Christmas tree production in Europe: Control of declared geographical origin by stable isotope analysis – a pilot study

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Christbaumproduktion in Europa: Kontrolle geographischer Herkunftsangaben durch Stabil-Isotopenuntersuchung – eine Pilotstudie

Introduction

Especially in Western Europe a Christmas tree is very popular and usual to have at home for the Christmas ceremony. Many consumers want to buy regional or local trees, as this is a tradition practiced by their parents. Moreover, there is the consumer's expectation that trees felled shortly before selling will keep their needles longer and regional farmers will be supported. Thus many Christmas trees grown in Austria have a banderole naming country and region of origin. However, cases have been reported where foreign trees have been incorrectly labeled using Austrian banderole, sold as Austrian trees and consumers have thus been deceived. Therefore a method is needed that can control the product itself for its origin of production.

Stable isotopes are already used on a routine base for the control of origin of European wine (e.g. CHRISTOPH et al., 2004), and in numerous studies have also been demon-

Summary

Conifer trees sold as Christmas trees in Austria often have a designation of origin, as Christmas is a traditional holiday and religious celebration and emotionally connected to one's home and region. Therefore many people want to strengthen this link by buying a tree of local origin. As imported conifer trees are usually cheaper than the locally grown ones, a measure to control the declaration of geographical origin is necessary. We analyzed spruce needle samples originating from Austria and different other European countries for their stable isotope pattern of H, C, N, S. Main discriminating parameters are hydrogen and sulfur isotopes. These variations are caused by differences in the environmental conditions at the respective locations such as climate and/or water sources, the proximity of the sea and the soil sulfur isotope composition.

Key words: Spruce, fir, hemlock, conifer, Christmas tree, geographic origin, stable isotope, precipitation, sulfur, hydrogen.

Zusammenfassung

Tannenbäume, die zur Weihnachtszeit verkauft werden, haben oft eine Herkunftskennzeichnung, da viele Leute bevorzugt heimische Bäume kaufen. Weihnachten ist ein traditioneller, religiöser Feiertag und emotional mit Heimat und Zuhause verbunden, was viele Menschen auch durch einen heimischen Tannenbaum zum Ausdruck bringen wollen. Da importierte Tannen gewöhnlich günstiger sind als die lokale Konkurrenz, ist eine Kontrolle der deklarierten Herkunft notwendig. In dieser Arbeit wird die H-, C-, N- und S-Isotopie von Tannennadeln aus Österreich und dem europäischen Ausland untersucht. Die aussagekräftigsten Parameter sind die Wasserstoff- und die Schwefelisotopie. Die beobachteten Unterschiede können durch umweltbedingte Unterschiede der jeweiligen Herkunft erklärt werden, wie etwa die klimatischen Bedingungen und/oder Wasserherkunft, die Nähe zum Meer und die Schwefelisotopie im Boden.

Schlagworte: Tannenbaum, Nadelbaum, Weihnachtsbaum, Herkunft, stabile Isotope, Niederschlag, Schwefel, Wasserstoff.

strated to be a potent tool for the control of origin of other kinds of food stuffs, as meat (e.g. HEATON et al., 2008; BONER and FÖRSTEL, 2004; CAMIN et al., 2007; GUO et al., 2008; HORACEK and MIN, 2010), milk (e.g. KORNEXL et al., 1996; CRITTENDEN, 2006; CAMIN et al., 2008; HORACEK and PAPESCH, 2008), vegetables (e.g. SCHLICHT et al., 2006; KELLY et al., 2009; HORACEK et al., in review) and fruits (e.g. CAMIN et al., 2009) or honey (e.g. SCHELLENBERG et al., 2010; KROPF et al., 2010).

HORACEK et al. (2008 and 2009) have demonstrated that the origin of Siberian larch wood can be controlled by stable isotope investigations. KAGAWA and LEAVITT (2010) published the use of carbon isotopes to determine the provenance of pine trees from southwest USA. Other techniques that might be useful for the determination or control of wood origin are DNA methods (e.g. DEGUILLOUX et al., 2004; DEGEN and FLADUNG, 2007) and tree-ring patterns (e.g. van Stone, 1958).

Carbon and oxygen isotope measurements in wood have been performed by numerous researchers to investigate the potential of tree rings as climatic archives for paleoclimatic studies (e.g. BALLANTYNE et al., 2006, and references therein). KEPPLER et al. (2007) investigated the hydrogen isotope composition of lignin methoxy groups from wood. All of the studies dealt with wood samples, not with tree needles, as often no needle samples were available any more. In this study the needles were analysed instead of wood material as they contain higher amounts of nitrogen and sulphur.

The isotopic composition of wood and tree needles is influenced by the environmental conditions at the cultivation sites. Carbon isotopes in photosynthetically produced organic matter are determined by the isotope ratio of the CO_2 incorporated by photosynthesis and the intercellular CO_2 concentration (FARQUHAR et al., 1982). Limited water availability results in closing of the plant stomata leading to a decrease of the intercellular CO_2 concentration causing reduced ^{13}C discrimination and therefore enriched $\delta^{13}C$ ratios (FARQUHAR et al., 1989; BARBOUR et al., 2002).

Oxygen and hydrogen isotopes in wood cellulose and tree needles are controlled by the isotope ratio of the soil water consumed and its enrichment due to leaf/needle transpiration (RODEN et al., 2000; YAKIR and STERNBERG, 2000; BARBOUR et al., 2001). The isotope ratio of the soil water is directly linked to precipitation and evaporation processes in the soil, which are both influenced by the geographic position and thus climatic conditions such as temperature. Transpiration is controlled by opening and closing of the leaf/needle stomata, which is depending on water availability.

The climate within Europe shows some variability, with maritime climate (mild winters, moderate summers, precipitation throughout the year) close to the coastal and generally western European regions and more continental climate (cold winters, hot summers, seasonal precipitation maxima) in eastern and central Europe, also evidenced by differences in the isotope composition of western and eastern European precipitation, as the isotope ratio in precipitation is controlled by climate and geographic position (BOWEN and REVENAUGH, 2003; Fig. 1). Water vapour evaporating from a water reservoir is isotopically depleted with respect to the water it emanates; it is fractionating isotopically (DANSGAARD, 1964). The fractionation is dependent on temperature, with strong fractionation at low and minor fractionation at elevated temperatures. Water vapour migrating in clouds from the Atlantic Sea eastwards across Europe becomes successively more and more isotopically depleted in ^{18}O and ^{2}H (latitude effect), as the heavy oxygen and hydrogen isotopes preferentially get into the liquid phase (rain, snow) and are in this way removed from the clouds (GAT & CONFIANTINI, 1981).

Materials and Methods

Fir tree twig samples have been taken from eight different locations: Northern and southern Waldviertel (northeastern Austria), Hungary, eastern and western Denmark, northern Germany and two samples from Ireland (see Fig. 1). The needles were removed from the twigs and dried in a dry-oven at 45 °C overnight. Afterwards the needle samples were homogenized and weighed into tin and silver capsules for C, N, S and H isotopes, respectively.

Measurements were performed with a Finnigan™ thermal combustion elemental analyzer (TC/EA) for hydrogen and a Vario™ elemental analyzer (EA) for C, N and S isotopes, both analyzers are connected via a Finnigan™ ConFlo to an Finnigan™ isotope ratio mass spectrometer (IRMS), where the isotope ratios are determined.

Results are reported in the conventional δ notation in permil (‰) with respect to international standards: V-SMOW (Vienna Standard Mean Ocean Water), V-PDB (Vienna Peedee Belemnite), N_{air} and CDT (Canyon Diablo Troilite) for hydrogen, carbon, nitrogen and sulfur, respectively. Standard deviation is better than 1.5 ‰ for hydrogen, 0.2 ‰ for carbon and nitrogen and 0.4 ‰ for sulfur isotopes, respectively (1 σ).

As the hydrogen isotopes partially exchange they have to

Figure 1: Map of Europe with indication of origin of the investigated samples. 1: Ireland, 2: western Denmark, 3: eastern Denmark, 4: northern Germany, 5: Hungary, 6: southern Waldviertel, 7: northern Waldviertel

Abbildung 1: Karte von Europa mit den Herkunftsorten der untersuchten Proben. 1: Irland, 2: West-Dänemark, 3: Ost-Dänemark, 4: Norddeutschland, 5: Ungarn, 6: südliches Waldviertel, 7: nördliches Waldviertel

be corrected with a calibrated standard (casein), see CAMIN et al. (2007), SCHELLENBERG et al. (2010) and HORACEK and MIN (2010).

Results

The results are shown in Table 1 and Fig 2A–C. The "Waldviertel" samples show values of -128 and -127 ‰, -30,3 and -26,7 ‰, -0,7 and 1,4 ‰ and 5,4 and 5,6 ‰ for hydrogen, carbon, nitrogen and sulfur isotopes, respectively; the Danish fir needles have $\delta\,^{2}H$ values of -122 and -113 ‰, δ^{13} C values of -31,8 and -31,2 ‰, δ^{15} N values of -1,9 and 2,2 ‰ and δ^{34} S values of 6,3 and 8,5 ‰; and the Irish trees show -107 and -101 ‰, -30,9 ‰, 2,4 and 3,3 ‰ and 8,2 and 8,7 ‰ for hydrogen, carbon, nitrogen and sulfur isotopes. The isotopic pattern for the fir needle sample from northern Germany is -111 ‰, -31,7 ‰, -0,2 ‰ and 8,1 ‰; and from Hungary -123 ‰, -30,2 ‰, 2,6 ‰ and 6,4 ‰ for hydrogen, carbon, nitrogen and sulfur isotopes, respectively.

Table 1: $\delta^{2}H$, $\delta^{13}C$, $d\delta^{15}N$ and $\delta^{34}S$ isotope values of investigated fir needle samples
Tabelle 1: $\delta^{2}H$-, $\delta^{13}C$-, $\delta^{15}N$- und $\delta^{34}S$-Isotopenwerte der untersuchten Tannennadelproben

		Sample No.	$\delta^{2}H$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{34}S$
1	Denmark – West	155969	-113	2,2	-31,2	8,1
2	Ireland	155970	-101	2,4	-30,9	8,2
3	Germany – North	155971	-111	-0,2	-31,7	8,1
4	Ireland	155972	-107	3,3	-30,9	8,7
5	Hungary	155973	-123	2,6	-30,2	6,4
6	Austria – northern Waldviertel	155974	-127	1,4	-26,7	5,6
7	Austria – southern Waldviertel	155975	-128	-0,7	-30,3	5,4
8	Denmark – East	155976	-122	-1,9	-31,8	6,3

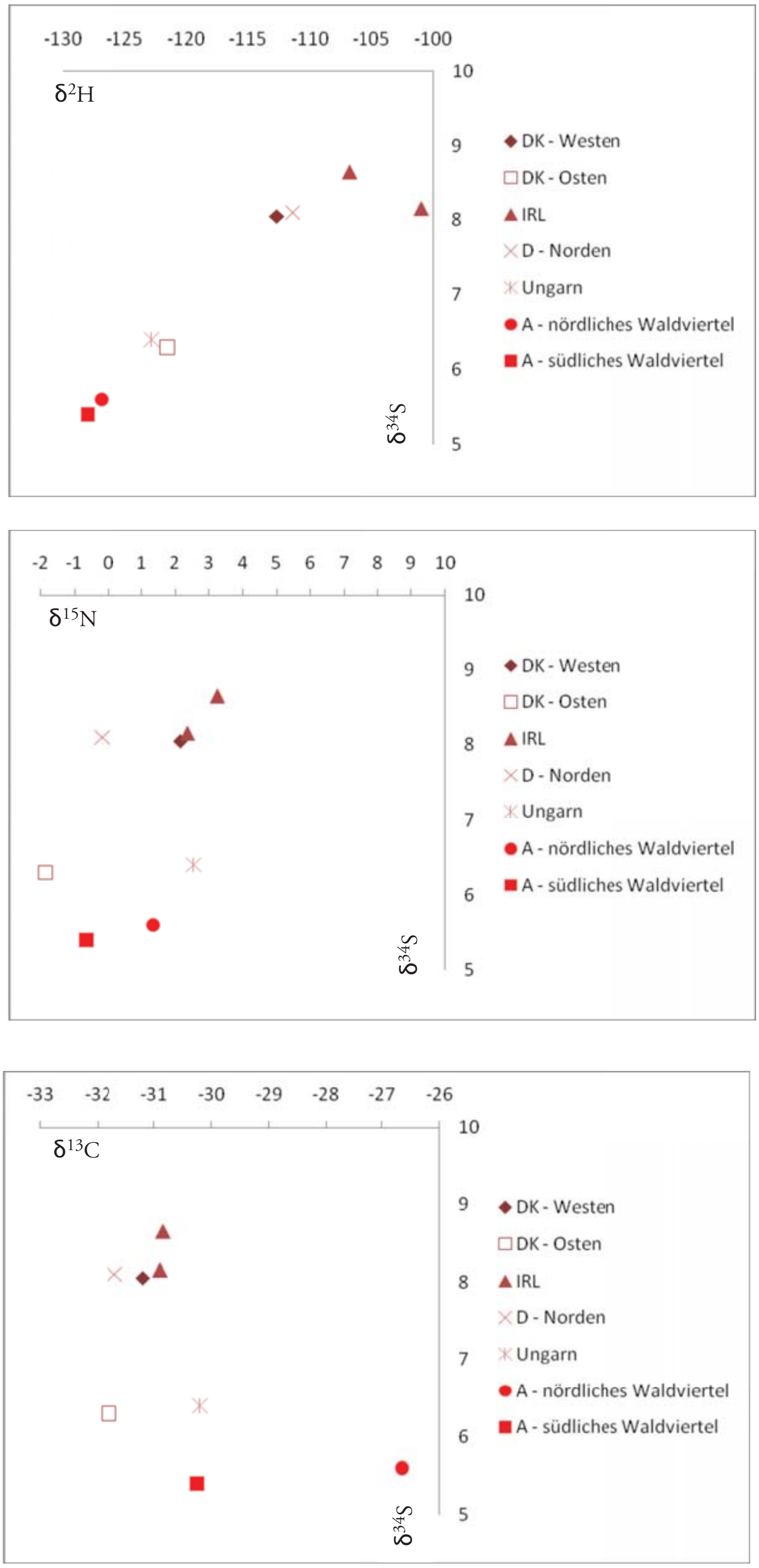

Figure 2A–C: A: δ^2H versus $\delta^{34}S$ of the analyzed tree needle samples. There are two sample groups: One group represents the trees grown in a continental climate (low δ^2H values) and the second group represents the trees grown in a maritime climate close to the coast (elevated δ^2H – values and elevated $\delta^{34}S$ values). It is interesting to note that the sample from Eastern Denmark plots in the "continental" group.
B: $\delta^{15}N$ versus $\delta^{34}S$. The $\delta^{15}N$ values show only a small variation giving no distinctive geographic indication so far.
C: $\delta^{13}C$ versus $\delta^{34}S$. Also $\delta^{13}C$ isotopes give mainly homogeneous values around -31 ‰. One Austrian sample is significantly enriched in ^{13}C with respect to the other samples.

Abbildung 2A–C: A: Darstellung der δ^2H- gegen $\delta^{34}S$-Ergebnisse der untersuchten Nadelproben. Es existieren 2 Gruppen: Eine Gruppe besteht aus den Bäumen, die in einem kontinentalen Klima gewachsen sind (niedrige δ^2H-Werte), die zweite Gruppe ergibt sich aus den Proben, die von einer Küstenregion stammen (angereicherte Wasserstoff- und Schwefelisotopenwerte). Interessant ist, dass auch die ostdänische Probe in die letztere Gruppe fällt.
B: Darstellung der $\delta^{15}N$- gegen die $\delta^{34}S$-Werte. Die $\delta^{15}N$-Werte zeigen nur geringe Variationen und geben daher keinen herkunftsrelevanten Hinweis.
C: $\delta^{13}C$ gegen $\delta^{34}S$. Auch die Kohlenstoffisotopenwerte zeigen gleichartige Werte um -31 ‰. Eine österreichische Probe ist jedoch signifikant angereichert im Vergleich mit den übrigen Proben.

Discussion

The hydrogen isotope values of the investigated samples can be related to the δ^2H pattern of the ambient precipitation water the sampled trees probably had access to, with higher δ^2H values in coastal areas and lower δ^2H signals in continental regions (BOWEN and REVENAUGH, 2003). It can be concluded that the hydrogen isotope ratio of the investigated samples is dominantly influenced by the isotope pattern of the precipitation in Europe, which in turn depends on factors like proximity to the sea, temperature and altitude. The hydrogen isotope values clearly distinguish two groups with one represented by high δ^2H values of the samples grown in coastal regions (Ireland, N-Germany and W-Denmark). The second group is formed by the samples of more continental origin having lower δ^2H values (Austria, Hungary and eastern Denmark). The latter result is quite interesting, as such a variation across Denmark was not anticipated and thus needs to be confirmed with a larger number of samples.

The $\delta^{13}C$ values of the Austrian fir samples (and also from the other samples investigated in this study) are more negative to barely reaching the carbon isotope values measured for the larch wood samples (ranging from -26,1 to -23,5 ‰ $\delta^{13}C$) in HORACEK et al. (2009). This might be due to the fact that the investigated samples are "farmed" trees with conditions for optimum growth and thus always sufficient water supply, whereas the larch trees often come from less favorable sites where they had to endure more water stress, or due to the presence of significant amounts of lipids, which are isotopically depleted with respect to wood cellulose and lignin, in the needles. Alternatively it also can be related to the different morphologies of the invested tree species with the larch being a deciduous tree and the fir a conifer. However, usually the deciduous trees are more depleted in ^{13}C than the conifers (unpublished data). One Austrian sample, however, shows significantly enriched $\delta^{13}C$ values, arguably evidencing a less favorable growing locality.

Nitrogen isotope values of the analyzed samples are generally quite low, from slightly negative to slightly positive values. This can be explained by the application of synthetic fertilizer having a nitrogen isotope composition close to 0 ‰ (BATEMAN and KELLY, 2007), as these trees grown in tree nurseries are usually fertilized (Karl Schuster, oral communication 2011).

The sulfur isotope composition of the investigated samples shows a pattern of "enriched" values (above about 8 ‰) at sites close to the sea (e.g. Ireland, northern Germany and western Denmark) and values significantly lower for sites further away from the sea. This can be explained by the influence of wind-transported sea spray bringing seawater sulfate from the sea on to the soil close by. The current sulfur isotope composition of the sea is around +23 ‰ (e.g. Kampschulte et al., 2004). This effect has been observed before, e.g. in lamb meat (CAMIN et al., 2007), beef (HORACEK et al., 2009) and honey (SCHELLENBERG et al., 2010).

Conclusions

Fir trees of different origin have been successfully differentiated by the stable isotope signatures of the fir needles, due to differing environmental conditions at the growth sites. Main discriminating parameters indicative for the investigated regions were the hydrogen isotope composition, related to the precipitation, and the sulfur isotope ratio, related to the proximity to the sea and the bed rock geology. This is a pilot study demonstrating the potential of stable isotope analysis for the determination of origin of Christmas trees. However, the investigation of a larger sample set will be necessary to verify these first results and to show the spread of the isotopic signal within the investigated regions.

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