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ANALYSIS OF CONTENTS OF SUGARS AND HEALTH-PROMOTING SUBSTANCES IN THE SAP OF SYCAMORE MAPLE *ACER PSEUDOPLATANUS* L. IN THE NOTEĆ FOREST

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ABSTRACT

The growing popularity of tree sap based products stems from the presumed health-promoting properties of this raw material. Moreover, the maple syrup market, dominated by Canada, is recording a steady increase in the size and value of production. The study attempted to expand knowledge regarding contents of sugars and health-promoting substances in the sap of sycamore maple *Acer pseudoplatanus* L. growing in the Promotional Forest Complex "Noteć Forest". Sap was collected in the period 5–8.03.2022 and analyses were conducted for individual compounds in the following groups: sugars, antioxidants, preservatives, and mineral compounds. Low contents of sugars and health-promoting substances were found, indicating that the study area may not be suitable for the economic use of sycamore sap. In addition, an elevated level of manganese was recorded, which may have negative effects on human health with sycamore sap regular consumption.

Keywords: sugars, F-AAS, HPLC, sycamore, preservatives, antioxidants, health-promoting substances, mineral compounds

INTRODUCTION

Maple syrup is one of the most widely recognized products based on tree sap. Canada is the largest producer of this natural sweetener, with annual production of about 75,000 tons of syrup worth about $400 million (Horticulture..., 2022). The key raw material in the product is maple sap, which is further concentrated and purified.

Tree sap is also collected in European countries, particularly Ukraine and Belarus. It is also valued in Asia (Bilek et al., 2015a; Hinrichs, 1998). In Poland the tradition of harvesting tree sap is limited primarily to the sap of silver birch, *Betula pendula* L. However, it should be noted that in our country birch is not the only species from which this raw material can be extracted (Bilek et al., 2016).

The sap was attributed extensive health-promoting properties. Traditionally it was believed to treat urinary tract diseases, eliminate freckles, or improve metabolism (Baraniak and Kania-Dobrowolska, 2019; Grochowski, 1990; Kostron, 1974). The belief in its

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salutary effects on health persists to this day. Today, it is often advertised as a detoxifying remedy or a weight loss aid (Grabowska, 2022). In recent years, tree sap-based products are gaining in popularity, primarily for alleviating gastrointestinal problems (Bilek et al., 2015b). Despite the growing consumption of tree sap-based products, their health-promoting properties are still insufficiently researched.

The following study aims to expand knowledge on tree sap in Poland using sycamore *Acer pseudoplatanus* L. from the "Noteć Forest" Promotional Forest Complex in the Wielkopolska voivodeship as a case study. The sap was evaluated for its contents of sugars and health-promoting substances, while at the same time assessing the potential of the area of the PFC "Noteć Forest" to start the economic use of this product.

METHODS

Site characteristics and tree selection

The "Noteć Forest" Promotional Forest Complex is a compact complex with a total forested area of over 129,000 hectares. The vast majority – approximately 90% of the site – Is covered by a continuous forest complex of over 116,000 ha (Biuro..., 2021). For the preliminary site assessment, stands within the Oborniki Forest District and the Regional Directorate of the State Forests in Poznań were selected. The selected divisions are characterized by a sycamore share of less than 5%. Study plots were chosen in three forest habitat types: fresh mixed coniferous forest (BMśw), fresh mixed broadleaved forest (LMśw), and moist broadleaved forest (Lw), which are characterized by increasing site fertility.

In each plot three trees were selected, each characterized by good health, a full and symmetrical crown, and located away from the plot edges. Trees were marked temporarily, their diameter at breast height (DBH) was measured using the Haglöf Mantax Blue 50 cm accurate to 1 mm rounded to 1 cm (error not declared by the manufacturer), and tree height was measured using the Suunto PM-5/360 PC clinometer accurate to 1 m (declared error: 0.25°– approximately 0.1 m). The following sycamores were selected:

- BMśw – division 701-b
  64 years old trees were selected, with an average breast height diameter of 34 cm (46 cm, 33 cm, 24 cm, respectively) and an average height of 18 m (20 m, 15 m, 18 m, respectively)
- LMśw – division 403A-g
  59 years old trees were selected, with an average breast height diameter of 28 cm (18 cm, 27 cm, 39 cm, respectively) and an average height of 18 m (15 m, 16 m, 25 m, respectively)
- Lw – division 403A-a
  106 years old trees were selected, with an average breast height diameter of 37 cm (32 cm, 35 cm, 45 cm, respectively) and an average height of 23 m (22 m, 20 m, 26 m, respectively).

Sample collection and preparation

On 2.03.2022, even before the sap started flowing, gutter cuts on the south side of the trunks were made with an axe at a 45° angle, 1 m above the ground. It should be noted that another method of trunk drilling is possible, but it was rejected so as not to create conditions promoting unnecessary fungal development (Fay and Berker, 2018). About 1 cm below the lower end of the incision, a sharpened and disinfected copper pipe was inserted. The sap began to exude on 5.03.2022, and sample collection began on the same day, continuing until 8.03.2022.

For sample collection, falcon-type tubes were attached to the spouts, into which approximately 50 ml of sap was collected. After collecting material from all three trees at a given plot, the samples were mixed in equal proportions and divided into four tubes corresponding to the respective analyses. The samples prepared in this way were frozen in dry ice within 15 minutes of collection. In the frozen state they were stored until analysis, which was conducted within one hour of thawing. Prior to each analysis, the samples were filtered through medium mesh size strainers.

Analysis of sap components

Contents of glucose, fructose, sucrose, citric acid, and malic acid were determined using an Agilent Technologies 1200 series liquid chromatograph (HPLC) (USA) equipped with an automatic sample feeder (G1329B), a pump (G1312B), and refractometric detector (G1362A). Citric acid was additionally detected using a DAD detector (G1315C) with a spectral sweep of 190–400 nm, monitored at 210 nm. A Rezex ROA 300 × 7.80 mm column (Phenomenex) was used for

the determinations. Eluents were H_2SO_4 solutions: 2.50 mM for glucose, sucrose, and citric acid, and 0.34 mM for fructose and malic acid, delivered isocratically at a flow rate of 0.6 ml/min. Analyses were carried out at 40°C and samples were applied to the column in 10 µl amounts. Qualitative and quantitative identifications were performed using an external standard method (measurement and computer integration were performed using ChemStation for LC 3D systems, Agilent).

The content of phenolic compounds was determined using an Agilent 1260 Infinity II liquid chromatograph (HPLC; Agilent Technologies, Inc., Santa Clara, CA, USA) equipped with an automatic sample feeder (G7129A), a pump (G7111A) and a detector (G7115A) with spectral overview (190–400 nm). The determination of vanillin and p-hydroxybenzoic acid was carried out in the 280 nm band; p-coumaric, synapic and ferulic acids in the 320 nm band; rutin in the 360 nm band; niacin in the 260 nm band; and chlorogenic acid in the 255 nm. A 50 mm × 4.6 mm SB-C18 column (Agilent Technologies) was used for the determinations. A methanol:acetic acid solution (98:2 v/v) was used as eluent at a flow rate of 0.75 ml/min, gradient: 0 min 2%, 22 min 40%, 26 min 40%, 28 min 100%, 35 min 100%, and 36 min 2%. Analyses were carried out at 25°C. Samples were applied to the column at 10 µl. Qualitative and quantitative identification was performed (measurement and computer integration performed using the OpenLab CDS, Agilent Technologies, Inc., Santa Clara, CA, USA) using peak areas (Kowalczewski et al., 2021).

Contents of mineral compounds – calcium, copper, iron, potassium, magnesium, manganese, sodium, and zinc – were determined using flame atomic absorption spectrometry (F-AAS, SpectrAA-800, Varian, USA) preceded by mineralization with nitric acid (Rybicka and Gliszczyńska-Swiglo, 2017).

Statistical analyses were conducted using the R version 4.5.1 (R Core Team, 2025) and the RStudio version 2025.09.0 + 387. For ordinal data (forest habitat type) the Kruskal-Wallis test (base R function) was applied. For interval-scale data normality was first assessed using the Shapiro-Wilk test (base R function). Observations meeting the assumption of normality were further tested for homogeneity of variance using Levene's test from the "car" package (Fox and Weisberg, 2019). Data meeting both assumptions were analyzed with a one-way ANOVA using the "multcomp" package (Hothorn et al., 2008). For observations showing statistically significant differences, Tukey's HSD post hoc test was applied ("multcomp" package). Observations that did not conform to the normal distribution or exhibited heterogeneity of variance were analyzed with the Kruskal-Wallis test. In cases when this test indicated statistically significant differences, Dunn's post hoc test with Holm correction was performed using the "dunn.test" package (Dinno, 2024). Data import and export were assisted with the "readxl" (Wickham and Bryan, 2025) and "writexl" (Ooms, 2025) packages. To simplify data manipulation, the "dplyr" package (Wickham et al., 2023) was used.

RESULTS

The samples contained the sugars sucrose, glucose, and fructose; the preservatives malic acid, citric acid, and p-hydroxybenzoic acid; as well as gallic acid. All the analyzed minerals were also detected.

Contents of sugars and health-promoting substances

In maple sap a statistically significant relationship was found between sucrose content and harvest day (p = 0.000772). The data were normally distributed and homogenous. On the first day the sap was sweeter, with an average sugar content of 1.73%. Across the study period, the sap contained 1.23% sucrose. No statistically significant differences were found between sucrose content and forest habitat type. Trace amounts of simple sugars – glucose and fructose – were also detected. Only in the Lw habitat fructose was not detected. The average content of these compounds over the entire study period was 0.006% for glucose and 0.001% for fructose. Differences in these concentrations with respect to harvest day or habitat type were not statistically significant.

The average malic acid content of the samples was 0.97 $g \cdot dm^{-3}$. Individual sample values ranged from 0.75 $g \cdot dm^{-3}$ to 1.21 $g \cdot dm^{-3}$. Differences between the concentrations of the preservative and the day or forest habitat type were not statistically significant. For citric acid, statistically significant differences (data normally distributed and homogenous) were observed

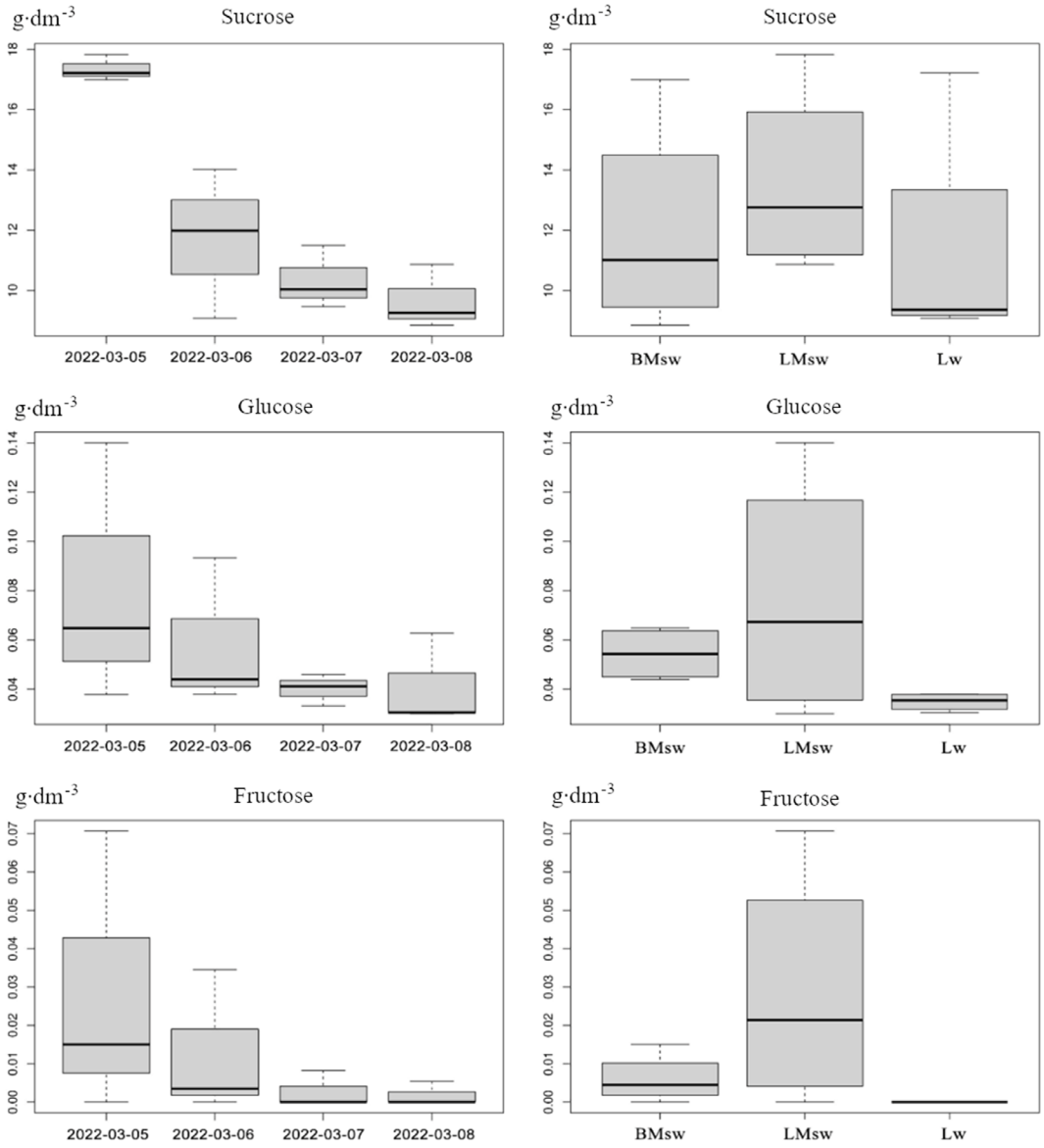

Fig. 1. Sugar contents in sap depending on harvest day and forest habitat type, g·dm^{-3}

between harvest date and compound concentrations (p = 0.023556). The content on the first day was higher, averaging 0.100 g·dm^{-3}, while the overall average across the study period it was 0.079 g·dm^{-3}. No significant differences were observed between citric acid content and forest habitat type.

The concentration of p-hydroxybenzoic acid depended on the day of harvest (p = 0.006353). The data were normally distributed and variances were homogenous. On the first day of flow, the acid was more concentrated, reaching an average content of 0.251 g·dm^{-3}. The average concentration over the study period was 0.079 mg·dm^{-3}. No statistically significant differences were found between acid content and forest habitat type. In contrast, gallic acid content showed statistically significant differences depending on forest habitat type (p = 0.017289). In the BMśw habitat the average content was 0.169 mg·dm^{-3}, in the

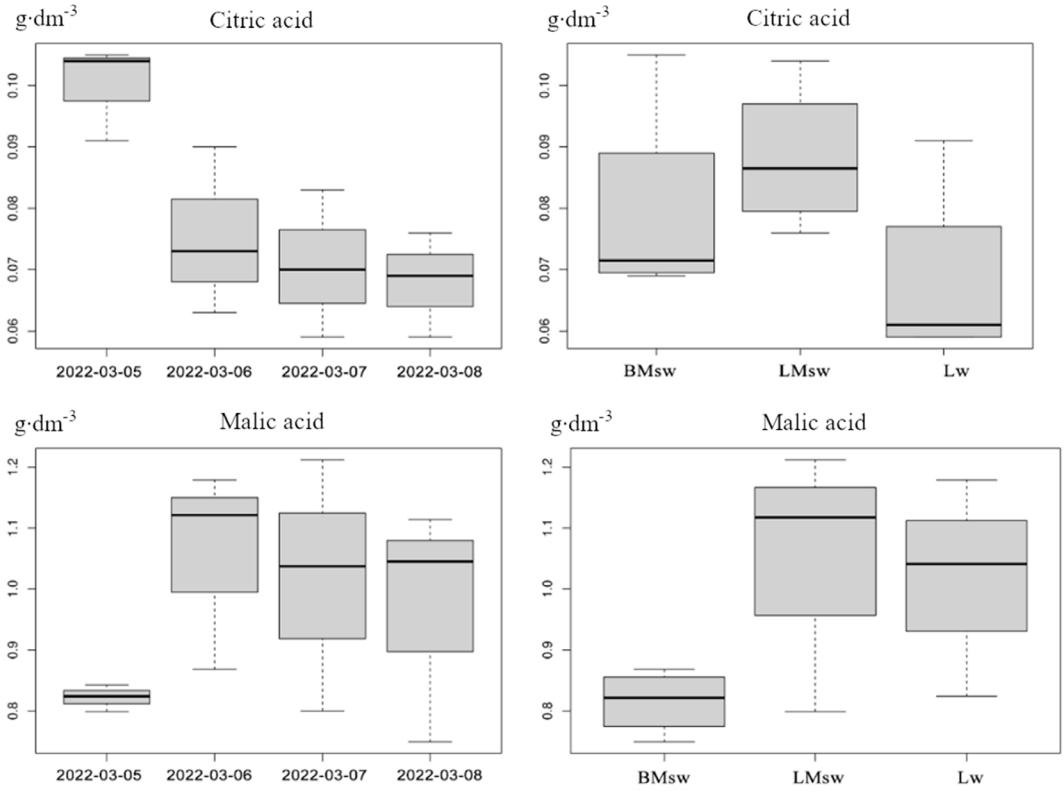

Fig. 2. Citric acid and malic acid contents in sap depending on harvest day and forest habitat type, g·dm^{-3}

LMśw habitat 0.124 mg·dm^{-3}, and in the the Lw habitat 0.144 mg·dm^{-3}. No correlation was found between harvest day and acid concentration.

Mineral contents

Trace amounts of zinc were found in the sap. Zinc content varied significantly depending on the forest habitat type (p = 0.00453). In the LMśw habitat the content was lower, with a mean of 0.388 mg·dm^{-3}. The average across the study period was 0.593 mg·dm^{-3}. No correlation was found between harvest day and zinc content. The copper content in sap is similar to that of zinc. The average concentration was 0.607 mg·dm^{-3}. A statistically significant lower content of copper was observed in the LMśw habitat (p = 0.00453), with an average of 0.402 mg·dm^{-3}. No correlation was detected between harvest day and copper content. Iron concentrations showed no statistically significant differences. Throughout the study period, samples contained an average of 0.075 mg·dm^{-3} of iron.

Statistically significant differences in manganese content were observed between forest habitat types (p = 0.00971). The average content in sap collected from the LMśw habitat was statistically higher, averaging 15.88 mg·dm^{-3}. Across the study period the sap contained an average of 12.44 mg·dm^{-3} of the mineral. No significant correlation was found between forest habitat type and manganese content. Potassium concentrations also varied significantly depending on forest habitat type (p = 0.018316). In the sap samples from the LMśw habitat the average content was 44.81 mg·dm^{-3}. Across the period the sap contained an average of 59.90 mg·dm^{-3} of potassium. No statistically significant differences were found for calcium content, either between harvest day or the forest habitat type. The average content of the compound over the study period was 390.62 mg·dm^{-3}.

Magnesium concentration was dependent on forest habitat type (p = 0.00971). In the BMśw habitat the sap contained an average of 53.35 mg·dm^{-3} of

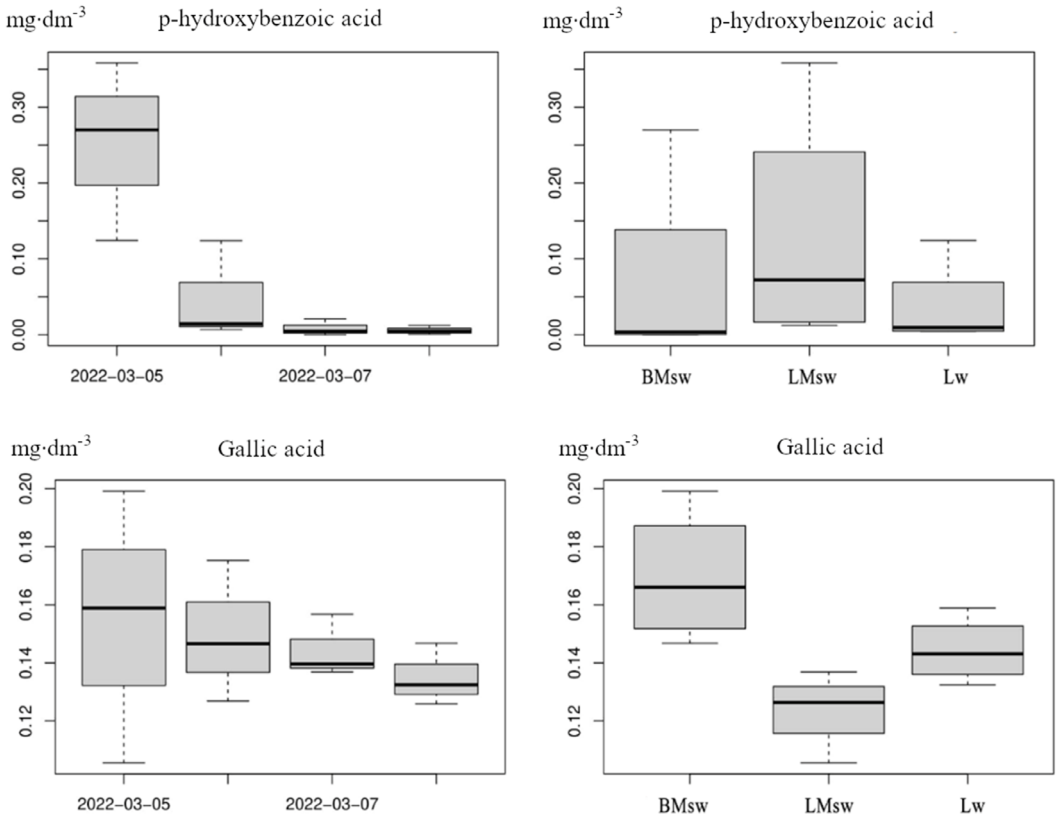

Fig. 3. Contents of p-hydroxybenzoic acid and gallic acid in sap depending on the day of harvest and forest habitat type, mg·dm^{-3}

magnesium, in the LMśw habitat it was an average of 82.54 mg·dm^{-3}, and in the Lw habitat an average of 67.73 mg·dm^{-3}. There was no correlation found between the day of harvest and the content of the magnesium. Sodium content varied significantly with harvest day (p = 0.006597, while being normally distributed and homogenous, with general increase over successive days. The average concentration was 8.13 mg·dm^{-3}. No significant differences were observed between forest habitat type and sodium content. Total sap mineralization was not significantly influenced by either forest habitat type or harvest date. The average mineralization of sap was 540 mg·dm^{-3}.

DISCUSSION

The sugar content determined in this study was slightly lower than values reported in the literature. Łuczaj et at. (2014) reported sugar concentration in sycamore sap at 3.2%, whereas Bilek et al. (2015b) indicated a sugar content of 1%. Essiamah (1980) also reported sugar concentrations ranging from 1% to 3.2%. The sap examined in this study had an average sugar level of 1.2%, which falls within the lower range of values reported by other authors.

A noticeably lower sugar content was observed in comparison with other tree species, such as sugar maple *Acer saccharum* (Baker et al., 2009), which shows a sugar content of 3–4%. Lagacé et al. (2015) reported a sugar concentration in sugar maple sap of 2.1%. Also in the study by Łuczaj et al. (2014) birch sap, considered significantly less sweet, exhibited a higher sugar content than that recorded in this study – 2.5%, while Mingaila et al. (2020) reported values ranging from 0.8% to 1.4%. An additional example is provided by Jones and Alli (2011), who in Canada recorded sugar

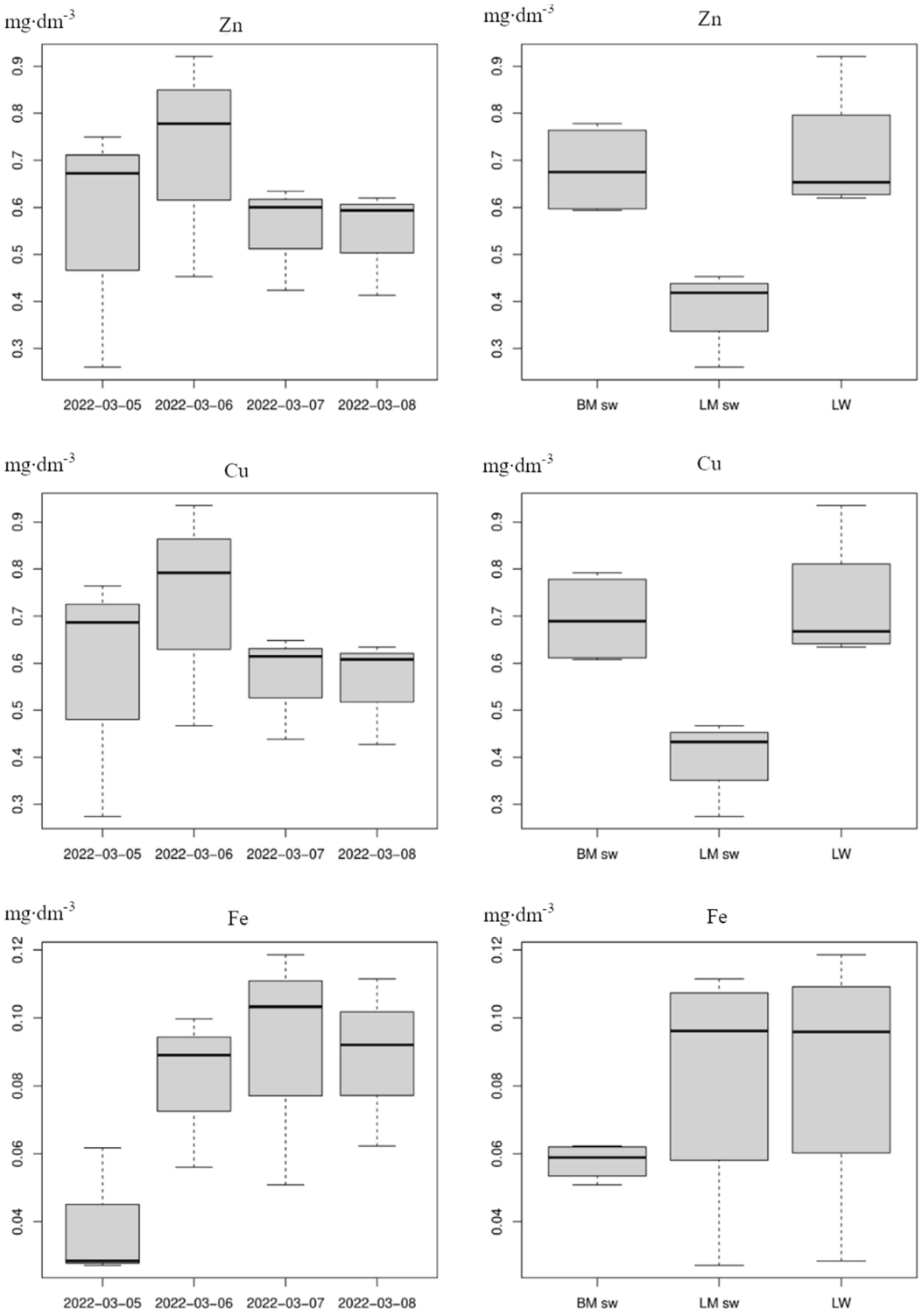

Fig. 4. Zinc, copper, and iron contents in sap depending on harvest day and forest habitat type, mg·dm^{-3}

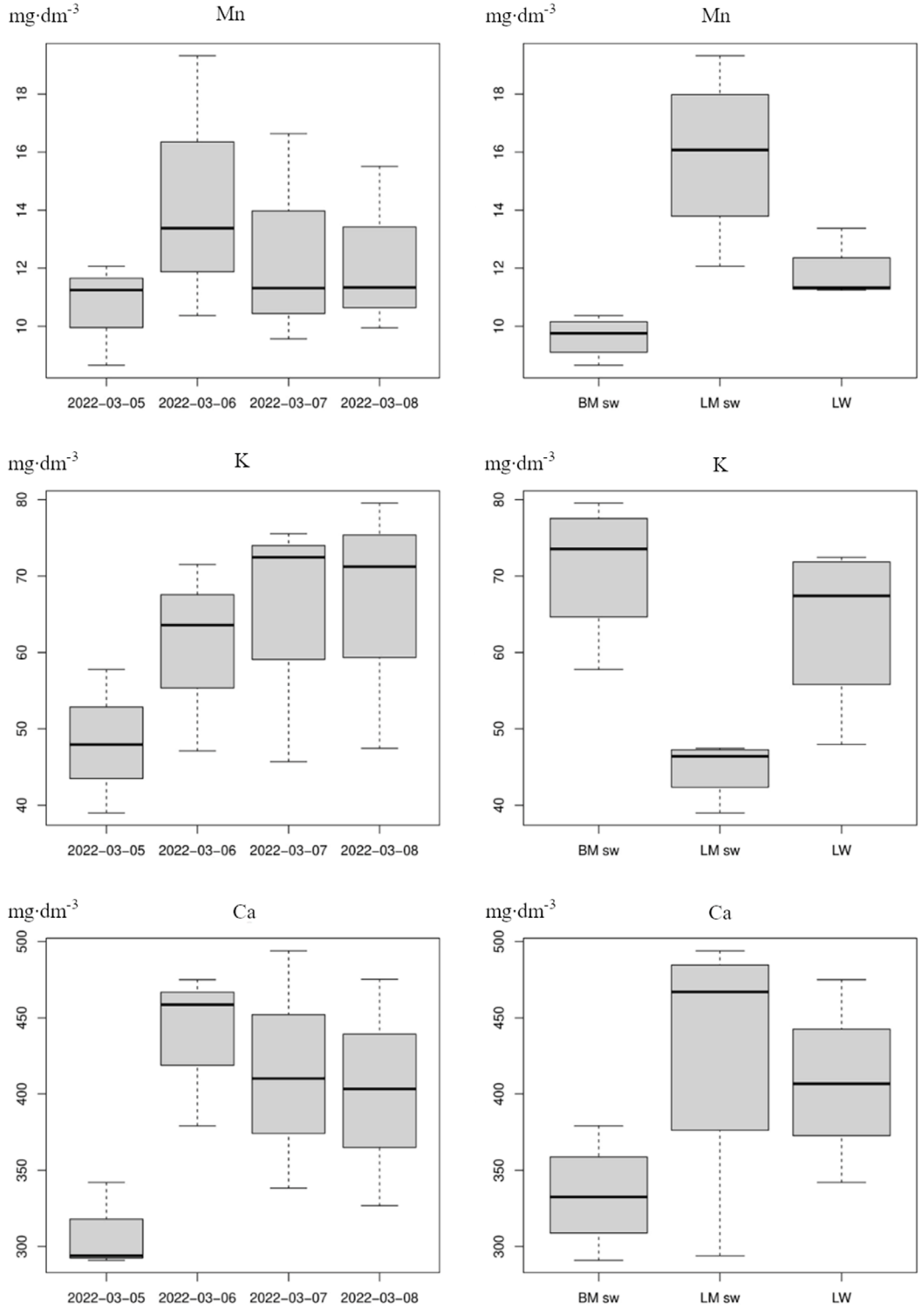

Fig. 5. Manganese, potassium and calcium contents of sap depending on the day of harvest and forest habitat type, mg·dm^{-3}

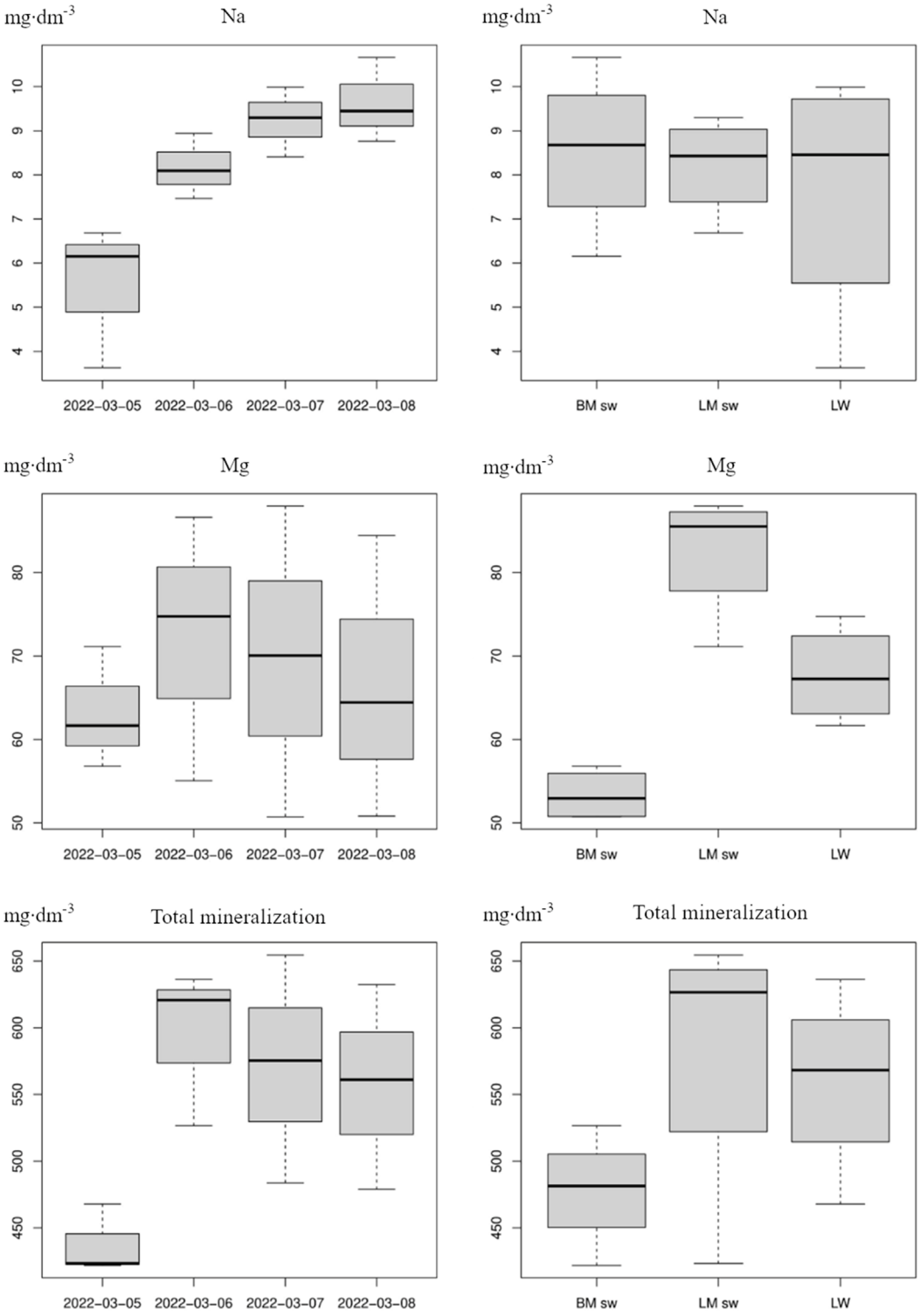

Fig. 6. Sodium and magnesium contents and total sap mineralization depending on harvest day and forest habitat type, mg·dm^{-3}

concentrations in birch sap (across several birch species) of 9.2% and in maple sap (*A. saccharinum* and *A. rubrum* species) of 22.2%. These reported values suggest that the sap obtained in the present study is relatively low in sugar, which may be attributed both to site-specific environmental conditions and meteorological conditions prevalent during the sampling period. Considering a typical spring with temperatures several degrees above zero, the sap flow can also be regarded as average.

High manganese content in the sap, measured at 12.44 mg·dm^{-3}, is of particular importance, as it could be compared to relatively manganese-rich rye bread (16.9 mg·kg^{-1}; Kot and Zaręba, 2005). Lagacé et al. (2015) reported manganese content more than 2.5 times lower, whereas Bilek et al. (2016) reported twice as low content for hornbeam. Other examples include willow (4.61 mg·dm^{-3}), birch (1.6-4.3 mg·dm^{-3}) and common maple (0.6 mg·dm^{-3}). Kuka et al. (2013) also reported manganese concentration of 0.24 mg·dm^{-3} for maple and 0.6 mg·dm^{-3} for birch. The EFSA recommends a regular manganese intake of no more than 8 mg per day (Turck et al., 2023). Researchers also highlight the neurotoxic potential of manganese at excessive intake levels. Therefore, regular consumption of large quantities of the studied sap (over 600 ml per day) may affect health. Nevertheless, a high manganese concentration may be beneficial for addressing dietary deficiencies of this element.

Contents of other compounds varied. The analyzed sap exhibited mean concentrations of zinc at 0.593 mg·dm^{-3}, copper 0.607 mg·dm^{-3}, iron at 0.075 mg·dm^{-3}, potassium at 59.90 mg·dm^{-3}, calcium at 390.62 mg·dm^{-3}, magnesium at 53.35 mg·dm^{-3}, and sodium at 8.13 mg·dm^{-3}, respectively. Lagacé et al. (2015) also investigated mineral contents, reporting comparable zinc levels, six-fold higher potassium, six-fold lower calcium, and eight-fold lower magnesium levels. Bilek et al. (2015b) observed seven-fold lower magnesium, three-fold lower copper and zinc, fourteen-fold lower calcium, and twenty-fold lower sodium contents. The mineral concentrations detected in the present study, in reference to adult dietary guidelines (Institute of Medicine, 2001; National Academies…, 2019), correspond to 39% of the recommended daily intake for calcium and 13% for magnesium, while for all the other minerals they accounted for less than 10%. Accordingly, the sap may serve as a supplementary source of calcium and magnesium in the diet.

It is important to note the limitations of the present study. Sampling was conducted during the first days of sap flow. Throughout the season, sugar content undergoes significant fluctuations, as previously noted by Taylor (1956). Therefore, sugar concentrations – and consequently the mean levels – might increase later in the season. This, together with the potential uniqueness of the season, in which the study was conducted, could be addressed through future studies over a longer, multi-year timeframe. Another potential source of uncertainty is the small sample size – three trees per forest habitat type. The low proportion of sycamore in the sampled plots – less than 5% – also could affect the results. The influence of other tree species on the microclimate surrounding the sampled sycamores remains unclear. Expanding the study to include sycamore monocultures would provide a more precise estimate of the potential of the Noteć Forest for tree sap production. Similarly, it would be advisable to investigate other tree species more commonly found in the forest, such as European birch *Betula pendula* and hornbeam *Carpinus betulus*.

Despite the previously mentioned sources of uncertainty, the results suggest that the Noteć Forest does not offer particularly promising conditions for sycamore sap production. The sugar content is distinctly low, and although the sap contains high levels of calcium and magnesium, the overall mineral composition is not particularly advantageous. The high manganese content may also pose challenges for its use. Further research should primarily include a greater variety of tree species, larger sample sizes, and an extended timeframe.

CONCLUSIONS

1. Sycamore sap can be a source of minerals in the diet – mainly calcium and magnesium.
2. Contents of other minerals are not highly relevant for an average person.
3. The tested sap contained high amounts of manganese, which may be unfavorable for humans if regularly consumed.
4. The amount of manganese could be beneficial in restoring proper manganese levels in the body.

5. The sugar content of the sap is relatively low.
6. The Noteć Forest area did not prove to be particularly attractive for sycamore sap extraction.
7. To fully assess the area's potential for sap production, further research is required. Such research should extend the duration of the study and prioritize potential sap contamination.

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ANALIZA ZAWARTOŚCI CUKRÓW I SUBSTANCJI PROZDROWOTNYCH W SOKU KLONU JAWORA *ACER PSEUDOPLATANUS* L. NA TERENIE PUSZCZY NOTECKIEJ

ABSTRAKT

Rosnąca popularność produktów z wykorzystaniem soków drzewnych opiera się na domniemanych właściwościach prozdrowotnych tego surowca. Na rynku syropu klonowego, który reprezentuje głównie Kanada, również odnotowano systematyczny wzrost rozmiaru i wartości produkcji. W badaniu podjęto próbę wzbogacenia wiedzy odnośnie zawartości cukrów i substancji prozdrowotnych soku klona jaworu *Acer pseudoplatanus* L. na terenie Leśnego Kompleksu Promocyjnego „Puszcza Notecka" poprzez zbiór soku w okresie 5–8.03.2022 r. i analizę poszczególnych związków w grupach: cukry, przeciwutleniacze, konserwanty, związki mineralne. Stwierdzono małą zawartość cukrów i substancji prozdrowotnych, które warunkują potencjalny brak wskazań do wykorzystania terenu badań pod kątem gospodarczego pozyskania soku jaworowego. Dodatkowo stwierdzono ilość manganu, która przy regularnym spożyciu może mieć negatywny wpływ na zdrowie człowieka.

Słowa kluczowe: cukry, F-AAS, HPLC, jawor, konserwanty, przeciwutleniacze, substancje prozdrowotne, związki mineralne