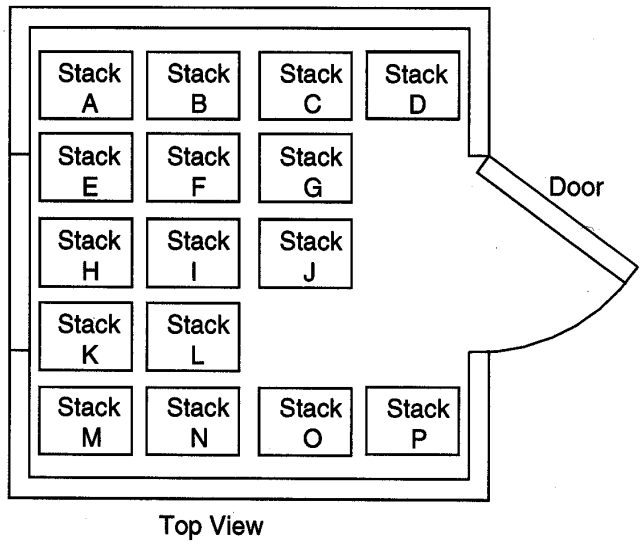

Fig. 1. Arrangement of stacks of trays for the freezing experiments with the prototype freezer.

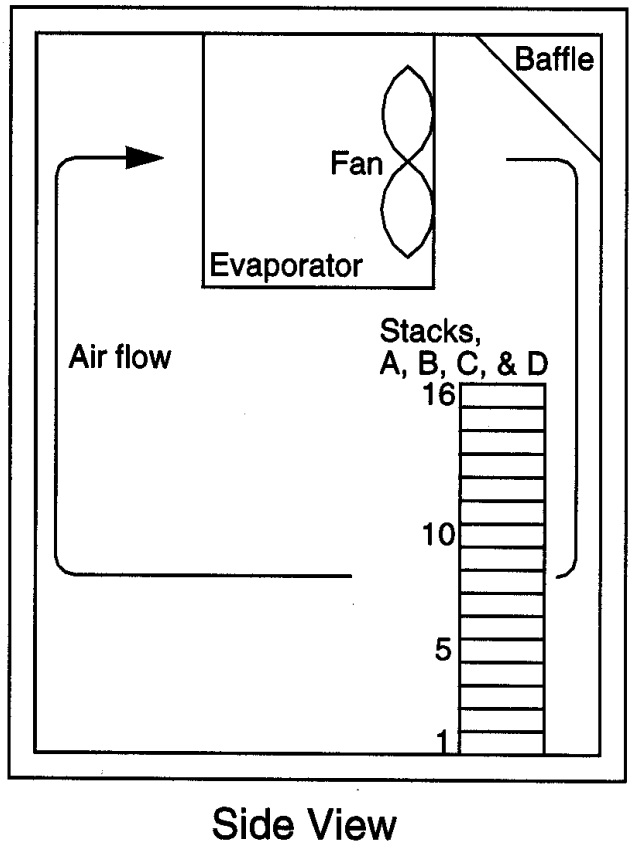

Fig. 2. Cross-sectional view of the prototype freezer illustrating the relative positions of the evaporator, fan, and stacks A, B, C, and D.

An air cooled condensing unit (model Copelametic CJDL-0300, Copeland Corporation, Brantford, ON), which consisted of a 2.2 kW compressor (model 2DF3-030E), was mounted on top of the chamber. The electrical requirement for the condensing unit was 37 A of single phase power at 230 V. Mounted inside the chamber was an evaporator (model SC-6040-E6, Blanchard Ness, St. Hubert, QC). This model is defined as having a capacity of 3.2 kW/°C and has an electric defrost and 236 fins per metre length of evaporator. A single 0.76-m diameter fan was attached to the evaporator. The heater for the electric defrost required 32 A and the fan motor required 5.1 A, both with single phase power at 230 V. The prototype freezer was charged with R507 refrigerant.

Prototype freezing experiments

Saskatoon berries (Smokey cultivar) were harvested in the 1999 and 2000 years when the berries had reached class nine maturity (Rogiers and Knowles 1997). The 1999 harvest period was relatively short, lasting from July 20 to July 26. In the year 2000, the harvest began on July 10 and lasted until July 18. Manual labour was used to harvest the berries. The berries were brought from the field to the farm yard where they were separated from leaves, soil, and rotten berries using a moving mesh belt and fan arrangement. On the average it took approximately 30 to 40 min from the moment berries were harvested to the moment they were placed in the prototype freezer.

After the saskatoons were harvested and cleaned, approximately 2.3 kg of saskatoons were placed in plastic trays which gave a three layer coverage of berries on the individual trays. The plastic trays were 470 mm long by 335 mm wide by 95 mm high. Perforations in both the bottom and sides of the trays allowed for air flow, without allowing saskatoon berries to fall through the holes. The trays were positioned inside the prototype freezer to fit a maximum of 4 across the width of the chamber and a maximum of 16 high (Fig. 1). A 30-gauge, copper-constantan thermocouple was inserted into the centre of a large, randomly chosen berry in a tray and the berry was positioned near the centre of the tray. Thermocouples were placed in trays 5 and 10 above the floor in stacks from A to D and from M to P where the air circulation was the lowest.

Stacks A, B, C, and D were stacked at the same end of the chamber where the fan was located (Fig. 2). The front of the evaporator was considered as the side where the fan was located. Trays were not stacked near the entry door so as not to inhibit access into the freezer. Stacks were started and finished in alphabetical order before starting the next stack. The rate that trays were brought in depended on the harvesting and cleaning rate. All the trays of saskatoons were removed from the prototype freezer the following morning and boxed in the storage freezer.

For the freezing experiment, five copper-constantan thermocouples of 24 gauge were positioned inside the chamber to monitor the air temperature. Two of the thermocouples were positioned on the wall behind the evaporator and two on the wall in front of the evaporator. These thermocouples were approximately at heights of 1.0 and 2.0 m and at the centre of the width of the wall. The fifth thermocouple was at the centre of the chamber.

All the 24-gauge and 30-gauge copper-constantan thermocouples were connected to a Hewlett Packard HP3421A (Hewlett Packard Company, San Diego, CA) data acquisition system (DAS) to monitor and record the time-temperature data.

Transportation and storage of saskatoon berries

For the quality tests, samples of approximately 1 kg of frozen or fresh saskatoon berries were chosen from the trays in the prototype freezer using a random number table or were collected from the freshly harvested bulk. Saskatoons were placed in plastic bags, which were then sealed and stored in either 2-L or 4-L pails. During the 1.5-h transport of the frozen samples to the University of Manitoba, the saskatoons were kept in a cooler with dry-ice, ice-packs, or both. The frozen samples were then stored at –15˚C until the samples were thawed for the quality analyses. The fresh samples were transported in a separate cooler with melting ice packs and then used immediately in quality tests in the laboratory at the University.

Quality analyses

The quality of fresh and frozen saskatoons was assessed by measuring colour and acidity, and anthocyanin, benzaldehyde, and carbohydrate content. These tests, performed in duplicate, were chosen based on previous research by Green and Mazza (1986) and Mazza and Hodgins (1985) to be representative of the quality changes that may occur as a result of freezing.

Colour evaluation The methodology for colour evaluation was adopted from Green and Mazza (1986). A HunterLab Colorimeter model D25L-2 (Hunter Associates Laboratory Inc., Fairfax, VA) was used for the colour evaluation of whole berries. A pink tile, with calibration coefficients of 'L' = 68.8, 'a' = 21.4, and 'b' = 10.9, was used to calibrate the Hunterlab Colorimeter. The colour was tested with a sample of 300 g of whole saskatoon berries. Three 'L', 'a', and 'b' values were recorded by rotating the container 90˚C between readings. The Hunter 'L' measures lightness, the 'a' measures redness when positive and greenness when negative, and 'b' measures yellowness when positive and blueness when negative (Green and Mazza 1986).

Anthocyanins and benzaldehyde Anthocyanins are responsible for the purple colour of saskatoons, while benzaldehyde is a chemical that produces the aroma of saskatoons and generates an almond flavour in cooked saskatoons (Green and Mazza 1986).

The method of Fuleki and Francis (1968a) and Green and Mazza (1986) was used to extract anthocyanin from saskatoons. A sample of 100 g of saskatoon berries was blended with an Osterizer Galaxie blender on high speed for 180 s with 100 mL of 95% ethanol / 1.5 M HCl (85:15 v/v). The sample was transferred to a beaker, covered, and stored overnight at 4˚C. The next day the sample was filtered using Whatman # 44 filter paper and then three 100-mL washings and one 75-mL washing, both with the ethanol-hydrochloric acid solution. The volume of the filtrate was brought up to 500 mL with the ethanol-hydrochloric acid solution. Total anthocyanin content was determined by the pH differential method (Fuleki and Francis 1968b; Green and Mazza 1986). Samples were prepared by diluting the extract with KCl (0.2 N) / HCl (0.2 N) (pH 1.0 buffer). The dilution that resulted in an absorbance reading of 0.6 to 0.8 was used to prepare diluted samples with both a KCl (0.2 N) / HCl (0.2 N) (pH 1.0 buffer) solution and a $NaC_2H_3O_2$ (1N) / HCl (1 N) / distilled water (100:60:90) (pH 4.5 buffer) solution. The diluted samples were allowed to equilibrate in the dark for 2 h. The absorbance at 510 nm of both dilutions (pH 1.0 and pH 4.5) was obtained using a Spectronic 601 spectrophotometer (Milton Roy, Rochester, NY) and a 10 mm cell. Distilled water was used as the blank. The total anthocyanin content was expressed as milligrams of cyanindin-3-galactoside per 100 g of berries (mg/100 g). Cyandin-3-galactoside is the major anthocyanin of saskatoon berries (Green and Mazza 1986).

The benzaldehyde analysis was based on methodology described by Mazza and Hodgins (1985). The sample was prepared by blending 50 g of berries with 50 mL of 60% methanol with an Osterizer Galaxie blender on high speed for 180 s. The mixture was transferred to an Erlenmeyer flask, stoppered, and stored overnight at room temperature. The mixture was transferred to a 500 mL evaporating flask, connected to an all-glass rotary vacuum evaporator (Büchi RE11 Rotavapor and Büchi 461 Water Bath, Büchi Laboratories, Flawil, Switzerland) and extracted for 15 min at 48 ± 1˚C. The volume of the benzaldehyde containing extract was brought up to 100 mL with 60% methanol. The absorbance of the benzaldehyde was read with a Spectronic 601 spectrophotometer (Milton Roy, Rochester, NY) at 249 nm, using 60% methanol as a blank. The standard method (19.102) of AOAC (1998) was used to establish a standard curve relating absorbance to benzaldehyde concentration of saskatoons. The absorbance of 1, 2, 4, 6, 8, and 10 ppm benzaldehyde concentrations were read on the spectrophotometer at 249 nm.

Total acidity and soluble solids The method used to prepare the sample for total acidity was adopted from an AOAC (1998) standard method (22.008), as described by Green and Mazza (1986). The sample was prepared by blending 150 g of berries with 150 mL of water with an Osterizer Galaxie blender on high speed for 180 s. Next, 250 mL of distilled water were added to the sample and the mixture boiled for 1 h. The volume of the slurry was brought up to 1000 mL with distilled water, filtered through two layers of cheese cloth, and suction filtered through Whatman #4 filter paper.

The glass electrode method, AOAC (1998) standard method (22.061), as described by Green and Mazza (1986), was used to determine pH and total acidity. An Accument pH meter (Model 901, Fisher Scientific Ltd., Napean, ON) was used for measurements. The pH meter was standardized using two point standardization with pH 7 and pH 10. From the filtered solution, 50 mL was titrated with 0.1N NaOH in a 250 mL beaker until the solution reached a pH of 8.7. The solution was continuously mixed with a magnetic stirrer. The initial pH, final pH, and volume of 0.1N NaOH titrated were recorded.

Malic and citric are the major acids of saskatoons (Mazza and Miniati 1993). Total acidity was expressed as percent malic acid.

The refractometer method for determination of soluble solids, expressed as percent sucrose, was based on AOAC (1998) standard method (31.011), as described by Green and Mazza (1986). A sample of 20 g of saskatoons was mixed with 75 mL of distilled water and blended with an Osterizer Galaxie blender on high speed for 180 s. The mixture was suction filtered through Whatman #4 filter paper. The volume of the slurry was brought up to 100 mL with distilled water. The refractometer (Carl Zeiss, Oberkochen, Germany) was standardized with distilled water. Two drops of the filtered

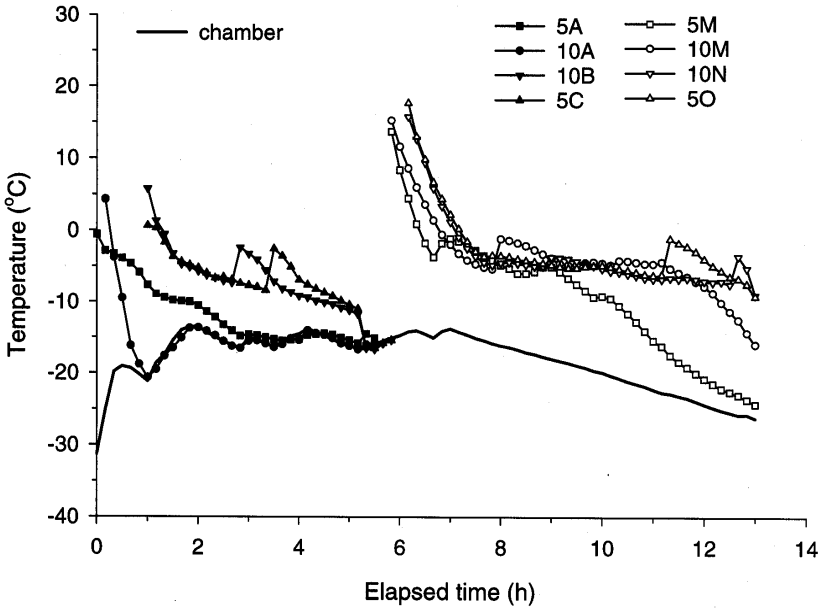

Fig. 3. Experiment with the prototype freezer on 17 July 2000, time 0 = 0730 h. Letters indicate the location of the stack of 16 trays (Fig. 1) and numbers indicate the position of the tray in the stack, beginning with 1 at the bottom. Approximately 2.3 kg of saskatoons were placed in each tray.

solution were placed on the refractometer, then the Brix (% sucrose w/w) and refractive index were obtained. The Brix value was multiplied by a mass ratio to represent the percent sucrose for a 100 g sample.

RESULTS and DISCUSSIONS

Prototype freezing experiments

On 17 July 2000, harvesting began at 0700 h and 30 min later the first stack (A) was placed (0 h in Fig. 3) in the empty prototype freezer. The chamber temperature at that time was approximately –30˚C. The next two stacks (B and C) were placed in the chamber 1 h later. Stacks D to P were placed one by one in approximately 30 min intervals (without removing the frozen product), therefore, stack M was placed in at the elapsed time of 5.5 h (Fig. 3) and stacks N and O at 6 h. Approximately 580 kg of saskatoons were harvested on that day and at the end of the day all the berries were accommodated in the prototype freezer.

The initial temperature of the berries entering the chamber, at the beginning of the harvest day, was approximately 5˚C. The ambient temperature within the handling shed, where the prototype freezer was located, was approximately 15˚C at 0730 h. The temperature of the shed affected the initial temperature of the saskatoons entering the prototype freezer. There was a 1 to 5 min time lag between placing the trays in the chamber and recording the initial temperatures of individual berries. Therefore, the initial temperatures of the berries handled with bare fingers were lower only by 2 to 3°C from the temperature in the shed. The berries that entered the chamber at 0 h reached –10˚C within 1 h. Berries that entered the chamber at about 1 h took approximately 2 h to reach a temperature of –10˚C. In both cases, there was a sharp rise in the chamber temperature due to the heat load of fresh berries entering the chamber. The freezer had only a 2.2 kW compressor and was unable to handle the quantity of fresh berries entering the chamber.

At the end of the harvest day, the last berries (stacks O and P) were placed in the chamber at approximately 1330 h with a chamber temperature of approximately –12˚C (6 h in Fig. 3). These berries dropped to 0˚C within 1 h. Rapid removal of field heat can halt post-harvest deterioration and quality loss because freshly-harvested fruit continues to respire rapidly until cooled to near 0˚C (St-Pierre et al. 1997). The temperature of the berries in the two trays dropped below –10˚C in approximately 4 and 6 h. Berries in the other two trays did not reach –10˚C within 7 h. The initial temperatures of these berries ranged between 15 and 20˚C, while the temperature in the shed was approximately 25˚C.

Quality analyses

Colour evaluation The values of "L" and "a" for fresh berries were in the range for maturity class 9 (Rogiers and Knowles 1997). The "b" values measured in both harvested years were lower by 2.0 to 2.5 from those reported by Rogiers and Knowles (1997) for maturity class 9. Analysis of variance showed a statistical significance in difference (at the 5% level) between the fresh and frozen samples only in the lightness value (Table 1). No significant statistical differences were detected among the frozen samples from the 2000 harvest year, however, those frozen for 5 d were slightly darker than the samples frozen for 2 and 3 d. This trend was not observed for the 1999 harvest year.

Table 1. Colour evaluation of fresh and frozen whole saskatoons.

Harvest year	Condition of berries	Storage period (d)	Hunter colour values*		
			L	a	b
1999	fresh	0	14.4±1.3	3.5±1.2	-0.9±0.5
	frozen	1	18.2±1.2	2.9±0.7	-0.2±0.1
	frozen	4	17.3±1.0	2.9±0.6	-0.4±0.1
2000	fresh	0	15.1±2.4	2.4±2.3	0.1±0.5
	frozen	2	18.0±1.8	6.2±1.6	-0.1±0.5
	frozen	3	18.0±2.2	3.9±1.5	-2.6±0.6
	frozen	5	19.5±1.5	4.8±2.1	0.0±0.5

* Mean ± standard deviation, n=3

Anthocyanins and benzaldehyde In 1999, the fresh and mature berries had the highest anthocyanin content at 143 mg/100 g. After freezing and storing at -15°C for 4 d, the anthocyanin content was reduced to the range between 98 and 120 mg/100 g. In the 2000 harvest year, anthocyanin contents of the fresh samples were between 107 and 122 mg/100 g while

for the frozen samples stored for 2 to 5 d it was 64 to 108 mg/100g. The fresh samples from 1999 had a higher anthocyanin content than the fresh samples in the 2000 harvest year. The average loss of anthocyanin content as a result of freezing and storing at -15°C for up to 5 d was 23% and 30% in the 1999 and 2000 harvest years, respectively. In 2000, the loss of anthocyanin was greater in samples stored for longer periods.

In 1999, the benzaldehyde concentration of the fresh samples was 25 to 28 ppm. As a result of freezing and storing at -15°C for 4 d, the range of benzaldehyde concentrations was from 16 to 25 ppm (approximately 23% reduction in aroma). In the 2000 year, the benzaldehyde concentration of the fresh and mature samples was 20 ppm and freezing (including 2 to 5 d storage at -15°C) reduced the aroma concentration to the range of 2 to 6 ppm (average reduction of 80%). The lower values of the benzaldehyde content in the year 2000 were probably attributable to the higher (by 10°C) initial temperature of the fruits coming in to the freezer and a longer freezing time for samples processed in the afternoon (Fig. 3).

Total acidity and soluble solids The fresh and mature berries from the 1999 harvest year had a malic acid level of 0.33%. The range of the malic acid for frozen samples in the 1999 harvest year was 0.29 to 0.35%. No differences in acidity between the fresh and frozen samples were detected. For the 2000-harvest-year, the malic acid of the fresh samples was 0.27 and 0.33%. The range of malic acid in frozen samples was 0.28 to 0.37%. The values of the malic acid for fresh and frozen samples overlapped. There was no recognizable trend indicating an effect of freezing on the malic acid of saskatoons.

The fresh and mature samples from the 1999 harvest year had a sucrose level of 14.8%. The average value for the frozen samples was 11.5%. In the 2000-harvest-year samples, the average value of sucrose in fresh samples was 11.3% (9.9 to 12.5% range). Whereas in frozen samples it was 10.8% (9.5 to 12.4% range). The decrease in soluble solids between the average of the fresh samples and the average of frozen samples, in the 2000 harvest year, was statistically not significant at the 5% level.

Analysis of freezing economics For the prototype freezer, the compressor, condenser, and fan required 8.4 kW. The evaporator fan and defrost heater drew 1.2 kW and 7.4 kW, respectively. The total cost for the prototype freezer was approximately $25 000, with an estimated useful life of 10 y and no salvage value. The prototype freezer was expected to run 16 h a day for 20 d each harvest. The depreciation cost calculated as the original cost minus salvage value and divided by the useful life (Granof et al. 1996) was estimated to be $2 500. The evaporator had three defrost cycles daily, each lasting approximately 0.5 h. Power requirements for the chamber lights and door heaters were negligible. The calculated energy requirements for 20 d for the condensing unit, evaporator fan, and defrost heater was 3220 kW h at an electricity cost of $0.0625/kW h (Manitoba Hydro 2001). Therefore, the cost of freezing 1 kg of berries using the prototype freezer was only $0.45.

Frozen berries would have to be stored at least at -15°C. The estimated cost of a single phase 1.5 kW storage freezer was $15 000, with an estimated useful life of 10 y and no salvage value with the depreciation cost of $1 500 per year. The total power requirements of the storage freezer was assumed to be 2/3 of the prototype freezer and was assumed to operate for 90 d instead of 20 d. The calculated total energy required by the storage freezer was 14 820 kW h giving an operational cost of $925 per harvest year.

Saskatoon yields range from 3250 to 8750 kg/ha. A yield of 3500 kg/ha was chosen because of risk factors and the short harvest period in the 1999 and 2000 harvest years. Thus the total harvest year production for a 2 ha operation is 7000 kg. Sales of fresh berries were estimated at 1000 kg, leaving 6000 kg of saskatoons to be frozen and stored. The estimated cost of freezing and storing at -15°C for 90 d for 6000 kg of berries was $0.85 per kg.

The prototype freezer could be used for other small fruits grown in the Prairie Provinces. Increasing the length of use and number of products frozen in the prototype freezer would improve freezing economics and a more mechanized system (i.e. a belt conveyor or other handling system) could become viable.

CONCLUSIONS

The time needed to freeze berries to -10°C in the prototype freezer was dependent on the harvesting time during the day. At the beginning of a harvest day, the prototype freezer was capable of freezing berries within 1 h. At the end of a harvest day, the time for the berries to reach –10˚C was between 4 and 7 h.

Freezing only effected colour lightness of berries (at the 5% level of significance). There was no recognizable trend indicating an effect of freezing on the total acidity of saskatoons. Freezing, however, caused some losses of anthocyanin (23 and 30% in 1999 and 2000, respectively), and benzaldehyde (approximately 23% and 80% reduction in 1999 and 2000, respectively).

The cost of freezing 1 kg of berries with the prototype freezer was estimated to be $0.45. Capital and operating costs of a $25 000 prototype freezer and a $15 000 storage freezer, both amortized over a period of 10 y, for a 2 ha producer was estimated at $0.85/kg of berries.

ACKNOWLEDGMENTS

This project was funded by the Manitoba Rural Adaptation Council (MRAC); they deserve recognition as their support made this research possible. The Natural Sciences and Engineering Research Council of Canada also provided funding through the financing of a research assistant. The authors gratefully thank John and Kim Ritz of Prairie Lane Saskatoons for their cooperation in this project.

REFERENCES

AOAC. 1998. *Official Methods of Analysis of AOAC International*, 16th edition. Washington, DC: Association of Official Analytical Chemists.

Fuleki, T. and F.J. Francis. 1968a. Quantitative methods for anthocyanins. 1. Extraction and determination of total anthocyanin in cranberries. *Journal of Food Science* 33:72-77.

Fuleki, T. and F.J. Francis. 1968b. Quantitative methods for anthocyanins. 2. Determination of total anthocyanin and degradation index for cranberry juice. *Journal of Food Science* 33:78-83.

Granof, H.G. P.W. Bell and R.C. Miller. 1996. *Financial Accounting Principles and Issues*, 2nd edition. Scarborogh, ON: Prentice-Hall Canada Inc.

Green, R.C. and G. Mazza. 1986. Relationships between anthocyanins, total pheloics, carbohydrates, acidity, and colour of saskatoon berries. *Canadian Institute of Food Science and Technology Journal* 19(3):107-113.

Manitoba Hydro. 2001. Manitoba hydro monthly rates and zones. Manitoba Hydro, Winnipeg, MB.

Mazza, G. and M.W. Hodgins. 1985. Benzaldehyde, a major aroma component of saskatoon berries. *Horticultural Science* 20(4):742-744.

Mazza, G. and E. Miniati. 1993. *Anthocyanins in Fruits, Vegetables, and Grains*. Boca Raton, FL: CRC Press Inc.

Mogens, J. 1984. *The Quality of Frozen Foods*. London, England : Academic Press Inc.

Rogiers, S.Y. and N.R. Knowles. 1997. Physical and chemical changes during growth, maturation, and ripening of saskatoon (Amelanchier alnifolia) fruit. *Canadian Journal of Botany* 75:1215-1225.

St-Pierre, R.G, H. Tulloch, C. Greuel and W. Ziehl. 1997. *Growing Saskatoons - A Manual for Orchadists*, 5th edition. Saskatoon, SK: Apex Graphics.