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Review

Chemical composition and mineralogical residence of maple syrup: A comprehensive review

Faez Mohammed [a,b,*], Paul Sibley [a,*], Dominique Guillaume [c,*], Nada Abdulwali [d]

[a] School of Environmental Sciences, University of Guelph, 50 Stone Road E, Guelph, ON N1G 2W1, Canada
[b] Faculty of Applied Science-Arhab, Sana'a University, Sana'a, Yemen
[c] ICMR, School of Medicine-Pharmacy, CNRS-UMR 7312, 51 Rue Cognacq Jay, 51100 Reims, France
[d] Department of Chemistry, University of Guelph, 50 Stone Road East, Guelph, Ontario N1G 2W1, Canada

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ABSTRACT

Maple syrup is a sweet-tasting product prepared by boiling and concentrating the sap of sugar maple (*Acer saccharum* March). Because of its potential health benefits (except for people with diabetes and those with blood sugar problems), desirable flavor, and taste, maple syrup is one of most popular natural products in the world. Maple syrup fundamentally consists of both organic and inorganic components. The composition of maple syrup plays an important role in determining its flavour, smell, color, and distinguishes it from other sugar syrups. Maple syrup constituents have been identified by different analytical techniques typically based on spectroscopy or spectrometry. Herein, we present the first comprehensive review of all available information on the chemical composition and mineralogical residence of maple syrup collected from over 117 years of published literature.

1. Introduction

Maple syrup is a naturally sweet product with characteristic flavour and taste, and nutritional and health benefits (Mohammed et al., 2021; Stuckel & Low, 1996; Li & Seeram, 2012; Panneton et al., 2013). In late winter or early spring, maple syrup is produced by boiling the sap of mature trees to evaporate water and concentrate the sugar content to 66–67° brix, resulting in a thick, sweet syrup (Legault et al., 2010; Singh et al., 2014). In 2020, approximately 14.3 million gallons (ca 54.13 million liters) of maple syrup were produced in Canada (Bedford, 2020) and 4 million gallons (ca 15.14 million liters) in the United States with an average price of $38.55 per gallon or $10.18 per liter. Consequently, in North America, maple syrup represents an important part of the economy for some Canadian provinces and States (Legault et al., 2019). In 2020, the total value of maple products in Canada was $558.5 million, up 7.9% from 2019 (Statistics Canada catalogue no. 11-001-X).

Maple syrup contains organic compounds, micronutrients, and phytochemicals (Lagacé et al., 2015; Yuan et al., 2013). Some of these components are formed during the concentration process (Underwood & Filipic, 1964; Underwood, 1971). The accepted composition of maple syrup depends on the country of marketing. The elemental composition of maple syrup is the origin of its unique flavour, high mineral nutrient value, antioxidant properties, and nutritional value (Stuckel & Low, 1996; Morselli, 1975a), as well as other health benefits (Stuckel & Low, 1996; Thériault et al., 2006; Li & Seeram, 2011a; Abou Zaid et al., 2008; Belford et al., 1991; Potter & Fagerson, 1992; Kermasha & Goetghebeur, 1995; Akochi et al., 1997; Li & Seeram, 2010). It also provides a unique signature that can be advantageously used to detect potential adulteration with cheap syrups such as those derived from beets, corn, and cane sugar (Mohammed et al., 2021).

In North America, maple syrup was introduced to colonizing Europeans by indigenous peoples. Syrup and maple products have been sold commercially since that time (Koelling et al., 1996). As commercial markets grew, and analytical methods improved, interest in examining the elemental composition of maple syrup increased. Consequently, over the past one hundred years, many scientific studies have elucidated the types of chemical compounds and mineral composition of maple syrup. However, these data have not been comprehensively synthesized in a single review. This review therefore provides a detailed assessment of the chemical composition and mineralogical residence of maple syrup. To our knowledge, such exhaustively compiled information regarding the composition of maple syrup is not available elsewhere. Therefore,

* Corresponding authors at: Environmental Department, School of Environmental Sciences, Ontario Agricultural College, University of Guelph, Canada (F. Mohammed). School of Environmental Sciences, Ontario Agricultural College, University of Guelph, Canada (P. Sibley). School of Medicine-Pharmacy, University of Reims, Champagne Ardenne, France (D. Guillaume).

E-mail addresses: faez@uoguelph.ca (F. Mohammed), psibley@uoguelph.ca (P. Sibley), dominique.guillaume@univ-reims.fr (D. Guillaume).

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we expect that this review will serve as a key reference on maple syrup chemistry. We believe that the centralization of chemical data into a single resource will help to guide future studies on the elemental composition of maple syrup and further serve as a repository for studies wishing to examine potential adulteration.

2. Chemical composition of maple syrup

The chemical composition of foods is very important in understanding health benefits, and in assessing their nutritional quality and authenticity. Indeed, information on food composition provides a helpful tool for assessing the overall quality of the diet, as well as developing and applying food-based dietary guidelines in the field of public health nutrition (Elmadfa & Al Meyer, 2010).

2.1. Chemical compounds

The first study on the chemical composition of maple syrup was reported in 1904 (Hortvet, 1904). In this study, based on 50 samples from various locations in the United States, maple syrup was essentially described as a dilute solution of sucrose, containing small amounts of proteins, malic acid, and other undescribed organic acids, with percent composition ranging from 1.49 to 3.11%, 0.22 to 0.33%, and 0.84 to 1.28%, respectively.

Shortly thereafter, Edson reported that 88 to 99% of the total carbohydrate content of maple syrup was in the form of sucrose, with varying amounts of invert sugars also present as a function of microbial fermentation of sap during storage, handling and processing (Edson, 1910; Edson and Jones, 1912).

Prior to the study of Nelson (1928), malic acid was identified as the predominant acid in maple syrup. Nelson (1928) also identified formic, acetic and citric, fumaric, and succinic acids as common constituents of maple syrup, albeit at lower concentrations compared to malic acid (Table 1). These organic acids occurred in concentrations of 0.81–1.04 g/L, 0.12–0.13 g/L, 0.085–0.15 g/L, 0.095–0.11 g/L, 0.0056–0.0063 g/L, respectively. The study also reported the presence of a small quantity of an unidentified acid described only as having a high melting point.

Eleven years later, Sair and Sne (1939) reported the presence of an enolic viscous oil, volatile at 0.03 mm Hg, at a proportion of 0.6 g/100 Gal in maple syrup extracted by chloroform (Table 1) (Sair & Sne, 1939). This substance is one of the main elements responsible for the distinct odor of maple syrup.

Vanillin and syringaldehyde were identified from the chloroform extract of maple syrup by Underwood et al. (1961) (Table 2). The authors suggested that these two compounds could come from precursors in the decomposition of lignin and speculated that they might also contribute to the odor properties of maple syrup. Several pure crystalline compounds of unreported structure and other impure materials were also isolated during this study. Table 2.

Davis et al. (1963) studied the chemical composition of "maple sugar sand", the solid material obtained by filtering commercial maple syrup. The chemical compounds present in this solid material were identified by paper chromatography as nonvolatile organic acids, including malic, citric, succinic, fumaric acids. The presence of three unidentified organic acids was also reported without mention of their respective concentration.

Underwood and Filipic (1963) used chloroform extraction to separate and identify additional flavor constituents in maple syrup. Two of the compounds identified were already known derivatives (vanillin and syringaldehyde), but the study led to the identification of dihydroconiferyl alcohol (Table 2).

Filipic et al. (1965) identified several flavour-compounds of maple syrup using gas chromatography. Acetol was the major constituent not previously detected, together with components present in lower concentrations, including acetoin, ethyl vanillate, syringoyl methyl ketone, and methylcyclopentenolone (Tables 2, 3).

Table 1
Elemental composition of maple syrup: Sugars, organic acids, amino acids, vitamins, and other compounds.

Identification	Molecular formula	Role	References
Sugars			
Sucrose	C12H22O11		(Stuckel et al., 1996)
Glucose	C6H12O6		(Stuckel et al., 1996)
Fructose	$C_6H_{12}O_6$		(Stuckel et al., 1996)
Oligosaccharides	$C_{37}H_{62}N_2O_{29}$		(Anon, 1984; Morselli,1975b)
Inulin	$C_{6n}H_{10n+2}O_{5n+1}$		(Sun et al., 2016)
Organic acids			
Malic acid	$C_4H_6O_5$	a	(Nelson, 1928; Davis et al., 1963; Filipic et al., 1969; Stuckel et al., 1996; Ball, 2007)
Fumaric acid	$C_4H_4O_4$	a	(Nelson, 1928; Davis et al., 1963; Filipic et al., 1969; Stuckel et al., 1996)
Succinic acid	$C_4H_6O_4$		(Nelson, 1928; Davis et al., 1963; Stuckel et al., 1996)
Citric acid	C6H$_8$O$_7$		(Nelson, 1928; Davis et al., 1963; Stuckel et al., 1996)
Acetic acid	$C_2H_4O_2$		(Nelson, 1928)
Lactic acid	$C_3H_6O_3$	a	(Filipic et al., 1969)
Levulinic acid	$C_5H_8O_3$	a	(Filipic et al., 1969)
Aliphatic acidse	$C_5H_8O_3$	a	(Filipic et al., 1969)
Oxalic acid	$C_2H_2O_4$	a	(Filipic et al., 1969)
Hexanoic acid	$C_6H_{12}O_2$	a	(Ball, 2007)
n-Hexanoic acid	$C_6H_{12}O_2$	a	(Kalli et all., 1988)
2-Ethylhexanoic acid	$C_8H_{16}O_2$	a	(Kalli et all., 1988)
n-Nonanoic acid	$C_9H_{18}O_2$	a	(Kalli et all., 1988)
Amino acids			
D-alanine	$C_3H_7NO_2$		(Patzold & Bruckner, 2005)
D-valine	$C_5H_{11}NO_2$		(Patzold & Bruckner, 2005)
D-proline	$C_5H_9NO_2$		(Patzold & Bruckner, 2005)
D-serine	$C_3H_7NO_3$		(Patzold & Bruckner, 2005)
D-leucine	$C_6H_{13}NO_2$		(Patzold & Bruckner, 2005)
D-asx	Asp + Asn		(Patzold & Bruckner, 2005)
D- phentermine	$C_{10}H_{15}N$		(Patzold & Bruckner, 2005)
D- glxine	Glu + Gln		(Patzold & Bruckner, 2005)
D-ornithine	$C_5H_{12}N_2O_2$		(Patzold & Bruckner, 2005)
D-lysine	$C_6H_{14}N_2O_2$		(Patzold & Bruckner, 2005)
D-Ile (L-isoleucine)	$C_6H_{13}NO_2$		(Patzold & Bruckner, 2005)
Vitamins			
Thiamine	$C_{12}H_{17}N_4OS+$		(Perkins et al., 2006)
Niacin	C6H$_5$NO2		(Perkins et al., 2006)
Riboflavin	C1$_7$H20N$_4$O6		(Perkins et al., 2006)
Folic Acid	$C_{19}H_{19}N_7O_6$		(Perkins et al., 2006)
Biotin	$C_{10}H_{16}N_2O_3S$		(Perkins et al., 2006)
Vitamin A	$C_{20}H_{30}O$		(Perkins et al., 2006)
Pyridoxine	C$_8$H11NO3		(Perkins et al., 2006)
Other compounds			
5′-Inosine monophosphate	$C_{10}H_{13}N_4O_8P$	b	(Belford et al., 1991)
Enolic viscous oil	$C_{15}H_{13}N_3O_4S$	c	(Sair & Sne, 1939)

a: Flavor compound, b: Taste compound, c: Odor compound.

Using gas chromatography-mass spectrometry, Filipic et al. (1969) reported several previously unrevealed flavour-related compounds found in trace levels including acetovanillone, guaiacyl acetone, and vanilloyl methyl ketone. Furfural, hydroxymethylfurfural, lactic acid and levulinic acid, C_5 to C_9 aliphatic acids and oxalic, fumaric and malic acids were also characterized in the maple syrup samples (Tables 1–3). Concentrations were not reported in this study.

In two independent studies, Morselli (1975b) and Anon (1984) showed that maple syrup consists essentially of sucrose (~66%), with small amounts of glucose (0.7%), fructose (0.4%) and trace levels of oligosaccharides, organic acids, amino acids and vitamins.

In one of the first studies to focus on the vitamin content of maple syrup, Morselli (1975a) identified the vitamins Niacin, Riboflavin, Folic Acid, Biotin, Pyridoxine (B6), and vitamin A (Table 1). The concentrations of Niacin and Riboflavin were 0.16 and 0.046 ppm, respectively, while the study indicated only trace amounts of Folic Acid, Biotin,

Table 2
Elemental composition of maple syrup: Phenolic compounds.

Identification	Molecular formula	Role	Ref
Vanillin	$C_8H_8O_3$	a, b, c	(Underwood, Willits & Lento, 1961; Underwood & Filipic, 1963; Filipic et al., 1965; Potter & Fagerson, 1992; Li & Seeram, 2010)
Syringaldehyde	$C_9H_{10}O_4$	a, b	Underwood, Willits & Lento, 1961; Underwood & Filipic, 1963; Filipic et al., 1965; Potter &Fagerson, 1992)
Dihydroconiferyl alcohol	$C_{10}H_{14}O_3$	a	(Underwood & Filipic, 1963; Filipic et al., 1965; Potter &Fagerson, 1992; Li & Seeram, 2011)
Coniferyl aldehyde	$C_{10}H_{10}O_3$		(Potter &Fagerson, 1992)
Ethyl vanillate	$C_{10}H_{12}O_4$	a	(Filipic et al., 1965)
Syringoyl methyl ketone	$C_{11}H_{12}O_5$	a	(Filipic et al., 1965)
Acetovanillone	$C_9H_{10}O_3$	a	(Filipic et al., 1969)
Guaiacyl acetone	$C_{10}H_{12}$	a	(Filipic et al., 1969)
Vanillyl methyl ketone	$C_5H_4O_2$	a	(Filipic et al., 1969)
Benzoic acid	$C_7H_6O_2$	c	(Abou-Zaid et al., 2008)
Gallic acid	$C_7H_6O_5$	c	(Abou-Zaid et al., 2008; Li & Seeram, 2010)
1-O-galloyl-β-D-glucose	$C_{13}H1_6O_{10}$	c	(Abou-Zaid et al., 2008)
γ-Resorcylic acid (2,6-Dihydroxybenzoic acid)	$C_7H_6O_4$	c	(Abou-Zaid et al., 2008)
p-Coumaric acid	$C_9H_8O_3$	c	(Abou-Zaid et al., 2008; Liu et al., 2017)
4-Methoxycinnamic acid	$C_{10}H_{10}O_3$	c	(Abou-Zaid et al., 2008)
Caffeic acid	$C_9H_8O_4$	c	(Abou-Zaid et al., 2008)
Ferulic acid	$C_{10}H_{10}O_4$	c	(Abou-Zaid et al., 2008)
Sinapic acid	$C_{11}H_{12}O_5$	c	(Abou-Zaid et al., 2008)
Chlorogenic acid	$C_{16}H_{18}O_9$	c	(Abou-Zaid et al., 2008)
Quercetin 3-O − β-D-glucoside	$C_{21}H_{20}O_{12}$	c	(Abou-Zaid et al., 2008)
Quercetin 3-O rhamnoglucoside	$C_{25}H_{28}O_{15}$	c	(Abou-Zaid et al., 2008)
Quercetin 3-O − β-L-rhamnoside	$C_{21}H_{20}O_{11}$	c	(Abou-Zaid et al., 2008)
Kaempferol 3-O − β-D-glucoside	$C_{21}H_{20}O_{11}$	c	(Abou-Zaid et al., 2008)
Kaempferol 3-O − β-D-galactoside	$C_{21}H_{19}O_{11}$	c	(Abou-Zaid et al., 2008)
Vanillic acid	C8H8O4	c	(Potter &Fagerson, 1992)
Gentisic acid	$C_7H_6O_4$	c	(Abou-Zaid et al., 2008)
1-O-galloyl-β-D-glucose	$C_{13}H_{16}O_{10}$	c	(Abou-Zaid et al., 2008)
Protocatechuic acid	$C_7H_6O_4$		(Li & Seeram, 2011
(+) –Catechin	$C_{15}H_{14}O_6$	c	(Abou-Zaid et al., 2008)
Epicatechin	$C_{15}H_{14}O_6$		(Liu et al., 2017)
4-Methoxycinnamic acid	$C_{10}H_{10}O_3$	c	(Abou-Zaid et al., 2008)
Quercetin	$C_{15}H_{10}O_7$	c	(Abou-Zaid et al., 2008)
Kaempferol	$C_{15}H_{10}O_6$	c	(Abou-Zaid et al., 2008)
Lyoniresinol	$C_{22}H_{28}O_8$	c	

Table 2 (*continued*)

Identification	Molecular formula	Role	Ref
			(Li & Seeram, 2010; Liu et al., 2017)
Secoisolariciresinol	$C_{20}H_{26}O_6$	c	(Li & Seeram, 2010; Liu et al., 2017)
5′-Methoxy-dehydroconiferyl alcohol	$C_{11}H_{16}O_4$	c	(Li & Seeram, 2010)
Erythro-guaiacylglycerol-β-O-4′-coniferyl alcohol	$C_{20}H_{26}O_7$	c	(Li & Seeram, 2010)
Scopoletin	$C_{10}H_8O_4$	c	(Li & Seeram, 2010)
Fraxetin	$C_{10}H_8O_5$	c	(Li & Seeram, 2010)
(E)-3,3′-Dimethoxy-4,4′-dihydroxystilbene	$C_{16}H_{16}O_4$	c	(Li & Seeram, 2010)
2-Hydroxy-3′,4′-dihydroxyacetophenone	$C_8H_8O_4$	c	(Li & Seeram, 2010)
1-(2,3,4-Trihydroxy-5-methylphenyl)ethanone	$C_9H_{10}O_4$	c	(Li & Seeram, 2010)
2,4,5-Trihydroxyacetophenone	$C_8H_8O_4$	c	(Li & Seeram, 2010)
Trimethylgallic acid methyl ester	$C_{11}H_{14}O_5$	c	(Li & Seeram, 2010)
Syringic acid	$C_9H_{10}O_5$	c	(Potter &Fagerson, 1992; Li & Seeram, 2010)
C-veratroylglycol	$C_{10}H_{12}O_5$	c	(Li & Seeram, 2010; Liu et al., 2017)
Catechol	$C_6H_6O_2$	c	(Li & Seeram, 2010)
5-(3″,4″-Dimethoxyphenyl)-3-hydroxy-3-(4′-hydroxy-3′-methoxybenzyl)-4-(hydroxymethyl)dihydrofuran-2-one[c]	$C_{21}H_{24}O_8$	c	(Li & Seeram, 2011; Liu et al., 2017)
(*Erythro*,*erythro*)-1-[4-[2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy]-3,5-dimethoxyphenyl]-1,2,3-propanetriol	$C_{21}H_{28}O_{10}$	c	(Li & Seeram, 2011; Liu et al., 2017)
(*Erythro*,*threo*)-1-[4-[2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy]-3,5-dimethoxyphenyl]-1,2,3-propanetriol	$C_{21}H_{28}O_{10}$	c,d	(Li & Seeram, 2011; Liu et al., 2017)
2,3-Dihydroxy-1-(3,4-dihydroxyphenyl)-1-propanone	$C_9H_{10}O_5$		(Li & Seeram, 2011; Liu et al., 2017)
(*threo*,*erythro*)-1-[4-[(2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy]-3-methoxyphenyl]-1,2,3-propanetriol	$C_{20}H_{26}O_9$	c	(Li & Seeram, 2011)
(*Threo*,*threo*)-1-[4-[(2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy]-3-methoxyphenyl]-1,2,3-propanetriol	$C_{20}H_{26}O_9$	c	(Li & Seeram, 2011)
Threo-guaiacylglycerol-β-O-4′-dihydroconiferyl alcohol	$C_{20}H_{26}O_7$	c	(Li & Seeram, 2011; Liu et al., 2017)
Erythro-1-(4-hydroxy-3-methoxyphenyl)-2-[4-(3-hydroxypropyl)-2,6-dimethoxyphenoxy]-1,3-propanediol	$C_{21}H_{28}O_8$	c	(Li & Seeram, 2011; Liu et al., 2017)
2-[4-[2,3-Dihydro-3-(hydroxymethyl)-5-(3-hydroxypropyl)-7-methoxy-2-benzofuranyl]-2,6-dimethoxyphenoxy]-1-(4-hydroxy-3-methoxyphenyl)-1,3-propanediol	$C_{31}H_{38}O_{11}$		(Li & Seeram, 2011; Liu et al., 2017)
Acernikol	$C_{31}H_{38}O_{11}$	c	(Li & Seeram, 2011 ; Liu et al., 2017)
Leptolepisol D	$C_{27}H_{32}O_{10}$	c	(Li & Seeram, 2011; Liu et al., 2017)
Buddlenol E	$C_{31}H_{36}O_{11}$	c	(Li & Seeram, 2011; Liu et al., 2017)
(1S,2R)-2-[2,6-dimethoxy-4-[(1S,3aR,4S,6aR)-tetrahydro-4-	$C_{32}H_{38}O_{12}$	c	(Li & Seeram, 2011)

(continued on next page)

Table 2 (*continued*)

Identification	Molecular formula	Role	Ref
(4-hydroxy-3,5-dimethoxyphenyl)-1H,3H-furo[3,4-*c*]furan-1-yl]phenoxy]-1-(4-hydroxy-3-methoxyphenyl)-1,3-propanediol			
Syringaresinol	$C_{22}H_{26}O_8$	c,d	(Li & Seeram, 2011; Liu et al., 2017)
Isolariciresinol	$C_{20}H_{24}O_6$	c	(Li & Seeram, 2011; Liu et al., 2017)
Icariside E4	$C_{26}H_{34}O_{10}$	c	(Li & Seeram, 2011; (Liu et al., 2017)
Sakuraresinol	$C_{24}H_{32}O_9$	c	(Li & Seeram, 2011; Liu et al., 2017)
1,2-Diguaiacyl-1,3-propanediol	$C_{17}H_{20}O_6$	c	(Li & Seeram, 2011; Liu et al., 2017)
2,3-Dihydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)propan-1-one	$C_{11}H_{14}O_6$	c,d	(Li & Seeram, 2011; Liu et al., 2017)
3-Hydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)propan-1-one	$C_{11}H_{14}O_5$	c,d	(Li & Seeram, 2011; Liu et al., 2017)
4-Acetylcatechol	$C_8H_8O_3$		(Li & Seeram, 2011)
3′,4′,5′-Trihydroxyacetophenone	$C_8H_8O_4$		(Li & Seeram, 2011)
3,4-Dihydroxy-2-methylbenzaldehyde	$C_8H_8O_3$		(Li & Seeram, 2011)
4-(Dimethoxymethyl)-pyrocatechol	$C_9H_{12}O_4$		(Li & Seeram, 2011)
Tyrosol	$C_8H_{10}O_2$		(Li & Seeram, 2011)
Isofraxidin	$C_{11}H_{10}O_5$		(Li & Seeram, 2011)
4-Hydroxyestrone	$C_{18}H_{22}O_3$		(Li & Seeram, 2011)
Phaseic acid	$C_{15}H_{19}O_5$		(Li & Seeram, 2011)
Quebecol (2,3,3-Tri-(3-methoxy-4-hydroxyphenyl)-1-propanol)	$C_{24}H_{26}O_7$		(Li & Seeram, 2011).
Secoisolariciresinol	$C_{20}H_{26}O_6$		(Liu et al., 2017)
Dihydrodehydrodiconiferyl alcohol	$C_{20}H_{24}O_6$		(Ball, 2007)
5-Methoxy-*trans*-dihydrodehydrodiconiferyl alcohol	$C_{21}H_{26}O_7$	c	(Li & Seeram, 2010)
Guaiacylglycerol β-coniferyl ether	$C_{20}H_{24}O_6$	c	(Li & Seeram, 2010)
Guaiacylglycerol-β-O-4′-dihydroconiferyl alcohol	$C_{20}H_{26}O_7$	c	(Li & Seeram, 2010)
3-[(4-[(6-Deoxy-α-L-mannopyranosyl) oxy]-3-methoxyphenyl)-5- (3,4-dimethoxyphenyl)dihydro-3-hydroxy-4-(hydroxymethyl)-2 (3H)-furanone	$C_{27}H_{34}O_{12}$	c,d	(Li & Seeram, 2010)
(E)-3,3′-Dimethoxy-4,4′-dihydroxy stilbene	$C_{16}H_{16}O_4$	c	(Li & Seeram, 2010)
Methyl gallate trimethyl ether	$C_{11}H_{14}O_5$	c	(Li & Seeram, 2010)
Resorcylic acid	$C_7H_6O_4$	c	(Abou-Zaid et al., 2008)
Catechaldehyde	$C_7H_6O_3$	c	(Li & Seeram, 2010)
Syringenin	$C_{11}H_{14}O_4$	c	(Li & Seeram, 2010)
Coniferyl alcohol	$C_{10}H_{12}O_3$		(Kermasha & Goetghebeur, 1995)
Catechin	$C_{16}H_{16}O_5$	c	(Abou-Zaid et al., 2008)
Astragalin	$C_{21}H_{20}O_{11}$	c	(Abou-Zaid et al., 2008)
Kaempferol 3-O-galacotoside	$C_{21}H_{20}O_{11}$	c	(Abou-Zaid et al., 2008)
Isoquercetrin	$C_{21}H_{20}O_{12}$	c	(Abou-Zaid et al., 2008)
Quercitrin	$C_{21}H_{20}O_{11}$	c	(Abou-Zaid et al., 2008)
Rutin	$C_{27}H_{30}O_{16}$	c	(Abou-Zaid et al., 2008)
Syringol	$C_8H_{10}O_3$		(Ball, 2007)
Homovanillic acid	$C_9H_{10}O_4$		(Potter &Fagerson, 1992)
Guaiacylglycerol-β-O-4′-coniferyl alcohol	$C_{20}H_{24}O_7$	c	(Liu et al., 2017)
Dehydroconiferyl alcohol	$C_{20}H_{24}O_6$	c	(Liu et al., 2017)
(*erythro,erythro*)-4′′,4′′′-dihydroxy-3,3′,3′′,3′′′,5,5′-hexamethoxy-7,9′;7′,9-die poxy-4,8′′;4′,8′′′-bisoxy-8,8′-dineolignan-7′′,7′′′,9′′,9′′′-tetraol	$C_{42}H_{50}O_{16}$		(Liu et al., 2017)
(*Threo,erythro*)-4′′,4′′′-dihydroxy-3,3′,3′′,3′′′,5,5′-hexamethoxy-7,9′;7′,9-diepoxy-4,8′′;4′,8′′′-bisoxy-8,8′-dineolignan-7′′,7′′′,9′′,9′′′-tetraol	$C_{42}H_{50}O_{16}$		(Liu et al., 2017)
3-Methylmaleic anhydride	C5H4O3		(Ball, 2007)
Furaneol	$C_6H_8O_3$		(Ball, 2007)
Phenethyl alcohol	$C_8H_{10}O$		(Potter &Fagerson, 1992)
Eugenol	$C_{10}H_{12}O_2$		(Potter &Fagerson, 1992)
Isoeugenol isomer	$C_{10}H_{12}O_2$		(Potter &Fagerson, 1992)
Syringic alcohol	$C_9H_{12}O_4$		(Potter &Fagerson, 1992)
Dihydrosinapyl alcohol	$C_{11}H_{16}$		(Potter &Fagerson, 1992)
Sinapaldehyde	$C_{11}H_{12}O_4$		(Potter &Fagerson, 1992)
4-Allyl-3,5-dimethoxytoluene			(Potter &Fagerson, 1992)
Erythro-Guaiacylglycerol-beta-O-4′-dihydroconiferyl alcohol[c]	$C_{20}H_{26}O_7$		(Li & Seeram, 2010; Liu et al., 2017)
3-[4-[(6-Deoxy-α-l-mannopyranosyl)oxy]-3-methoxyphenyl]methyl]-5-(3,4-dimethoxyphenyl)dihydro-3-hydroxy-4-(hydroxymethyl)-2 (3H)-furanone[c]	$C_{28}H_{36}O_{12}$		(Li & Seeram, 2010; Liu et al., 2017)
(*Erythro,erythro*)-1-[4-(2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy)-3-methoxyphenyl]-1,2,3-propanetriol	$C_{20}H_{26}O_9$		(Liu et al., 2017)

a: Flavor compound, b: Odor compound, c: Antioxidant compound, d: Anti-inflammatory compound.

Pyridoxine (B6), and vitamin A in maple syrup.

Jones and Ali (1987), sampled white birch (*Betula papyrifera*), sweet birch (*B. lenta*), and yellow birch (*B. alleghaniensis*) to identify sugar content in their respective syrups and compared it to syrup produced from sugar maple (*A. saccharum* Marsh). Syrup analyses showed the average sugar content of all birch syrups and all maple syrups were 302 and 711 g/L, respectively. However, detailed comparative studies on maple versus non-maple syrups are lacking.

Kallio et al. (1988) reported the presence of thirteen new flavor compounds in maple syrup, including: three alcohols (2-ethyl-l-hexanol, 2-hydroxymethylcyclopenten-2-en-ol, 2-furanmethanol), three organic acids (2-ethyl-l-hexanoic acid, *n*-hexanoic acid, *n*-nonanoic acid), and seven ketones (2-hydroxy-3-methyl-2-cyclopenten-l-one, 2-methyl-2-cyclopenten- 1-one, 2-methyl-2,5-cyclohexadien-l,4-dione, 2,3-dihydro-3,5-dihydroxy-6-methyl(4H)-pyran-4-one, 2,5-dimethyl-4-hydroxy-3(2H)-furanone, 3-methyl-3-buten-2-one, 3-methyl-2,5-furandione) (Tables 1, 3) (Kallio et al., 1988). Concentrations were not reported in this study.

Alli et al. (1990), using dichloromethane extraction and capillary gas chromatographic analysis, identified the presence of several flavor compounds including methylpyrazine, 2,3-dimethylpyrazine, 2,5-dimethylpyrazine, 2,6-dimethylpyrazine, ethylpyrazine, 2-ethyl-6-methylpyrazine and trimethylpyrazine in several commercial maple syrup samples from Quebec, Canada (Table 4). In a subsequent study, Alli et al. (1992) identified several additional flavour compounds in maple syrup samples from Quebec involving primarily phenolic compounds, pyrazines and carbonyl compounds (Tables 2, 4). Belford et al.,

Table 3
Elemental composition of maple syrup: Alcohols, ketones, and aldehydes.

Identification	MolecularFormula	Role	References
Alcoholic compounds			
2-Ethyl-l-hexanol	$C_8H_{18}O$	a	(Kalli et all., 1988)
2-Hydroxymethyl cyclopentane-2-en-ol	$C_6H_{10}O_2$	a	(Kalli et all., 1988)
2-Furanmethanol	$C_5H_6O_2$	a	(Kalli et all., 1988)
2-Hydroxymethylcyclopent-2-en-1-ol	$C_6H_{10}O_2$	a	(Kalli et all., 1988)
Ketone compounds			
2-Hydroxy-3-methyl-2-cyclopenten-l-one	$C_6H_8O_2$	a	(Kalli et all., 1988)
2-Methyl-2-cyclopenten-1-one	C_6H_8O	a	(Kalli et all., 1988)
2-Methylcyclohexa-2,5-diene-1,4-dion	$C_7H_6O_2$	a	(Kalli et all., 1988)
2,3-Dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one	$C_6H_8O_4$	a	(Kalli et all., 1988)
2,5-Dimethyl-4-hydroxy-3(2H)-furanone	$C_6H_8O_3$	a	(Kalli et all., 1988)
3-Methyl-3-buten-2-one	C_5H_8O	a	(Kalli et all., 1988)
3-Methyl-2,5-furandione	$C_5H_4O_3$	a	(Alli et al, 1990)
Isopropenyl methyl ketone	C_5H_8O		(Ball, 2007)
2-Methyl-2-cyclopentenone	C_6H_8O		(Ball, 2007)
2-Hydroxymethyl-2-cyclopentenone	$C_6H_8O_2$		(Ball, 2007)
Cyclotene	$C_6H_8O_2$		(Ball, 2007)
3-Methyl-2-cyclopenten-2-ol-l-one	$C_6H_8O_2$		(Filipic et al., 1965)
3-Hydroxybutanone	$C_4H_8O_2$	a	(Kalli et all., 1988; Alli et al, 1990)
3-Hydroxy-2-pyranone	$C_5H_4O_3$	a	(Alli et al, 1990)
Methyl cyclopentenolone	$C_6H_8O_2$	a	(Filipic et al., 1965)
3-Hydroxy-2-pyrone	$C_5\ H_4\ O_3$		(Ball, 2007)
2,3-Dihydro-3,5-dihydroxy-6-methyl-4-pyranone	$C_6H_8O_4$		(Ball, 2007)
2-Methylbenzoquinone	$C_7H_6O_2$		(Ball, 2007)
Homosotolone	C7H10O3		(Ball, 2007)
2, 6-Dimethoxybenzoquinonee	$C_8H_8O_4$	a	(Filipic et al., 1965)
Acetol	$C_3H_6O_2$	a	(Filipic et al., 1965)
Acetoin	$C_4H_8O_2$	a	(Filipic et al., 1965)
3-Hydroxy-4-methyl-5-ethyl-2(5H)-furanone	$C_7H_{10}O_3$	a	(Alli et al, 1992)
Aldehyde compounds			
Propionaldehyde	C_3H_6O	a	(Alli et al, 1992)
Furfural	$C_5H_4O_2$	a	(Filipic et al., 1969)
Hydroxymethylfurfural	$C_6H_6O_3$	a	(Filipic et al., 1969)
Acetaldehyde	C_2H_4O	b	(Li & Seeram, 2010)

a: Flavor compound, b: Antioxidant compound.

(1991) reported the presence of 5′-inosine monophosphate in maple syrup (Table 1). This compound, whose concentration was not reported, likely contributes to important taste characteristics of maple syrup.

Potter and Fagerson (1992) detected 133 compounds in medium amber maple syrups from Massachusetts (USA), that were extracted by "acid/neutral" dichloromethane. The study indicated that phenolics accounted for 41% of these compounds and comprised over 70% of the total mass of compounds detected.

Akochi et al. (1994) used capillary gas liquid chromatography to measure the content of total pyrazines in amber, medium and light maple syrup grades from Quebec, Canada at 48.89 ng/g, 70.68 ng/g and 57.29 ng/g, respectively. They found that 2,6-dimethylpyrazine was the most abundant pyrazine across the maple syrup grades, constituting 34–43% of the total pyrazines. 2,5-Dimethyl- and 2-methylpyrazines, trimethylpyrazine were also found in what was described only as considerable amounts. Trimethylpyrazine plays a role in giving the characteristic maple flavour. This study also used gas chromatography/mass spectrometry to measure several pyrazines which had not been previously detected in maple syrup: 2-ethyl-3-methyl-, 2-ethyl-6-methyl-, 2-ethyl-5-methyl-, 2-ethyl-3,5-dimethyl-, 3-ethyl-2,5-dimethyl- and 2,3,5,6-tetramethylpyrazine (Table 4).

Determination of chemical compounds of maple syrup using high performance liquid chromatography (HPLC) and ultraviolet (UV) light was reported by Stuckel et al. (1996). The study confirmed that maple syrup contains major carbohydrates: sucrose, glucose and fructose, and as major organic acids: malic, citric, succinic and fumaric acid. The sucrose content ranged from 51.7 to 75.6% whereas, glucose and fructose content were below 9.6% and 3.9%, respectively. As shown previously, malic acid was found to be the major organic acid in maple syrup with levels ranging from 0.1 to 0.7%, while citric, succinic and fumaric acid were found in trace amounts.

Candi (1997) reported for the first time the presence of Thiamine vitamin in maple syrup at a concentration of 1.3 ppm (Table 1). The study indicated also the presence of Niacin and Riboflavin at a level of 1 and 0.6 ppm, respectively. These vitamin levels are higher than those reported by Morselli (1975a).

Maple syrup is known to be rich in natural amino acids. Pätzold and Brückner (2005) used gas chromatography-mass spectrometry to detect the presence of large quantities of D-amino acids, up to 34% of which was comprised of D-alanine (Table 1). These D-amino acids resulted from partial conversion of L-amino acids through reversible stages of the Maillard reaction (Pätzold & Brückner, 2005).

Ball (2007) determined that sucrose, glucose, and fructose content in maple syrup comprised 68.0%, 0.43%, and 0.30%, respectively. Water content of maple syrup was 31.7%, while malic and fumaric acid levels were 0.47%, and 0.004%, respectively.

Twenty-four phenolic compounds were isolated from a medium-grade maple syrup by Abou-Zaid et al. (2008). These compounds are (a) benzoic acid and several hydroxylated and methoxylated derivatives (gallic acid, 1-O-galloyl-β-d-glucose, γ-resorcylic acid); (b) cinnamic acid derivatives (p-coumaric acid, 4-methoxycinnamic acid, caffeic acid, ferulic acid, sinapic acid, and the ester chlorogenic acid); and (c) flavonoids, including the flavanols catechin and epicatechin, and the flavonols kaempferol and its 3, -O-β-D-glucoside, 3-O-β-D-galactoside, quercetin and its 3-O-β-D-glucoside, 3-O-β-L-rhamnoside and 3-O-rhamnoglucoside (rutin) (Table 2). Concentrations were not reported in this study.

Li & Seeram, (2010) isolated twenty-three phenolic compounds from a butanol extract of Canadian maple syrup (MS-BuOH) (Table 2). They identified several phenolic compounds: 7 lignans lyoniresinol, secoisolariciresinol, dehydroconiferyl alcohol, 5′-methoxy-dehydroconiferyl alcohol, *erythro*-guaiacylglycerol-β-O-4′-coniferyl alcohol, *erythro*-guaiacylglycerol-β-O-4′-dihydroconiferyl alcohol, and [3-[4-[(6-deoxy-α-l-mannopyranosyl) oxy]-3-methoxyphenyl]methyl]-5-(3,4 dimethoxyphenyl)dihydro-3-

Table 4
Elemental composition of maple syrup: Pyrazine compounds.

Identification	Molecularformula	Role	Ref
Methylpyrazine[a]	$C_5H_6N_2$	a	(Alii et al., 1990; Sabik et al., 2012)
2,3-Dimethylpyrazine[a, b]	$C_6H_8N_2$	a,b	(Alii et al., 1990; Sabik et al., 2012)
2,5-Dimethylpyrazine[a,b]	$C_6H_8N_2$	a,b	(Alii et al., 1990; Akochi et al., 1994; Sabik et al., 2012)
2,6-Dimethylpyrazine[a,b]	$C_6H_8N_2$	a,b	(Alii et al., 1990; Akochi et al., 1994)
Ethylpyrazine[a]	$C_6H_8N_2$	a	(Alii et al., 1990)
Trimethylpyrazine[a]	$C_7H_{10}N_2$	a	(Alii et al., 1990; Akochi et al., 1994; Sabik et al., 2012)
2-Ethyl-6-methylpyrazine[a, b]	$C_7H_{10}N_2$	a,b	(Alii et al., 1990; Sabik et al., 2012)
2,5-Dimethyl-3,6-diisobutyl pyrazine[a]	$C_{14}H_{24}N_2$	a	(Alii et al., 1992)
5-Isopropyl-2,3-dimethylpyrazine[a]	$C_9H_{14}N$	a	(Ball, 2007)
2-Methylpyrazine[b]	$C_5H_6N_2$	b	(Akochi et al., 1994)
2-Ethylpyrazine[b]	$C_6H_8N_2$	b	(Sabik et al., 2012)
2-Ethyl-5-methylpyrazine[b]	$C_7H_{10}N_2$	b	(Sabik et al., 2012)
2-Ethyl-3-methylpyrazine[b]	$C_7H_{10}N_2$	b	(Sabik et al., 2012)
2-Methyl-3-isopropylpyrazine[a]	$C_8H_{12}N_2$	a	(Sabik et al., 2012)
2-Methoxy-3-(1-methylethyl)pyrazine[b]	$C_8H_{12}N_2O$	b	(Sabik et al., 2012)
2,6-Diethylpyrazine[a]	$C_8H_{12}N_2$	a	(Sabik et al., 2012)
2-Ethyl-3,5-dimethylpyrazine[a]	$C_8H_{12}N_2$	a	(Sabik et al., 2012)
2,3-Diethylpyrazine[b]	$C_8H_{12}N_2$	b	(Sabik et al., 2012)
2,5-Diethylpyrazine[a]	$C_8H_{12}N_2$	a	(Sabik et al., 2012)
3-Ethyl-2,5-dimethylpyrazine[b]	$C_8H_{12}N_2$	b	(Sabik et al., 2012)
Tetramethylpyrazine[b]	$C_8H_{12}N_2$	b	(Sabik et al., 2012)
2-Methyl-5-propylpyrazine[a]	$C_8H_{12}N_2$	a	(Sabik et al., 2012)
2-Methyl-3-propylpyrazine[a]	$C_8H_{12}N_2$	a	(Sabik et al., 2012)
3,5-Diethyl-2-methylpyrazine[a]	$C_9H_{14}N_2$	a	(Sabik et al., 2012)
2,3-Diethyl-5-methylpyrazine[b]	$C_9H_{14}N_2$	b	(Sabik et al., 2012)
2-Ethenyl-6-methylpyrazine[b]	$C_7H_8N_2$	b	(Sabik et al., 2012)
2-Ethenyl-5-methylpyrazine[b]	$C_7H_8N_2$	b	(Sabik et al., 2012)
2-Acetyl-3-ethylpyrazine[b]	$C_8H_{10}N_2O$	b	(Sabik et al., 2012)

a: Flavor compound, b: Odor compound.

hydroxy-4-(hydroxymethyl)-2(3H)-furanone], 2 coumarins [scopoletin and fraxetin], a stilbene [(E)-3,3′-dimethoxy-4,4′-dihydroxystilbene], and 13 phenolic derivatives [2-hydroxy-3′,4′-dihydroxyacetophenone, 1-(2,3,4-trihydroxy-5-methylphenyl)ethanone, 2,4,5-trihydroxyacetophenone, catechaldehyde, vanillin, syringaldehyde, gallic acid, trimethyl gallic acid methyl ester, syringic acid, syringenin, (E)-coniferol, C-veratroylglycol, and catechol]. Concentrations of these chemicals were not reported.

Li and Seeram (2011a) isolated and identified 30 compounds from maple syrup extracted by ethyl acetate. Four compounds (5-(3″,4″-dimethoxyphenyl)-3-hydroxy-3-(4′-hydroxy-3′-methoxybenzyl)-4-(hydroxymethyl)dihydrofuran-2-one, (*erythro*,*erythro*)-1-[4-[2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy]-3,5-dimethoxyphenyl]-1,2,3-propanetriol, (*erythro*,*threo*)-1-[4-[2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy]-3,5-dimethoxyphenyl]-1,2,3-propanetriol, and 2,3-dihydroxy-1-(3,4- dihydroxyphen yl)-1-propanone) were new in the field of chemistry, and 20 compounds ((*threo*,*erythro*)-1-[4-[(2-hydroxy-2-(4-hydroxy-3-methoxyphen yl)-1-(hydroxymethyl)ethoxy]-3-methoxyphenyl]-1,2,3-propanetriol, (*threo*,*threo*)-1-[4-[(2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy]-3-methoxyphenyl]-1,2,3-propanetriol, *Threo*-guaiacylglycerol-β-O-4′-dihydroconiferyl alcohol, *Erythro*-1-(4-hydroxy-3-methoxyphenyl)-2-[4-(3-hydroxypropyl)-2,6-dimethoxyphenoxy]-1,3-propanediol, Leptolepisol D, Buddlenol E, (1S,2R)-2-[2,6-dimethoxy-4-[(1S,3aR,4S,6aR)-tetrahydro-4-(4-hydroxy-3,5-dimethoxyphenyl)-1H,3H-furo[3,4-*c*]furan-1-yl]phenoxy]-1-(4-hydroxy-3-methoxyphenyl)-1,3-propanediol, Isolariciresinol, Icariside E4, Sakuraresinol, 1,2-diguaiacyl-1,3-propanediol, 2,3-Dihydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)propan-1-one, 3-Hydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)propan-1-one, 4-Acetylcatechol, 3′,4′,5′-Trihydroxyacetophenone, 3,4-Dihydroxy-2-methylbenzaldehyde, 4-(dimethoxymethyl)-pyrocatechol, Isofraxidin, 4-Hydroxyestrone, Phaseic acid) have been reported in maple syrup for the first time. The four new compounds involved 3 lignans and 1 phenylpropanoid. In addition, 5 other phenolic compounds were isolated including 2-[4-[2,3-dihydro-3-(hydroxymethyl)-5-(3-hydroxypropyl)-7-methoxy-2-benzofuranyl]-2,6-dimethoxyphenoxy]-1-(4-hydroxy-3-methoxyphenyl)-1,3-propanediol, Acernikol, Dihydroconiferyl alcohol, 3′,4′,5′-Trihydroxyacetophenone, Protocatechuic acid, Tyrosol (Table 2). Concentrations were not reported in this study.

A novel phenolic compound, 2,3,3-tri-(3-methoxy-4-hydroxyphenyl)-1-propanol named quebecol (Table 2), was isolated by using a combination of chromatographic methods and identified by detailed 1D and 2D nuclear magnetic resonance (NMR) and mass spectral (MS) analyses (Li & Seeram, 2011b). The study indicated quebecol is not present in raw maple sap, but is produced during the processing and/or extraction of maple syrup. Concentrations were not reported in this study.

By using headspace solid-phase microextraction with gas chromatography–mass spectrometry, in a qualitative study Sabik et al. (2012) reported 27 pyrazine compounds in maple syrup. Half of these compounds had not previously been discovered and 15 of the pyrazines were flavour components (Table 4).

By ethanol precipitation, anion exchange chromatography, and nuclear magnetic resonance spectroscopy, Sun et al. (2016) isolated but not quantified inulin (Table 1), and two acidic polysaccharides that were identified as arabinogalactans in maple syrup.

Liu et al. (2017) isolated and identified thirty phenolic compounds from maple syrup. Compounds identified included 2,3-dihydroxy-1-(3,4-dihydroxyphenyl)-1-propanone, 1, C-253 veratroylglycol, 2, 2,3-dihydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)-1-propanone, (*erythro*,*erythro*)-1-[4-(2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy)-3-methoxyphenyl]-1,2,3-propanetriol, 1,2-diguaiacyl-1,3-propanediol, (*eryth ro*,*erythro*)-1-[4-[2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy]-3,5-dimethoxyphenyl]-1,2,3-propanetriol, epicatechin, (*threo*,*erythro*)-1-[4-[2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)e thoxy]-3,5-dimethoxyphenyl]-1,2,3-propanetriol, 3-hydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)propan-1-one, coumaric acid, leptolepisol D, guaiacylglycerol-β-O-4′-coniferyl alcohol, lyoniresinol, *threo*-guaiacylglycerol-β-O-4′-dihydroconiferyl alcohol, isolariciresinol, *erythro*-guaiacylglycerol-β-O-4′-dihydroconiferyl alcohol, [3-[4-[(6-deoxy-α-L-mannopyranosyl)oxy]-3-methoxyphenyl]methyl]-5-(3,4-dimethoxyphenyl)-dihydro-3-hydroxy-4-(hydroxymethyl)-2(3H)-furanone, *erythro*-1-(4-hydroxy-3-methoxyphenyl)-2-[4-(3-hydroxypropyl)-2,6-dimethoxyphenoxy]-1,3-propanediol, 5-(3′',4′'-dimethoxyphenyl)-3-hydroxy-3-(4′-hydroxy-3′-methoxybenzyl)-4-(hydroxym ethyl)dihydrofuran-2-one, secoisolariciresinol, icariside E4, 21, sakuraresinol, dehydroconiferyl alcohol, syringaresinol, acernikol, 2-[4-[2,3-dihydro-3-(hydroxymethyl)-5-(3-hydroxy propyl)-7-methoxy-2-benzofuranyl]-2,6-dimethoxyphenoxy]-1-(4-hydroxy-3-methoxyphenyl)-1,3-propanediol, (1S,2R)-2-[2,6-dimethoxy-4-[(1S,3aR,4S,6aR)-tetrahydro-4-(4-hydroxy-3,5-dimethox (Table 2). These phenolic compounds included the phenylpropanoid-based lignan tetramers, (*erythro*, *erythro*)-4′',4′''-dihydroxy-3,3′,3′',3′'',5,5′-hexamethoxy-7,9′;7′,9-diepoxy-4,8′';4′,8′''-bisoxy-8,8′-dineolignan-7′',7′'',9′',9′''-tetraol and (*threo*, *erythro*)-4′',4′''-dihydroxy-3,3′,3′',3′'',5,5′-hexamethoxy-7,9′;7′,9-diepoxy-4,8′';4′,8′''-bisoxy-8,8′-dineolignan 7′',7′'',9′',9′''-tetraol, which had not been detected in maple syrup previously (Table 2). Concentrations were not reported in this study.

The results of over a century of chemical analyses of maple syrup, have resulted in the isolation of more than 200 naturally occurring and processed-induced compounds. Maple syrup is comprised of a mixture of sugars, water, and other organic compounds such as organic acids, amino acids, proteins, pyrazines, phenolics and some vitamins. In addition, maple syrup contains unique compounds such as an enolic viscous oil and 5′-inosine monophosphate that are responsible for its special taste and odor. The progressive discovery of compounds in maple syrup, especially in the past two decades, reflects significant advances in analytical techniques such as gas chromatography, Nuclear magnetic resonance, and mass spectrometry.

The unique chemical signature of maple syrup can be used to detect adulteration. Most of the studies reported for detecting adulteration of maple syrup focus on malic acid and carbohydrate content (Mohammed et al., 2021). The wide range of chemical compounds (organic acids, amino acids, vitamins, phenolics, pyrazines…) encountered in maple syrup suggests that these components could possibly be used to distinguish maple syrup from other syrups or to detect adulteration of maple syrup. Further studies in this direction are undoubtedly needed.

2.2. Metal composition

Maple syrup contains a wide range of essential and some non-essential metals, which can be concentrated during processing of maple sap. For example, a four-tablespoon serving of maple syrup provides more than 100% of the recommended daily intake of manganese, 18% of zinc, 7% of magnesium, 5% of calcium and 5% of potassium (International Maple Syrup Institute, 2012).

Among the maple syrup minerals, potassium and calcium were reported to be in the highest concentrations compared to magnesium, manganese, and phosphorus. Sodium, iron, zinc, copper, and tin content was low (Table 5) (Morselli, 1975a), with the presence of tin possibly resulting from the use of tin-plated buckets to collect the sap.

Morselli and Whalen (1987) reported a wide range of sodium concentrations (0.1–492 ppm) in maple syrup (Table 5). The study indicated the elevated sodium content may be due to the use of sodium hypochlorite as a sanitizer in maple tubing.

Robinson et al. (1989) analysed the copper, iron, lead, and zinc content in maple syrup samples from Nova Scotia, New Brunswick, and Quebec. Study results indicated that copper, iron, and zinc presence were within the range normally found in food and water except for lead, which ranged from 0.33 to 2.68 ppm (Table 5) which was higher than its typical content in food and water <0.02–0.21, and <0.001–0.08 ppm, respectively (Meranger et al., 1981; Meranger & Smith, 1972).

Stuckel and Low (1996) analyzed potassium, magnesium and calcium content in maple syrup obtained from primary syrup producers in Canada (Quebec, and Ontario) and the United States (Vermont, Massachusetts, Wisconsin, and New Hampshire). The study reported that potassium was present in the greatest concentration range (1005–2990 ppm) compared with magnesium (10–380 ppm) and calcium (266–1702 ppm) (Table 5).

Dumont (1996) analysed potassium, calcium, magnesium, manganese, sodium, phosphorus, iron, zinc, copper, lead, and cadmium content in maple syrup from Quebec. The study showed that the concentration range of potassium was the greatest compared to the other metals, while cadmium was found to be present in the smallest concentration range (Table 5).

Stilwell and Musante (1996) determined lead content in 44 maple syrup samples from trees in Connecticut. The results showed the concentration range of lead over a period of two seasons was 0.38 to 0.95 ppm (Table 5), which is lower than that found by Robinson (1989). The authors suggested that the presence of lead may be due to the use of a bronze gear pump employed in sap transfer steps.

The content of lead, arsenic, cadmium, cobalt, copper, manganese, vanadium and zinc in commercial maple syrups from Vermont was

Table 5
Element content in maple syrup.

Source of maple syrup	Mineral	Concentration (ppm)	Ref
United States (Vermont)	Potassium	1300–3900	(Morselli, 1975a)
Canada (Quebec, Ontario), United States (Vermont, Massachusetts, Wisconsin, New Hampshire, Michigan)		1005–2990	(Stuckel & Low, 1996)
Canada (Quebec)		541–4031	(Dumont, 1996)
–		1600–2590	(Perkins (unpublished, Perkins et al., 2006)
–		963–3319	(van den Berg, Perkins and Isselhardt (unpublished), Perkins et al., 2006)
United States (Vermont)	Calcium	400–2800	(Morselli, 1975a)
Canada (Quebec, Ontario), United States (Vermont, Massachusetts, Wisconsin, New Hampshire, Michigan)		266-l 707	(Stuckel & Low, 1996)
Canada (Quebec)		541–4031	(Dumont, 1996)
–		600–1250	(Perkins (unpublished, Perkins et al., 2006)
–		278–2494	(van den Berg, Perkins and Isselhardt (unpublished)., Perkins et al., 2006)
United States (Vermont)	Magnesium	12–360	(Morselli, 1975a)
Canada (Quebec, Ontario), United States (Vermont, Massachusetts, Wisconsin, New Hampshire, Michigan)		10–380	(Stuckel & Low, 1996)
Canada (Quebec)		11–575	(Dumont, 1996)
–		0–198	(Perkins (unpublished)., Perkins et al., 2006)
–		25–543	(van den Berg, Perkins and Isselhardt (unpublished)., Perkins et al., 2006)
United States (Vermont)	Manganese	2–220	(Morselli, 1975a)
Canada (Quebec)		< 1–252	(Dumont, 1996)
United States (Vermont)		0.002–0.101	(Bhandari & Amarasiriwardena, 2000)
–		0–117	(Perkins (unpublished)., Perkins et al., 2006)
–		0.01–223	(van den Berg, Perkins and Isselhardt (unpublished)., Perkins et al., 2006)
United States (Vermont)	Sodium	0–6	(Morselli, 1975a)
United States (Vermont, Sugarmakers)		0.1–492	(Morselli & Whalen, 1987)
Canada (Quebec)		< 1–261	(Dumont, 1996)
–		0–27	(Perkins (unpublished, Perkins et al., 2006)
–		0.01–492	(van den Berg, Perkins and Isselhardt (unpublished), Perkins et al., 2006
	Phosphorus	79–183	(Morselli, 1975a)

(continued on next page)

Table 5 (*continued*)

Source of maple syrup	Mineral	Concentration (ppm)	Ref
United States (Vermont)			
Canada (Quebec)		< 2–235	(Dumont, 1996)
–		20–113	(Perkins (unpublished, Perkins et al., 2006)
–		0.01–91	(van den Berg, Perkins and Isselhardt (unpublished), Perkins et al., 2006)
United States (Vermont)	Iron	0–36	(Morselli, 1975a)
Canada (Nova Scotia, New Brunswick, Quebec)		0.41–44	(Robinson et al., 1989)
Canada (Quebec)		0–18	(Dumont, 1996)
–		0–18	(Perkins (unpublished, Perkins et al., 2006)
–		0.01–61	(van den Berg, Perkins and Isselhardt (unpublished), Perkins et al., 2006)
Source of maple syrup	Mineral	Concentration (ppm)	Ref
United States (Vermont)	Zinc	0–90	(Morselli, 1975a)
Canada (Nova Scotia, New Brunswick, Quebec)		2.81–129	(Robinson et al., 1989)
Canada (Quebec)		2–43	(Dumont, 1996)
United States (Vermont)		0.0052–0.044	(Bhandari & Amarasiriwardena, 2000)
–		0–96	(Perkins (unpublished, Perkins et al., 2006)
–		0–130	(van den Berg, Perkins and Isselhardt (unpublished), Perkins et al., 2006)
United States (Vermont)	Copper	0–20	(Morselli, 1975a)
Canada (Nova Scotia, New Brunswick, Quebec)		0.09–8.28	(Robinson et al., 1989)
Canada (Quebec)		0–8	(Dumont, 1996)
United States (Vermont)		0.051–2.416	(Bhandari & Amarasiriwardena, 2000)
–		0–6	(Perkins (unpublished, Perkins et al., 2006)
United States (Vermont)	Tin	0–33	(Morselli, 1975a)
–		0–24	(Perkins (unpublished, Perkins et al., 2006)
United States (Vermont)	Lead	0–0.25	(Morselli, 1975a)
Canada (Nova Scotia, New Brunswick, Quebec)		0.33–2.68	(Robinson et al., 1989)
Canada (Quebec)		0–0.49	(Dumont, 1996)
United States (Connecticut)		0.38–0.948	(Stilwell & Musante, 1996)
United States (Vermont)		0.018–0.367	(Bhandari & Amarasiriwardena, 2000)
–		0–0.35	(Perkins (unpublished, Perkins et al., 2006)
Canada (Quebec)	Cadmium	0–0.09	(Dumont, 1996)
United States (Vermont)		1.5–49	(Bhandari & Amarasiriwardena, 2000)
–		0–0.07	(Perkins (unpublished, Perkins et al., 2006)
–	Aluminum	0.01–18	(van den Berg, Perkins and Isselhardt (unpublished), Perkins et al., 2006)
–	Boron	0.01–3	(van den Berg, Perkins and Isselhardt (unpublished), Perkins et al., 2006)
–	Sulfur	0.01–100	(van den Berg, Perkins and Isselhardt (unpublished), Perkins et al., 2006)
United States (Vermont, Sugarmakers)	Chloride	31–191	(Morselli & Whalen, 1987)
United States (Vermont)	Arsenic	0.0015–0.0071	(Bhandari & Amarasiriwardena, 2000)
United States (Vermont)	Cobalt	0.011-< 0.089	(Bhandari & Amarasiriwardena, 2000)
United States (Vermont)	Vanadium	<0.0011–0.173	(Bhandari & Amarasiriwardena, 2000)

reported by Bhandari & Amarasiriwardena, (2000). Lead levels ranged from 0.018 to 0.367 ppm, this range is less than the range of lead that Robinson et al. (1989) and Stilwell & Musante (1996) indicated, respectively. Concentration ranges of other elements such as As, Cd, Co, Cu, Mn, V were 0.0015–0.0071 ppm, 1.5–49 ppm, 0.011-<0.089 ppm, 0.051–2.416 ppm, 0.002–0.101 ppm, and <0.0011–0.173 ppm, respectively (Table 5).

Perkins et al. (2006), cited unpublished studies from their group about the content of potassium, calcium, magnesium, manganese, sodium, phosphorus, iron, zinc, copper, tin, lead, and cadmium in maple syrup samples as presented in Table 5. Lead levels ranged from 0 to 0.35 ppm. This range is close to the range of lead measured in the study of Bhandar & Amarasiriwardena, (2000). The level ranges of copper (0–6 ppm) and zinc (0–96 ppm) were higher than food safety levels and for copper (0.17–2.79) ppm and zinc (0.5–43 ppm), respectively.

Greenough et al. (2010) analyzed 39 elements in maple syrup. The study demonstrated that the degree of boiling, and associated change of color, had an effect on the metal composition of maple syrup. The study indicated that osmosis syrups have lower high field-strength element (3+ and 4+) concentrations than boiled syrups. This is attributed to the loss of small cations passing through the osmosis membrane with water.

Based on the studies presented in this section, clear trends of either increasing or decreasing metal content of maple syrup across the different years of production were noted. The precise reason for these fluctuations is unknown, but two explanations can be put forward: 1) it is a consequence of regretful and undetected accidents or exposure to processing equipment during the maple syrup preparation process, or 2) the result of climatic changes in the maple tree production regions. Though all studies of mineralogical residence of maple syrup indicated potassium content was greatest in concentration compared to other metals, nevertheless a change (both increases and decreases) in its content during production years was also observed. Four studies (Robinson et al., 1989; Stilwell & Musante, 1996; Bhandari & Amarasiriwardena, 2000; Perkins et al., 2006) showed lead content was elevated compared with its typical content in food and water < 0.02–0.21, and < 0.001–0.08 ppm, respectively (Meranger et al., 1981; Meranger & Smith, 1972).

As with the use of organic signatures in maple syrup to detect adulteration, metal content determination has recently gained a lot of interest as a method of choice to detect adulteration in food (Latorre et al., 1999; Mohammed et al., 2018; Mohammed et al., 2019). In conjunction with the development of analytical tools, the possibility of using the elemental content of maple syrup as a strong marker that could be used to fingerprint maple syrup against other syrups needs to be actively investigated. Literature analysis supports the possibility of identifying percentages allowing the detection of adulteration of maple syrup with inexpensive syrups using element content. However, large fluctuations in metal content have been reported which obscures consistent comparisons, and possible release of metal from instruments can disrupt data accuracy.

3. Conclusion and future perspective

More than 200 chemical compounds have been identified in maple syrup. Maple syrup also contains various metals whose content was found to fluctuate, increasing and decreasing over the production years as shown in Table 5. These fluctuations may result from annual climatic variability and soil type in the maple tree production regions leading to differential uptake of soil elements or could be linked to process-related contamination during maple syrup preparation (e.g., use of tin containers to collect sap; lead in gear pumps during processing, etc.). While many studies have measured the metal content of maple syrup, no studies have attempted to systematically relate temporal fluctuations to environmental factors. In fact, such studies are rare for most elements found in maple and other syrups. Interestingly, compounds often found in minute amounts are responsible for the specific taste and smell of maple syrup; and other compounds, present in both minute amount and larger quantities, contribute to its health benefits. Exact knowledge of maple syrup composition should be useful to fully assess the health benefits of maple syrup and possibly identify new health benefits. In this context, many of the chemicals identified in maple syrup have no ascribed function. Future research, therefore, should focus on establishing their contributions, if any, to taste, odor, or nutritional quality. Further, conducting such studies will be useful to identify powerful markers to discriminate maple syrup from other syrups to avoid forgery or adulteration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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