Chemical Composition of Silver Birch (*Betula pendula* Roth.) and Downy Birch (*Betula pubescens* Ehrh.) Sap

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Abstract

The unmixed silver birch (*Betula pendula* Roth) and downy birch (*Betula pubescens* Ehrh.) stands were chosen in the Middle Lithuania for the purposes of this research. Chemical composition of fresh birch tree sap was determined right after collection of samples. The first sampling was done at the beginning of sap exudation and the second one at the stage of the most intensive sap exudation. Concentrations of sugars in sap of *Betula pendula* and *Betula pubescens* trees growing on temporarily overmoistured soil (Lcp) were higher at the beginning of sap exudation. Sap of *Betula pubescens* was sweeter than *Betula pendula* (2.4 % sugars). Level of ascorbic acid (7.0 mg 100 g^{-1}) in *Betula pendula* sap did not change during the sap exudation period, while in *Betula pubescens* sap it increased by 10.0 % at the stage of the most intensive sap exudation. During the same stage the total concentration of sugars in sap of *Betula pendula* trees growing on the light soil of normal humidity (Ncl) rose by 10 %. Higher concentrations of sugars were determined in sap of birch trees growing on more humid soils: 2.0 % at the beginning and 1.9 % at the later stage of sap exudation period. The highest content of soluble solids was determined in sap collected from the *Betula pendula* trees growing on temporarily overmoistured soil (Lcp). Soil type and sap sampling time had no effect on the content of ascorbic acid in *Betula pendula* sap. The mineral composition of sap improved significantly at the stage of the most intensive sap exudation. The sap of *Betula pendula* and *Betula pubescens* contained 80.4 and 60.0 mg kg^{-1} potassium and 74.3 and 57.7 mg kg^{-1} calcium, respectively. These two elements constituted the major part of the total amount of measured macro- and microelements. *Betula pendula* sap contains larger amounts of mineral elements than the sap of *Betula pubescens* irrespective of soil type and sap sampling time.

Keywords: *Betula pendula*, *Betula pubescens*, birch sap chemical compounds, mineral composition.

Introduction

In recent years many of Lithuanian state forestry divisions and private forest owners became aware of the fact that growing of birch in Lithuania is becoming an important and economically profitable forestry activity. Productivity of birch stands is lower compared to that of spruce stands, yet the birch tree is growing the first decades, therefore in many countries (e.g. Sweden, Finland, Latvia, Estonia, Germany etc.) birch trees are considered to be the most suitable for afforestation of lands, which ceased to be under agricultural crops; birch trees are often favoured more than other tree kinds from aesthetical point of view as well (Elfving 1986, Karlsson 1994).

Data obtained from the national forest stocktaking activities carried out in Lithuania in 2014 suggest that birch stands cover 459.7 thousand ha and make up 22.4 % of the total forest area (Lithuanian forestry statistics 2014). Four species of birch grow naturally in Lithuania, two of them – silver birch (*Betula pendula* Roth) and downy birch (*Betula pubescens* Ehrh.) – make major part of birch stands (Navasaitis et al. 2003, Navasaitis 2004). The aforementioned two birch species are similar to each other in their external features as well as in wide ecological plasticity (Данченко 1990), but the productivity and marketability of their stands is different (Atkinson 1992). Silver birch stands are better in shape and quality (Hynynen et al. 2010, Nieuwenhuis and Barret 2002), the average productivity of silver birch stands (especially of the ones growing on mineral soils) is by 15–20 % higher compared to the downy birch stands. The quality of the silver birch stem is better as well. On the other hand, the ecological plasticity of downy birch is wider (Koski 1991, Bareika and Ozolinčius 2009).

Since the number of studies conducted in Lithuania on biology, ecology, selection and productivity of silver birch and downy birch is small, it is difficult to compare the specific features of these two birch species. New techniques for identification of the aforementioned birch species were developed only recently; they are based on the results of birch inner bark treatment with 2,4-dinitrophenylhydrazine (Lundgren et al. 1995) and on the complex assessment of the most important morphological features (Bareika and Ozolinčius 2006a, b, Bareika et al. 2007, Bareika 2012). Special attention is given to the studies on occurrence and heterogeneity of mixed stands of downy birch and silver birch. Silver birch is a typical mesophyte, i.e. it prefers moderately humid growing conditions, while downy birch is a mesohygrophyte (i.e. prefers sub-humid growing conditions) and is more tolerant of less fertile acid marshy soils (Perala and Alm 1990, Ellenberg et al. 1991, Navasaitis et al. 2003, Navasaitis 2004). However, both species share the same natural occurrence area and are found in a wide range of different habitats (Scholz 1972, Endtmann 2004, Schneck and Naujoks 1998, Michaelis 1998).

The chemical analyses data suggest that silver birch inner bark contains high levels of glucosides (20–60 mg/g dry matter), while the amounts of glucosides in the inner bark of downy birch are very low (<0.5 mg/g dry matter) (Lundgren et al. 1995). Based on these results it can be assumed that the levels of glucosides in wood and sap of silver birch tree are higher than those in wood and sap of downy birch tree. Birch trees begin to exude the sap in early spring, when daily average air temperature reaches + 4... + 6 ºC and leaf buds begin to swell. Birch tapping can last till the end of April (until the leaves are fully expanded). Birch tree sap flow intensity and its chemical composition depend (among other factors) on the time of day (Harju and Huldén 1990). The best time range for collecting the birch tree sap is between 12 p.m. and 6 p.m., when the sap flow is more intensive. Ever more countries consider the birch tree sap to be beneficial to human health. The researchers from the northern countries conducted studies on the chemical composition of birch tree sap, the mechanisms of sap exudation and medicinal benefits of birch tree sap; their findings revealed the nutritional and medicinal value of this product (Drozdova et. al. 1995, Shen et al. 2001, Patzold and Bruckner 2005). Birch tree sap is considered to be a valuable food ingredient in Denmark, Sweden, Finland and Norway; it is used in production of different food products and beverages, in earlier days it was used in production of cheese with an aim to protect the product from pests. It is stated that silver birch tree exudes lesser amounts of sap, yet it is sweeter than downy birch tree sap and therefore preferred by the consumers (Svanberg et al. 2012). It was noticed that sap is sweeter after dry summer and cold winter (Maher et al. 2005). Glucose and fructose constitute the major part of sugars present in birch tree sap (Zyryanova et al. 2010). The sap is rich in mineral micro- and macroelements: calcium (Ca), sodium (Na), magnesium (Mg), potassium (K) and iron (Fe) are prevailing elements followed by small amounts of Mn, Zn, Cu, Al and Ni (Zyryanova et al. 2010, Jeong et al., 2013). Chemical composition of birch tree sap depends on the stage of exudation period (Kallio and Ahtonen 1987a). The levels of malic, citric, phosphoric and succinic acids in sap are the highest at the stage of the most intensive sap exudation; they decrease substantially, when leaf buds break. As regards the levels of sugars in sap, the tendency is exactly opposite to the acids (Kallio and Ahtonen 1987b).

Results obtained from the studies conducted in Lithuania confirmed that the species of birch differ from each other in phenotype (Bareika and Ozolinčius 2006a, Bareika et al. 2007, Bareika 2012, Bareika et al. 2013a), phenology (Bareika and Ozolinčius 2007, 2009a, 2009, Bareika 2013b), ecological occurrence, productivity and wood quality (Bareika and Ozolinčius 2009). Study on sap of different birch species as one of the valuable products was not carried out in Lithuania. There are some data accumulated from the episodical tests on quality of sap obtained from stands of mixed birch species (Viškelis and Rubinskienė 2011). Aim of this research was to assess the biochemical and chemical properties of sap obtained from silver birch (*Betula pendula* Roth) and downy birch (*Betula pubescens* Ehrh.) trees growing on different types of soil.

Materials and Methods

Raw material. During the research on birch tree sap field work, sampling and collection were conducted in 2013. The unmixed silver birch (*Betula pendula* Roth) and downy birch (*Betula pubescens* Ehrh.) 50-60 years old in four of stands were chosen in the Middle Lithuania (Kaunas district) for research purposes. Three plots (in N and L hydrotopes and c trophotope) were selected in the chosen stands (latitude - 54°50; 51´ N; longitude - 24°02; 03´ E) (Table 1). Sap samples were collected on 17-29 of April at the beginning of sap exudation and at the stage of the most intensive sap exudation. One hole (diameter 2 cm) was drilled in each selected tree at 55 cm height above the soil surface.

The research was conducted in representative stands of silver birch and downy birch (Table 1). Five dominant sample trees of class A (after L. Kairiūkštis 1958, 1979),

Table 1. Common characteristics of birch stands, in which qualitative analyses of birch tree sap were performed, site types and soil properties (Dubrava EMMU, Vaišvydava forestry division)

No.	Birch species and stand origin	Age, year	Forest type	Number of model trees	Site type	Soil type	Soil properties
1.	*B.pubescens*, spontaneous	55	*m-ox**	5	Lcp	Endocalcari-Endohypogleyic Cambisols CMg-n-w-can	Temporarily overmoistured soils, fertile, binary soils (sandy loam or sand on clay or loam lying deeper than 50 cm)
2.	*B. pendula*, spontaneous	60	*m-ox**	5	Lcp	Endocalcari-Endohypogleyic Cambisols CMg-n-w-can	
3.	*B. pendula*, spontaneous	53	*ox***	5	Ncl	Epidystri-Cambic Arenosols ARb-dye	Mineral soils of normal humidity, fertile, light (sand, sandy-loam)
	Total			15			

**m-ox myrtillo-oxalidosa* forest type; ***ox oxalidos*a forest type

or class II (after G. Kraft 1884), were selected in each plot using systemic principle (trees closest to the centre of the plot). In total 15 sample tree were selected for the research − 10 trees of silver and 5 trees of downy birch. The species of birch tree was identified using chemical method based on the birch inner bark treatment with 2.4-dinitrophenylhydrazine (Lundgren et al. 1995).

Determination of chemical compounds. Chemical composition of fresh birch tree sap was determined right after collection of samples at the beginning of sap exudation and at the stage of the most intensive sap exudation. Birch sap samples were analysed at the Laboratory of Biochemistry and Technology, Institute of Horticulture LAMMC. Ascorbic acid content in sap was measured using titration with 2,6-dichlorphenolindophenol sodium chloride solution (AOAC 1990 a); amount of soluble solids was detected refractometrically using ATAGO PR-32 digital refractometer (Atago Co. Ltd., Tokyo, Japan). Monosaccharides and sucrose content in sap was determined by Bertrand method (AOAC 1990 b).

Determination of macro- and microelements. Birch tree sap samples were analysed for macro- and microelements at the Agrochemical Research Laboratory. Potassium (K) content in sap was determined by flame photometry with Jenway PFP7 (Bibby Scientific Limited, Staffordshire, UK), content of calcium (Ca), magnesium (Mg), zinc (Zn), manganese (Mn) and iron (Fe) was detected by atomic absorption spectrophotometry (AAnalyst 200, Perkin Elmer precisely, Waltham, USA).

Birch tree sap samples were analysed for heavy metal content. Sap samples were kept in refrigerator at approximately 4 °C. The test tube was placed in sand bath and the mineralization of heavy metals in aqua regia (10.5 ml HCl and 3.5 ml HNO_3) was carried out at 160 °C for 4 hours. The cooled down sample was diluted to the test tube mark with analysis water, shook well and filtered through blue band filter paper. The filtrate was analysed with atomic emission spectrometer (Perkin Elmer Optima 2100 DV) aided with computer using software package WinLab 32™ for ICP, V 3.3.1., Windows 2000 and XP operating systems, and equipped with automatic sample injection system in accordance with LST EN ISO 11885:2009.

Calculations. Chemical composition tests were performed in triplicate. Results were presented as the averages of 3 measurements with the standard errors of the means. Statistical processing of results was carried out using *MS Excel* and software package *SELEKCIJA* (Tarakanovas and Raudonius 2003).

Results

Results of the chemical composition tests performed on the samples of sap collected from silver birch (*Betula pendula*) and downy birch (*Betula pubescens*) trees growing on temporarily overmoistured soil (Lcp) are presented in Figures 1 and 2. Amounts of monosaccharides and sucrose in sap and their ratio depended on the sap sampling time (Figure 1). The levels of sugars in sap of both birch species were higher at the beginning of sap exudation; sap of *Betula pubescens* was sweeter, it contained 2.4 ± 0.13 % of sugars. The concentration of sugars in sap collected at the stage of the most intensive sap exudation decreased by 5.4 % in *Betula pendula* sap and by 36.3 % in *Betula pubescens* sap. The ratio of monosaccharides and sucrose in *Betula pendula* sap remained almost unchanged − 4.0 and 3.9, respectively, while the concentration of sucrose in *Betula pubescens* sap decreased by 38.2 %, therefore the ratio of monosaccharides and sucrose rose from 1.4 to 1.5.

Higher levels of soluble solids in sap of both birch species were determined at the beginning of sap exudation (Figure 2). The content of soluble solids in sap collected at the stage of the most intensive sap exudation decreased by 0.24 % in *Betula pendula* sap and by 0.2 % in *Betula pubescens* sap. At the beginning of sap exudation *Betula pendula* sap contained 7.0 ± 0.38 mg 100 g^{-1} ascorbic acid – by 12.0 % more than the sap of *Betula pubescens* (Figure 2). Yet at the stage of the most intensive sap exudation the concentration of ascorbic acid in *Betula pubescens* sap increased significantly – by 10.0 %, while in *Betula pendula* sap it decreased by 2 %.

Content of sugars in *Betula pendula* sap collected from the trees growing on temporarily overmoistured soil (Lcp) and on light soil of normal humidity (Ncl) is presented in Figure 3. The data obtained from our research suggest that irrespective of the sap sampling time, the levels of monosaccharides and sucrose in *Betula pendula* sap collected from the trees growing on more humid soil were higher than those determined in sap of trees growing on soil of normal humidity. On the other hand, sap sampling time affected the sweetness of *Betula pendula* sap. Sap collected from the trees growing on overmoistured soil (Lcp) was sweeter at the beginning of sap exudation than at the stage of the most intensive sap exudation (content of sugars decreased by 5 %), while the sap collected from the trees growing on soil of normal humidity (Ncl) was by 10 % (content of sucrose increased by 25 %) sweeter at the stage of the most intensive sap exudation than at the beginning of sap exudation (Figure 3).

The highest content of soluble solids was determined in sap collected from the silver birch trees growing on temporarily overmoistured soil (Lcp) (Figure 4). Differently than in case of trees growing on soil of normal humidity (Ncl), at the stage of the most intensive sap exudation the concentration of soluble solids in sap of birch trees growing on Lcp soil decreased by 21.0 %. As regards the ascorbic acid content in silver birch sap collected from the trees growing on different types of soil, no significant differences were recorded; the most noticeable was a 5 % decrease in sap collected from the trees growing on light Ncl soil at the stage of the most intensive sap exudation (Figure 4).

Birch tree sap samples were tested for the levels of six macro- and microelements (Figures 5, 6). The samples were collected from the *Betula pendula* trees growing on the light soil of normal humidity (Ncl) (Figure 5). Higher levels of macro- and microelements were determined in sap collected at the stage of the most intensive sap exuda-

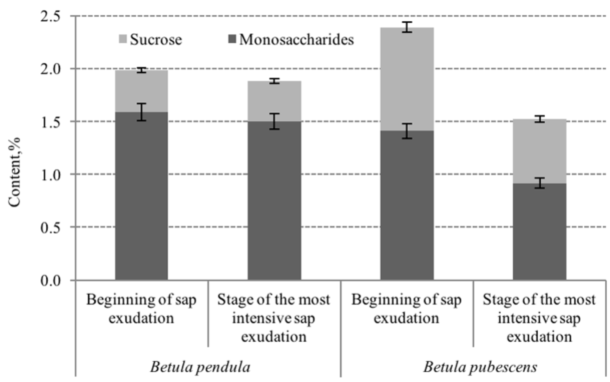


Figure 1. Content of sugars in fresh sap of *Betula pendula* Roth and *Betula pubescens* Ehrh. (site type: Lcp, temporarily overmoisted)

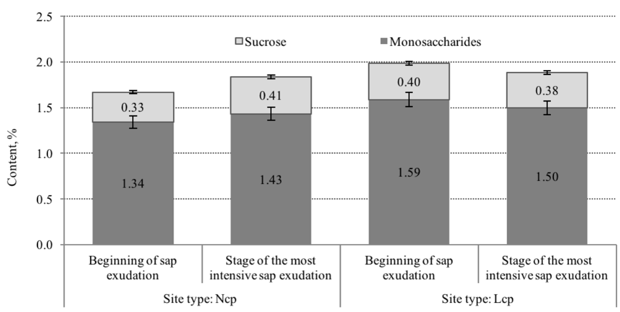


Figure 3. Sugar content in fresh sap of *Betula pendula* (site type: Ncp, of normal humidity; site type: Lcp, temporarily overmoisted)

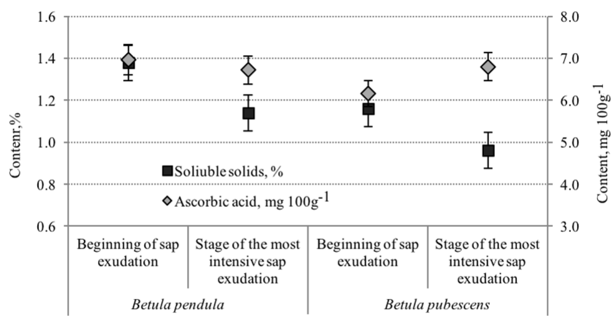


Figure 2. Content of soluble solids and ascorbic acid in fresh sap of *Betula pendula* Roth and *Betula pubescens* Ehrh. (site type: Lcp, temporarily overmoisted)

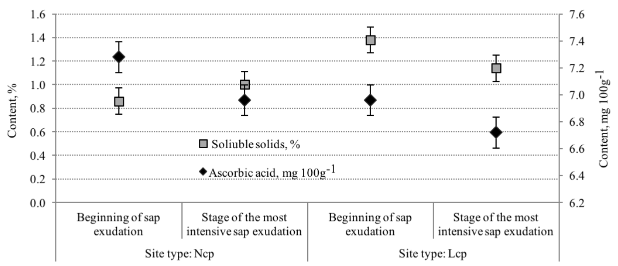
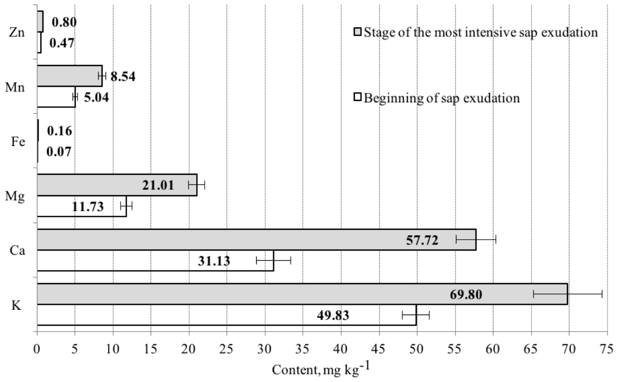
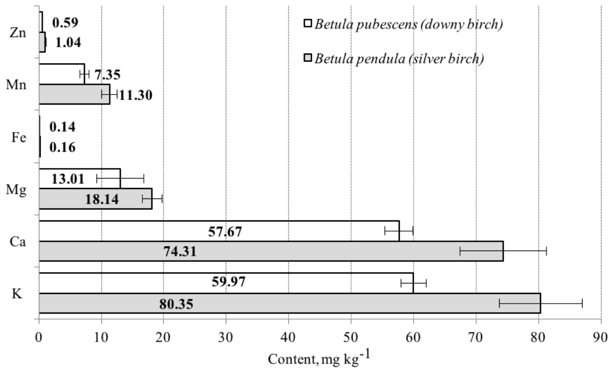


Figure 4. Content of soluble solids and ascorbic acid in fresh sap of *Betula pendula* (site type: Ncp, of normal humidity; site type: Lcp, temporarily over moisted)



Note. Values are significantly different ($p \leq 0.05$) by *Student's t*-test

Figure 5. Content of macro- and microelements in fresh sap of *Betula pendula* (site type: Ncl, of normal humidity)



Note. Values are significantly different by *Student's t*-test ($p \leq 0.05$)

Figure 6. Content of macro- and microelements in fresh sap of *Betula pendula* and *Betula pubescens* (site type: Lcp, temporarily over moisted, stage of the most intensive sap exudation)

tion: concentration of iron (Fe) increased by 2.4 times, calcium (Ca) and magnesium (Mg) by 1.8 times, zinc (Zn) and manganese (Mn) by 1.7 times and potassium (K) by 1.4 times. The sap contained 69.8±17.5 mg kg^{-1} potassium (K), 57.7±9.99 mg kg^{-1} calcium (Ca), 21.0±4.14 mg kg^{-1} magnesium (Mg) and 8.5±1.82 mg kg^{-1} manganese (Mn) followed by zinc and iron.

Differences between the levels of macro- and microelements determined in *Betula pendula* and *Betula pubescens* sap samples collected from the trees growing on temporarily overmoistured soil (Lcp) at the stage of the most intensive sap exudation were statistically significant (Figure 6). The sap of *Betula pendula* and *Betula pubescens* contained 80.4 ± 20.5 and 60.0 ± 7.84 mg kg^{-1} potassium and 74.3 ± 22.81 and 57.7 ± 8.67 mg kg^{-1} calcium, respectively. These two elements constituted the major part of the total amount of macro- and microelements measured in sap samples. Sap of *Betula pendula* contained higher levels of elements than that of *Betula pubescens*: potassium and calcium by 1.3 times, magnesium by 1.4 times, manganese by 1.5 times, zinc by 1.8 times. Data obtained from our research suggest that *Betula pendula* sap contains larger amounts of mineral elements than the sap of *Betula pubescens* irrespective of soil type and sap sampling time (Figures 5, 6).

Discussion

Content of sugars, vitamins and minerals in birch tree sap is affected by many factors, therefore we assume that our research provided us only with preliminary data on the chemical and mineral composition of sap obtained from the birch trees growing in Lithuania. It was noticed, for example, that the levels of sugars in birch tree sap are affected by the time of day, stage of sap exudation period (beginning / end), size and age of the tree, soil fertility, climatic conditions and even the changes in composition of atmospheric gases (Kriebel 1990, Larochelle 1998, Łuczaj et al. 2014). The largest part of sugars present in the sap of birch tree is invert sugar (differently from the maple tree sap composition) consisting of 50 % fructose and 45 % glucose (Helfferich 2003). The concentration of glucose and fructose depends on the stage of sap exudation period: it is lower at the beginning, and at the end of sap exudation period it increases by 1.4 times (Zyryanova et al. 2010). Silver birch (*Betula pendula*) sap contains approximately 2.14 % monosacharides (1.21 % is fructose) (Łuczaj et al. 2014). The data obtained from our research suggest that fructose and glucose levels in sap obtained from the *Betula pendula* trees growing in Lithuania are lower (1.34−1.59 %, depending on the soil type and the stage of sap exudation period). On the other hand, sucrose levels (up to 0.40 %) in sap of birch trees growing in Lithuania are higher than those determined in other territories (Viškelis and Rubinskienė 2011). There is an assumption that content of sugars in birch tree sap depends on the soil / site type and the sap of trees growing on drier soil is sweeter (Helfferich 2003). In our research, it has been noticed that at the beginning of sap exudation period the sap of *Betula pubescens* Ehrh. trees was sweeter even when they grew on temporarily overmoistured soil, and the ratio of different sugars was similar to the one determined by the researchers from Northern Europe (Kallio et al. 1985, Kallio and Ahtonen 1987, Kallio et al. 1989, Taghiltsev and Kolesnikova 2000, Zyryanova 2010).

Flavour of birch tree sap is brisk; the taste is not sweet, sour or bitter. Thanks to the balanced amounts of nutrients, the birch tree sap is a perfect beverage; it is valued for the minerals it contains – researchers reasonably reckon it among the mineralised beverages. The major mineral elements found in birch tree sap are potassium, magnesium and calcium. Other elements are present only in small quantities. It is stated that calcium and magnesium together with microelements (e.g. zinc) are attributed to the group of the most important nutrients. They are essential for performing various physiological functions: moving, digesting, production of energy etc. Unfortunately, we do not get enough minerals in our diet, therefore particular attention is given to the products valued for their mineral composition (El-Naggar et al. 2014). We have measured the levels of nine macro- and microelements in the sap of birch trees growing in Lithuania in our previous research (Viškelis and Rubinskienė 2011). Level of potassium in sap was the highest (115 mg kg^{-1}), followed by calcium (56.5 mg kg^{-1}), magnesium (22.0 mg kg^{-1}), sodium (14.5 mg kg^{-1}), zinc, manganese, iron, copper and chrome (Viškelis and Rubinskienė 2011). Data obtained by Latvian researchers supported the results of our research, yet the levels of calcium in sap obtained from the *Betula pendula* trees growing in Latvia were higher than the levels of potassium. Levels of manganese were the highest among the microelements measured in the sap (Kūka et al. 2013). In our research we have assessed the mineral composition of birch tree sap collected from the trees of two different birch species growing on two different types of soil. Levels of six macro- and microelements in sap were measured (Figures 5, 6). Significant differences were observed between the mineral compositions of sap samples collected in different stages of sap exudation period from the *Betula pendula* trees growing on the light soil of normal humidity (Ncl). The mineral composition of sap improved significantly at the stage of the most intensive sap exudation (22-29 of April). On the other hand, the variations of value changes differed. Somewhat larger variation in the mineral composition of sap was recorded at the beginning of sap exudation. The highest coefficient of variation (*CV*) was calculated for magnesium (25.5 %), followed by iron (24.5), manganese (23.5 %), calcium (20.8 %), potassium (13.8 %) and zinc (8.7 %).

Conclusions

1. Levels of sugars in sap of *Betula pendula* and *Betula pubescens* trees growing on temporarily overmoistured soil (Lcp) were higher at the beginning of sap exudation; sap of *Betula pubescens* was sweeter (2.4±0.13 % sugars). Level of sucrose in *Betula pubescens* sap decreased significantly at the stage of the most intensive sap exudation. The ratio of different carbohydrates increased to 1.5.

2. Levels of soluble solids in sap of *Betula pendula* and *Betula pubescens* trees growing on temporarily overmoistured soil (Lcp) were higher at the beginning of sap exudation. Level of ascorbic acid (7.0±0.38 mg 100 g^{-1}) in *Betula pendula* sap changed insignificantly during the sap exudation period. At the stage of the most intensive sap exudation the concentration of ascorbic acid in *Betula pubescens* sap increased by 10.0 % and reached the level found in *Betula pendula* sap.

3. During the sap exudation period the total concentration of monosacharides and sucrose in sap of *Betula pendula* trees growing on temporarily overmoistured soil decreased, yet remained higher than that determined in sap of trees growing on the light soil of normal humidity (Ncl), even though the latter rose by 10 % (content of sucrose increased by 25 %) at the stage of the most intensive sap exudation.

4. The highest content of soluble solids was determined in sap collected from the *Betula pendula* trees growing on temporarily overmoistured soil (Lcp). Soil type and sap sampling time had no effect on the content of ascorbic acid in *Betula pendula* sap.

5. Mineral composition of sap improved significantly at the stage of the most intensive sap exudation, yet the variations of value changes differed. Somewhat larger variation in the mineral composition of sap was recorded at the beginning of sap exudation. The highest coefficient of variation (*CV*) was calculated for magnesium (25.5 %), followed by iron (24.5), manganese (23.5 %), calcium (20.8 %), potassium (13.8 %) and zinc (8.7 %).

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