Food Chemistry **25** (1987) 293–304

Seasonal Variations of the Sugars in Birch Sap

H. Kallio & S. Ahtonen

Department of Chemistry and Biochemistry, Laboratory of Food Chemistry, University of Turku, SF-20500 Turku, Finland

(Received 11 December 1986; accepted 13 January 1987)

ABSTRACT

*The content of the main sugars of birch sap (*Betula pendula *Roth. and* B. pubescens *Ehrh.), which will be used for syrup production in Finland, were monitored by GLC as TMS-derivatives. Glucose and fructose had a concentration maximum at the end of April or at the beginning of May (5–8 g litre^{-1}). This sugar can be regarded as invert sugar. The content of sucrose (0–0·7 g litre^{-1}) decreased and in many cases it had totally disappeared by April. A correlation between sucrose and other sugars was not observed. The concentration of galactose was always low (0·01–0·03 g litre^{-1}). No diurnal variation was observed in the content of any sugar. The highest sap flow was obtained in the third flow week at the end of April and more than one-third of the total sugar yield could be collected during that period.*

INTRODUCTION

The increasing use of birch sap for food production is limited especially by the low dry matter content of the sap. Thus, any effort to increase the sugar content of the raw material lowers the threshold of a real commercial production of a wider variety of birch sap products as, for example, juice, syrup and liqueurs.

As early as 1837 two scientific papers were published showing that birch sap contains sugar ('Schleimzucker'), which does not crystallize (Brandes, 1837; Geisler, 1837). Most of the soluble solids in sap, 77–92%, are sugars (Lenz, 1909; Löhr, 1953). Variations are often great, from almost zero (Lenz, 1909; Richter, 1925) to over 20 g litre^{-1} (Burström & Krogh, 1946), and in special cases up to 35 g litre^{-1} (Orlov, 1963; Essiamah, 1980).

Table 1 reviews the literature concerning the sugar contents of birch sap, covering more than one hundred years. Highly different analytical methods have been used, e.g. refractometer and various chromatographic and gravimetric systems. It is, however, evident that the sugar content of birch sap varies widely around 1%.

During the short period in spring when the pressure in the birch trunk is positive, sap flow is possible. As early as two weeks before the start of the flow, sugar will be concentrated in the sap (Schroeder, 1865). The sugar and dry matter content of the sap depends on many environmental and genetic factors affecting the formation and catabolism of the sugars (Schroeder, 1865; Telishevskyj, 1970). Schroeder showed that a high temperature improves, and a low temperature retards, the conversion of starch to sugars, as expected. At the same time an elevated temperature increases the

TABLE 1
Dry Matter and Sugar Content in Birch Sap. A Literature Review

Species	*Reference*	*Content of dry matter and/or sugar (%)*[a]
B. pendula	Richter (1925)	0–1
	Burström & Krogh (1946)	1·1–2·1
	Holmberg (1948)	0·2–1·1
	Löhr (1953)	1·3
	Korolyak & Tomchuk (1973)	0·5–1·4
	Kalinichenko (1974)	1·1–1·2
	Essiamah (1980)	<4·3
	Källman (1982)	0·6–1·6
	Kallio *et al.* (1985*a*)	0·8–0·9
B. papyrifera	Johnson (1944)	0·8–1·0
	Ganns *et al.* (1982)	0·6–1·3
B. populifolia	Kok (1977)	0·7–0·8
	Kok *et al.* (1978)	0·6–1·0
B. alba	Schroeder (1871)	0·3–1·9
	Schroeder (1877)	0·6–2·0
	Lepeschkin (1928)	0·4–>0·8
B. pubescens	Löhr (1953)	<1·3
	Kallio *et al.* (1985*a*)	0·5–0·9
B. pendula + pubescens	Orlov (1963)	0·7–1·1
B. alleghaniensis	Kok (1977)	0·8
B. dahurica	Kalinichenko (1974)	1·8
B. lutea	Johnson (1944)	0·9
B. odorata	Nordal (1944)	0·8–1·5
B. platyphylla	Kalinichenko (1974)	1·7–1·9
	Osypenko & Ryabchuk (1975)	1·0–1·1

[a] °Brix or w/v % measured with varying methods.

consumption of sugar. The total amount of sugar produced by one tree depends on the energy reserves stored the year before (Schroeder, 1877). Low rain in spring increases the dry matter content of birch sap (Orlov, 1963). In general, birch trees growing in dry soil have sap with a high dry matter content (Telishevskyj, 1970).

The sugar content of birch sap is not the same in each part of the tree. Schroeder (1865, 1871, 1877) noticed that the sugar content increases from the ground level up to a certain height and then decreases towards the top of the tree and tips of the branches. In some works (Hornberger, 1887; Holmberg, 1948) the maximum concentrations were observed at a height of about 4 m. Lepeschkin (1928) and Orlov (1963) recognized sweeter sap higher in the tree than near the ground level. This apparent discrepancy may be explained by the location of the maximum sugar content being between the ground and the lowest boughs and moving downward during the flow (Schroeder, 1865, 1871, 1877). Schroeder also showed that the difference in the sugar contents near the ground and high in the tree diminished evenly during the spring from 0·7 to 0·2 per cent units.

In the roots the sugar content decreases further away from the trunk (Schroeder, 1865, 1871, 1877). The sap gathered from a stump has the same dry matter content as that from the tree before felling (Osypenko & Ryabchuk, 1975). As early as 1887 Hornberger proved that the main sugar components in birch sap are glucose and fructose. In addition, the sap is known to occasionally contain small amounts of sucrose (Johnson, 1944; Löhr, 1953; Beveridge *et al.*, 1978; Essiamah, 1980; Ganns *et al.*, 1982; Kallio *et al.*, 1985*a*).

Birch syrup is not yet in commercial production anywhere. In Finland the density of birch forests is one of the highest in the world and the reasonable availability of birch sap for industrial use may be guaranteed. A pilot scale process for birch syrup production has been developed in Finland with details of the pre-concentration system already published (Kallio *et al.*, 1985*b*). The quality, and especially the yield, of the syrup depends on the sugar profile during the short flow season in spring. To obtain the optimal sap for syrup production the seasonal and diurnal variations in the sugar content in the sap of the two most common birch species in Finland, *Betula pendula* Roth. and *B. pubescens* Ehrh., were studied.

MATERIALS AND METHODS

Origin of the sap

The sap was gathered during the flow seasons of 1983 and 1984 from the same birch trees growing in the Natural Park of Aulanko in central Finland

TABLE 2
Specification of the Birch Trees Tapped (Measured in 1983)

Tree	*Age (years)*	*Diameter (cm at a height of 1·3 m)*	*Height of the tree (m)*	*Height of the crown (m)*
Betula pendula				
pe-1	47	19	22	16
pe-2	45	21	22	15
pe-3	45	18	28	11
B. pubescens				
pu-1	40	17	18	11
pu-2	38	16	16	11
pu-3	52	17	17	10

(61°02′N, 24°28′E). Three individuals of the species *Betula pendula* Roth. (pe-1, pe-2, pe-3) and three of *B. pubescens* Ehrh. (pu-1, pu-2, pu-3) were chosen randomly for the study (Table 2). The growing site was Oxalis-Myrtillus-type forest land. The sap was collected at a height of 0·5 m, from holes 50 mm deep and 12 mm in diameter through teflon spiles in 4 ml polyethylene tubes, then frozen and stored at −20°C until analysed. In 1983 collection of the sap and measurement of the sap flow were performed at 8 am and 8 pm each day from April 6th to May 8th. In addition to this, gathering and measurements were carried out during 2-day periods (April 6–8 and April 25–27) at 3-h intervals (pe-1, pe-2, pu-1, pu-2). In 1984 the sampling was reduced, being performed only once a week at 8 am from April 9th to May 8th.

Analytical methods

The analyses of sugars were carried out by capillary-GLC as their TMS-derivatives as stated before (Kallio *et al.*, 1985*a*).

RESULTS AND DISCUSSION

The main sugars of birch sap: glucose, fructose, sucrose and galactose (Kallio *et al.*, 1985*a*) were determined quantitatively. The standard deviations of the method (including preparation of the sample and GLC-analysis) were, in the case of glucose, 2·8%, fructose, 4·4%, and sucrose, 2·6%.

The sap flow and the total yield of glucose and fructose in 1983 are summarized in 1-week periods in Table 3. The small volumes of sap are due to the young trees used in this study. Large trees, if they are vigorous and

TABLE 3
Sap Flow and Total Yields of Sugars in 1983

Tree	Volume of sap (litres/week)					Yield of sugars (g/week) Glucose					Fructose					g/5 weeks
	Ordinal of the week, from April 6th															
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
1983																
pe-1	11·7	10·8	26·6	21·3	3·2	31·4	53·4	97·5	86·5	14·1	31·2	46·6	77·3	69·5	12·8	520
pe-2	41·4	40·4	58·5	45·0	8·5	116·6	212·6	158·1	136·0	39·7	107·5	192·0	156·8	141·7	48·6	1 310
pe-3	9·1	12·6	26·3	20·8	3·3	16·6	37·1	63·4	66·2	31·5	11·2	25·5	45·0	49·5	27·2	370
pu-1	21·4	18·4	47·8	20·7	2·4	55·4	75·7	125·9	60·2	5·1	44·0	104·9	115·6	63·9	7·7	620
pu-2	13·3	14·7	36·9	30·9	4·4	24·6	47·9	84·0	93·0	26·9	25·3	47·9	79·0	90·6	32·2	550
pu-3	17·0	12·8	42·4	19·5	1·9	28·3	43·4	55·3	43·6	7·3	23·7	34·0	47·7	47·9	9·0	340
1984																
pe-1	15·1	30·2	74·6	55·4	15·1	46·3	106·6	236·4	212·5	3·6	39·2	98·3	195·1	178·6	2·9	1 120
pe-2	60·5	70·6	93·7	87·7	89·7	254·9	184·4	357·4	216·7	16·2	223·8	179·7	360·1	236·2	16·8	2 050
pe-3	10·1	16·1	60·5	48·4	33·3	56·0	54·7	281·3	148·7	4·6	45·6	46·0	198·3	124·2	4·3	960
pu-1	15·1	41·3	66·5	49·4		41·3	112·1	198·0	100·9		38·7	99·9	170·4	134·5		900
pu-2	23·2	28·2	43·3	54·4		58·6	76·1	133·9	132·3		48·8	63·3	137·8	114·3		770
pu-3	10·1	20·2	48·4	42·3		23·4	55·9	91·5	64·1		15·9	47·8	68·3	77·0		440

growing, give a much better yield. For example, one tree which was used for syrup production gave 74·5 litres of sap in a 24-h period during the maximal flow. Its trunk diameter at a height of 1·3 m was 0·7 m and age about 140 years. However, the size of the tree evidently does not influence the sugar content of the sap (Schroeder, 1877; Kok, 1977). The sap of *B. pendula* is said to contain more sugar than that of other birch species (Telishevskyj, 1970; Essiamah, 1980). Also in this study *B. pendula* gave a somewhat better sugar yield than *B. pubescens* and also the concentration of sugars was somewhat higher in the former. The whole work was based on about 750 individual measurements of the sugars. The variations during the flow seasons were very high, which made it pointless to calculate the means with deviations for single trees. Figures 1 (*B. pendula*) and 2 (*B. pubescens*) show the dynamic fluctuation of the sugar contents in sap during the two flow seasons. It has been demonstrated in several works that the content of sugars increases at the beginning and declines towards the end of the flow period (Schroeder, 1865; Schroeder, 1877; Richter, 1925; Lepeschkin, 1928; Johnson, 1944; Nordal, 1944; Orlov, 1963; Korolyak & Tomchuk, 1973; Kok *et al.*, 1978; Källman, 1982). The main sugars, glucose and fructose, had their maxima typically at the end of April or at the beginning of May. Fructose had its peak generally some days later than glucose. Sucrose showed the maximal values much earlier.

The highest total amounts of sugars (*B. pendula*) reached the level 10 g litre^{-1}. In some very late lots of the sap from *B. pubescens* the sugar content hardly reached 2 g litre^{-1}. In *B. pendula*, 50% of the samples contained glucose at least 3·2 g litre^{-1} and fructose 3·0 g litre^{-1}. The corresponding values in *B. pubescens* were 2·4 and 2·4 g litre^{-1}. The concentration of sucrose was always lower than that of glucose and fructose; in only 2% of the samples it exceeded the level of 0·5 g litre^{-1}. The lowest contents of glucose, fructose and sucrose were most often found towards the end of the season. Especially in 1983 the content of sucrose was very low at the end of April, but the following year the concentration was higher and showed wide variations. The typical disappearance of sucrose in birch sap in late spring had been observed earlier by Beveridge *et al.* (1978). Galactose existed in trace amounts; in only two single samples did it exceed 0·03 g litre^{-1}. The differences in the sap composition between the six trees, during two consecutive years, 1983 and 1984, are due to the very dissimilar weather conditions. The year 1983 was about 'normal', but the next spring was unusually warm throughout the whole country. The sum of the mean temperatures in 1984 from the beginning of April to the end of May was 6·1°C higher than in the long-term statistics. This led to the abnormal rapid break of the dormancy and to the development of the buds and thus to the early sugar liberation and consumption.

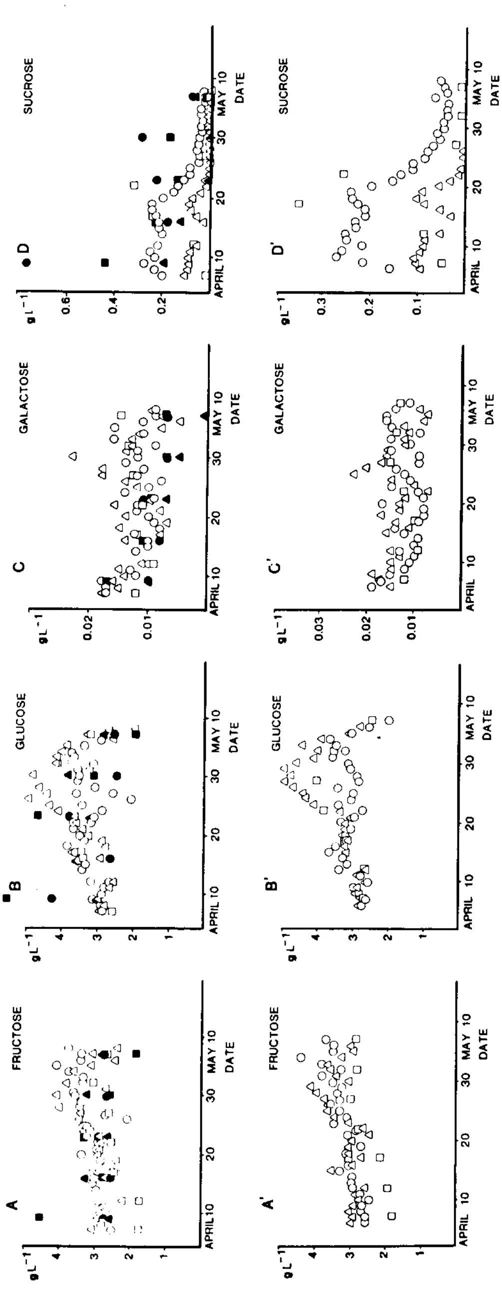

Fig. 1. Sugar contents in the sap of *B. pendula* in the morning (at 8 am, A–D) and in the evening (at 8 pm, A′–D′). Open symbols 1983, black symbols, 1984. Δ, pe-1; ○, pe-2; □, pe-3.

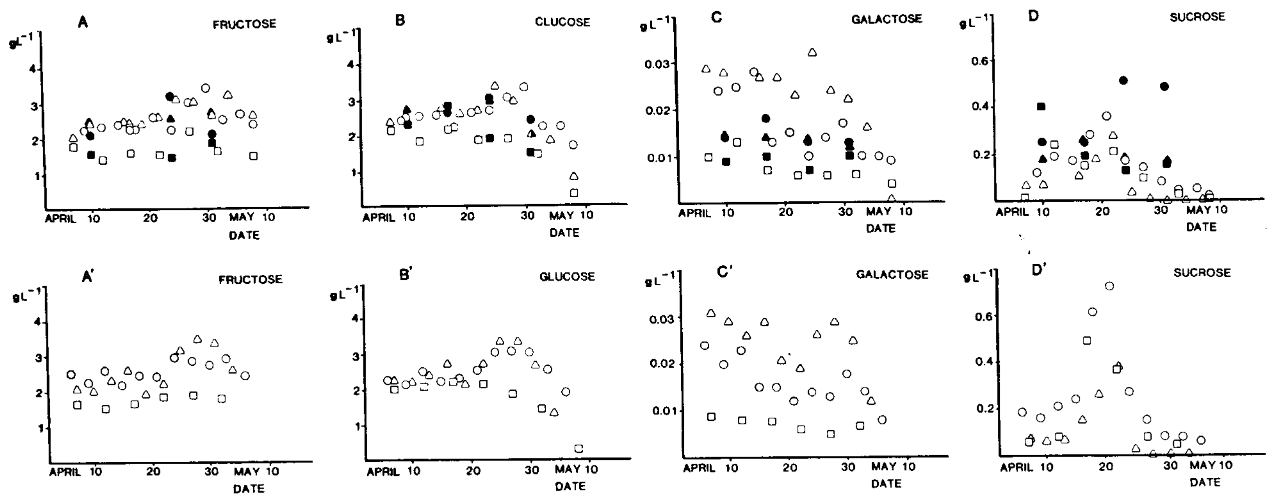

Fig. 2. Sugar contents in the sap of *B. pubescens* in the morning (at 8 am, A–D) and in the evening (at 8 pm, A′–D′). Open symbols 1983, black symbols, 1984. Δ, pu-1; ○, pu-2; □, pu-3.

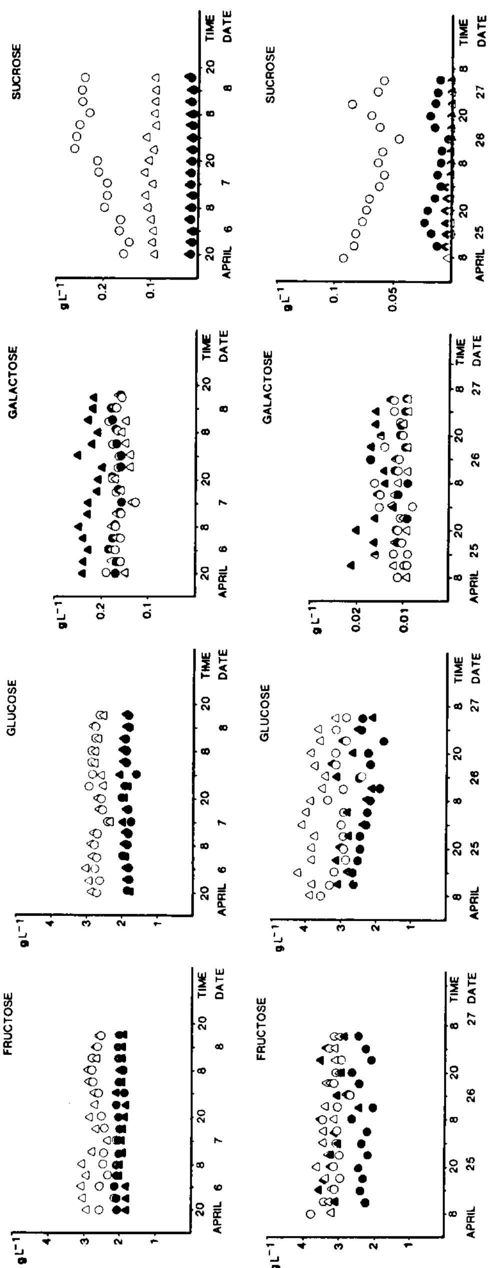

Fig. 3. Diurnal variations in the sugar content of birch sap in 1983. Δ, pe-1; ○, pe-2; ▲, pu-1; ●, pu-2.

The sugar contents of the diurnal samples taken at 3-h intervals are shown in Fig. 3. No statistically significant rhythm in the contents of sugars could be observed, but usually during the day the flow was faster. Especially glucose, fructose and galactose showed a linear pattern. The curve for sucrose was more irregular. Schroeder (1877) also observed no diurnal variation in the sugar content as a mean of several years' study. Hornberger's (1887) findings for sap collected from holes near the ground level were in agreement with this. In sap from holes drilled higher up in the trunk the sugar content was always higher in the morning than in the evening (Hornberger, 1887). This might depend primarily on the varying consumption of energy in the different parts of the tree, and on the asymmetrical distribution of lipid and starch reserves.

The linearity of the correlation between the contents of glucose and

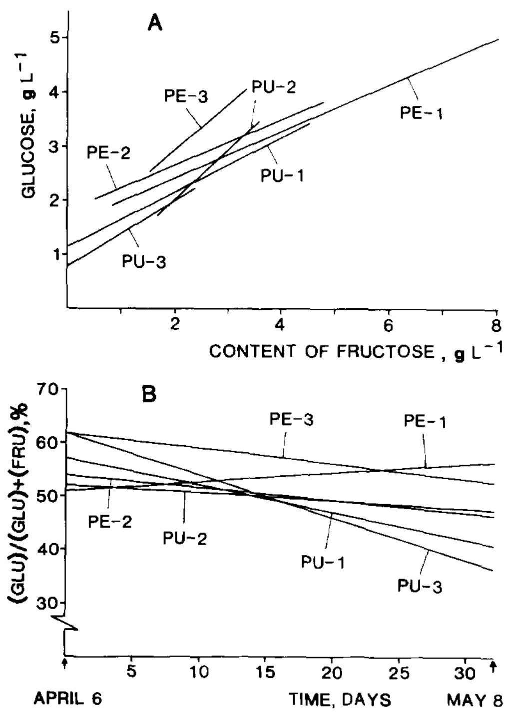

Fig. 4. A. Linear correlations between the contents of glucose and fructose in 1983. pe-1, $y = 0{\cdot}430\ x + 1{\cdot}551$ ($r = 0{\cdot}695$***); pe-2, $y = 0{\cdot}421\ x + 1{\cdot}798$ ($r = 0{\cdot}451$***); pe-3, $y = 0{\cdot}850\ x + 1{\cdot}196$ ($r = 0{\cdot}739$**); pu-1, $y = 0{\cdot}507\ x + 1{\cdot}133$ ($r = 0{\cdot}370$, ns); pu-2, $y = 0{\cdot}932\ x + 0{\cdot}124$ ($r = 0{\cdot}713$***); pu-3, $y = 0{\cdot}606\ x + 0{\cdot}786$ ($r = 0{\cdot}261$, ns). B. Dependence of the share of glucose (of the sum of glucose and fructose) on the moment in flow season in 1983. pe-1, $y = 1{\cdot}132\ x + 50{\cdot}898$ ($r = 0{\cdot}405$**); pe-2, $y = -0{\cdot}292\ x + 54{\cdot}076$ ($r = -0{\cdot}742$***); pe-3, $y = -0{\cdot}253\ x + 61{\cdot}160$ ($-0{\cdot}750$**); pu-1, $y = -539\ x + 56{\cdot}953$ ($r = -0{\cdot}698$***), pu-2, $y = -0{\cdot}152\ x + 51{\cdot}908$ ($r = -0{\cdot}481$*); pu-3, $y = -0{\cdot}796\ x + 61{\cdot}693$ ($r = -0{\cdot}734$***).

fructose in 1983 is presented in Figs 4A and 4B. The results show that the formation and consumption of glucose and fructose were controlled coordinatively. Variations between different trees were high, but the sugar may, however, be called 'invert sugar'. The content of glucose exceeded that of fructose when the level of both sugars was low (below 2 g $litre^{-1}$) (Fig. 4A). At the beginning of the one-month season in 1983 the share of glucose was about 50–60%, decreasing later by about 10 per cent units (Fig. 4B).

No correlation between glucose and sucrose or fructose and sucrose could be observed. This makes it possible to assume that sucrose is derived from the small starch reservoirs and the invert sugar from the lipid bodies existing mainly in the roots (Lepeschkin, 1928).

The highest sap flow was obtained on the third flow week, i.e. the last week of April (Table 3). The sugar peak fell during the same period, and more than one-third of the total sugar yield could be collected during that week; in some cases, even 50%.

ACKNOWLEDGEMENTS

The assistance of Ms Anne Ahlgren BS, Ms Anne Kankaanpää, BS, Mrs Katharina Jünger-Mannermaa, BS, Ms Tuija Teerinen, BS and Mr Timo Ylitalo, forest technician, in the collection of sap is acknowledged. The Ministry of Trade and Industry and Suomen Luonnonvarain Tutkimussäätiö (The Foundation for Research of Natural Reserves in Finland) are acknowledged for financial support.

REFERENCES

Beveridge, T., Bruce, K. & Kok, R. (1978). Carbohydrate and mineral composition of gray birch syrup. *J. Inst. Can. Sci. Technol. Aliment.* **11**, 28–30.

Brandes, R. (1837). Chemische Untersuchung des Birkensaftes. *Arch. Pharm.* **10**, 170–6.

Burström, H. & Krogh, A. (1946). The biochemistry of the development of buds in trees and the bleeding sap. *Kgl. Danske Vidensk. Selsk. Biol. Medd.* **22**(2), 1–27.

Essiamah, S. (1980). Spring sap of trees. *Ber. Deutsch. Bot. Ges.* **93**, 257–67.

Ganns, R. A., Zasada, J. C. & Phillips, C. (1982). Sap production of paper birch in the Tanana Valley, Alaska. *For. Chron.* **1**, 19–22.

Geisler, Dr. (1837). Zuckergehalt des Birkensaftes. *Arch. Pharm.* **10**, 167–70.

Holmberg, B. (1948). Zur Kenntis des Frühjahrsafts der Birke. *Ark. Kem. Miner. Geol.* **26B**(15), 1–6.

Hornberger, R. (1887). Beobachtungen über den Frühjahrssaft der Birke und der Hainbuche. *Forst. Blätter.* **128**, 321–36.

Johnson, L. P. V. (1944). Sugar production by white and yellow birches. *Can. J. Res.* **22(C)**, 1–6.

Kalinichenko, A. A. (1974). The sap productivity of some species of the birch. *Rastit. Resur.* **10**, 117–120.
Kallio, H., Ahtonen, S., Raulo, J. & Linko, R. (1985*a*). Identification of the sugars and acids in birch sap. *J. Food Sci.* **50**, 266–7, 269.
Kallio, H., Karppinen, T. & Holmbom, B. (1985*b*). Concentration of birch sap by reverse osmosis. *J. Food Sci.* **50**, 1330–2.
Källman, S. (1982). Preliminära analysdata för några vilda vaxter tidigare anväda som föda/nödföda i Sverige. Mindre beaktade nödfödoväxter. Del II. FOA rapport C54041-HI. Stockholm. 18 pp.
Kok, R. (1977). The production of birch syrup. *Maple Syrup J.*, Feb., 8.
Kok, R., Norris, E. R. & Beveridge, T. (1978). Production and properties of birch syrup (*Betula populifolia*). *Can. Agric. Engin.* **20**, 5–9.
Korolyak, I. S. & Tomchuk, R. I. (1973). Birch sap flow in relation to stem diameter, air temperature, date of tapping, and time of day. *Lesn. Zh.* **16**(6), 27–33.
Lenz, W. (1909). Über Birkensaft. *Ber. Deutsch. Pharm. Ges.* **19**, 332–43.
Lepeschkin, W. W. (1928). Untersuchungen über das Frühlingsbluten der Birke und des Ahorns. *Planta* **4**, 113–39.
Löhr, E. (1953). Die Zuckerarten im Blutungssaft von Betula und Carpinus. *Physiol. Plant.* **6**, 529–32.
Nordal, A. (1944). Tilskot til kjenneskapet av innhaldstoffa i bjørkesevje. *Medd. Norsk. Farmac. Selsk.* **6**(7), 159–68.
Orlov, I. I. (1963). Birch and maple sap. *Sverdlovskoje Knižnoje Izdatelstvo.* 40 pp.
Osypenko, Y. F. & Ryabchuk, V. P. (1975). Obtaining birch sap from stumps. *Lesn. Khoz.* **4**, 14–15.
Richter, K. (1925). Beiträge zur Chemie des Blutungs- oder Frühjahrssaftes einiger Gehölze. *Mitteil. Deutsch. Dendrol. Ges.* **35**, 138–46.
Schroeder, J. (1865). Ueber den Frühjahrssaft der Birke. *Jahresber. Agrikulturchem.* **8**, 157–69.
Schroeder, J. (1871). Die Frühjahrsperiode der Birke (*Betula alba* L.) und des Ahorn (*Acer platanoides* L.). *Lantw. Vers.-Stat.* **14**, 118–46.
Schroeder, J. (1877). Untersuchung der chemischen Constitution des Frühjahrssaftes der Birke, seiner Bildungsweise und weiteren Umvandlung bis zur Blattbildungsperiode. *Arch. Naturkunde Liv-, Ehst- and Kurlands* (*II*) **VII**, 1–82.
Telishevskyj, D. (1970). Collection and use of birch sap. *Lesn. Khoz.* **6**, 80–2.