Apidologie 30 (1999) 277–287

Original article

Radionuclides and selected elements in soil and honey from Gorski Kotar, Croatia

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(Received 1 August 1998; revised 27 March 1999; accepted 5 May 1999)

Abstract – This research compared the transfer of ^{137}Cs, ^{40}K, Ca, Fe, Rb, Sr, Cu, Zn, Pb, Ni, Mn and Cr from soil into honey derived from meadow flora, mixtures of floral and honeydew honey, and honeydew honey from fir and spruce forests in Gorski Kotar, Croatia. Radionuclides were measured by gamma-ray spectrometry, while other element concentrations were measured by X-ray fluorescence (XRF). Transfer factors (T_f) from soils into the studied honey types, expressed as a percentage, are defined as the ratio between element concentration in honey and in soil multiplied by 100. No significant differences were found, at $P < 0.05$, for all studied element concentrations for honeydew honey and mixed honey, in relation to the respective soil types from which honeys were collected. Concentrations of all studied cations were, at $P < 0.05$, significantly higher in honeydew honey compared to either mixed honey or floral honey. Honeydew honey could be used as a pollution indicator of ^{137}Cs, Cu, Rb, Cr and possibly Ni. © Inra/DIB/AGIB/Elsevier, Paris

radionuclides / trace elements / soil / honey / transfer / biological indicator

1. INTRODUCTION

Radionuclides, as well as heavy metals and trace elements occur either as normal constituents of soils or as a result of dry and wet depositional processes due to global atmospheric contamination. Cations can migrate upwards from soils into nectar and

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honeydew by plant uptake. A plant's ability to take up radionuclides and other elements depends on various factors: plant species, sorption and desorption processes in soil, soil mineral composition, soil moisture and precipitation, grain size and specific surface area, soil types, pH, organic matter content, cations competitive effects and other factors [5, 9, 10, 17, 19–22].

Depending on the aforementioned factors, different cations, including pollutants and radionuclides, appear in honey [2, 8, 11, 14]. Honey bees and their products have been used as indicators and monitors of a variety of environmental pollutions because of their ability to reflect the immediate environmental conditions [6, 15, 16, 23, 24]. Among plant species, heather, *Calluna vulgaris*, is a well-known indicator of caesium pollution [1, 13].

Relatively high ^{137}Cs activities, found in honeydew honey [15], indicate high rates of cation uptake by coniferous trees. Honeydew is a sugar solution yielded by the hindgut of homopteran insects. These insects pierce and feed on young branches and needles of trees. Leaf-lice and shield-shaped-lice are prevalent in spruce and fir woods of the Gorski Kotar area.

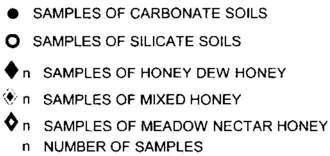
In their nectar gathering, honey bees forage a radius of a few kilometres from the hive. While collecting nectar and honeydew, honey bees provide a composite sample from thousands of different points spreading across a broad area. On a typical day, a colony of bees will make several tens of thousands of foraging flights [7].

Measurements of radionuclides and selected elements in soil, fir and different honey types have been used in previous studies to determine the indicator capability of honey for caesium and to follow behaviour and the fate of caesium in the environment [3, 15]. The research described in this report was carried out in order to examine selected cation concentrations in different honey types collected from meadow and forest areas far from any known source of pollution. The Gorski Kotar area of Croatia is thought to be exposed only to pollutants that are deposited as fallout from global atmospheric contamination. The resultant transfer factors for soil macroelements potassium (^{40}K activity of ≈309 Bq·kg^{-1} corresponds to 1 % of total potassium), calcium and iron, for microelements and/or possible pollutants (Rb, Sr, Cu, Zn, Pb, Ni, Mn and Cr) and for global radioactive pollutant ^{137}Cs are presented in this paper. The aim of this study was to find which kind of honey and which cations can be used best as pollution indicator.

2. MATERIALS AND METHODS

Soil samples were taken in 1994, 1996 and 1997. Each sample was a composite from the surface down to 15 cm in depth. Two main soil types were analysed; soils developed on Palaeozoic bedrock and Quaternary lacustrine sediments (dominantly silicate soils) and soils developed on Mesozoic limestones and dolomites (dominantly carbonate soils). Air-dried soil was repeatedly passed through a 2-mm sieve and quartered to produce material with a grain size less then 0.5 mm. The sieved fraction was then dried at 105 °C to a constant weight, and pressed into pellets prior to XRF and gamma-ray spectrometry analyses.

Since 1993, samples of honey have been regularly collected in the summer and early autumn. Twelve stationary apiaries and six single colonies with *Apis mellifera* have been used in this study. Locations of soil and honey sampling are shown in *figure 1*. Honey samples were collected mechanically, by extracting honey from combs. Honey types (meadow honey, mixed floral and honeydew honey, and honeydew honey) were identified on the basis of pollen analyses [18] and electroconductivity measurements [25] performed by a multirange conductivity meter HI 8733 (Hanna Instruments). A standard sample of 300 pollen grains was used for pollen- and honey-type determination. Among determined pollen grains, in meadow and mixed honey *Centaurea* sp., *Trifolium* sp., *Plantago* sp., *Lotus corniculatus, Salvia* sp., *Campanula* sp., *Anthyllis* sp., *Alectorolopus* sp. and *Thymus* sp. prevailed. Determination of radioactivity and selected element concentrations in honey were performed by gamma-ray spectrometry and the XRF method.



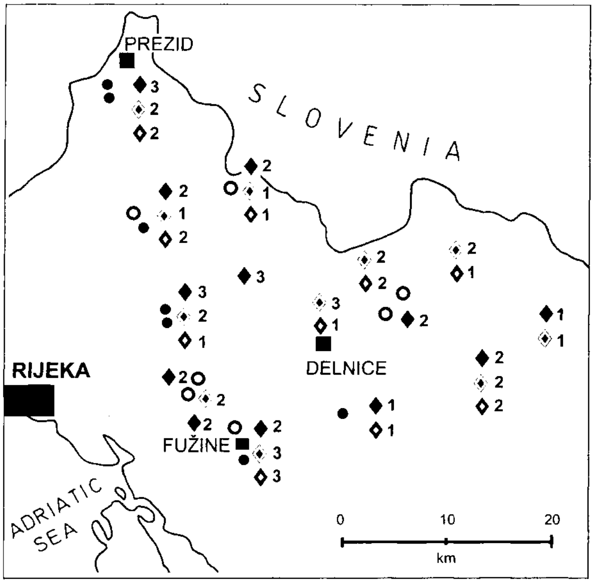


Figure 1. Sketch map of Gorski Kotar area, Croatia, indicating soil and honey sampling locations.

2.1. XRF method

Samples of soil, pressed into pellets or samples of honey in native form were placed in counting vessels. Specimens were excited by a ^{109}Cd annular source IPR, 25 mCi. Emitted characteristic X-rays were detected by the system's Si-detector (resolution 165 eV at 5.9 keV) and Canberra MCA S-100 software. Counting times were 10 000–50 000 s. United States National Bureau of Standards (NBS) Orchard Leaves SRM 1571 was used for quantitative analysis. X-ray spectra were evaluated by International Atomic Energy Agency (IAEA) software 'QXAS-AXIL', using the procedure 'simple quantitative analysis – elemental sensitivities' [12]. Single counting errors were taken as detection limits.

2.2. Gamma-ray spectrometry

The activities of ^{137}Cs and ^{40}K were determined by gamma-ray spectrometry, using a low background hyper pure germanium (HPGe) semiconductor detector system coupled to a 4096 channel analyser. The spectra were recorded 80 000 s, and analysed with a personal computer (PC) using GENIE PC Canberra software. Activities of ^{137}Cs in samples were recalculated on the 1 July of each year of sample collection. Double counting errors were taken as detection limits.

2.3. Statistical evaluation

The majority of sampled honeys were collected from the mixture of silicate and carbonate terrains, only one third originated from well-known, strictly silicate or carbonate terrains. Because the small number of well-defined samples of soil or meadow were available, only the t-test was used in statistical evaluation of collected data.

3. RESULTS

All measured element concentrations, excluding Zn, were higher in soils developed on carbonate bedrocks than in dominantly silicate soils (*table I*). This was especially evident in the case of Rb, Sr, Mn and Fe (at $P < 0.01$) as well as in the case of Ca and Ni at $P < 0.05$. The highest concentrations of these elements in dominantly silicate soils seldom exceeded the lowest concentrations found in soils developed from car-

Table I. Radionuclide activities ($Bq \cdot kg^{-1}$) and selected element concentrations ($mg \cdot kg^{-1}$) in Gorski Kotar soils.

Element	All analysed soils ($n = 14$)		Carbonate soils ($n = 7$)		Silicate soils ($n = 7$)	
	Range	Mean ± σ	Range	Mean ± σ	Range	Mean ± σ
^{40}K	259–715	411 ± 106	342–507	423 ± 50	259–715	398 ± 147
^{137}Cs	43.1–500.0	176.0 ± 126.6	51.2–500.0	199.5 ± 143.7	43.1–342.0	152.5 ± 113.0
Rb	76.5–177.3	123.9 ± 33.0	124.7–177.3	150.7 ± 18.6	76.5–109.8	97.1 ± 12.3
Ca	1 400–50 400	11 600 ± 14 650	6 550–50 400	20 550 ± 16 650	1 400–4 100	2 650 ± 900
Sr	35.6–115.3	76.7 ± 26.7	79.0–115.3	99.9 ± 12.6	35.6–69.8	53.5 ± 11.6
Ni	10.1–59.4	25.2 ± 14.8	20.7–59.4	37.0 ± 11.8	10.1–16.3	13.5 ± 2.0
Cu	19.9–61.3	36.8 ± 11.2	19.9–61.3	41.6 ± 13.1	21.5–42.7	32.1 ± 7.1
Zn	47.4–874.0	181.6 ± 209.7	108.0–255.6	177.9 ± 50.2	47.4–874.0	185.2 ± 304.5
Pb	31.6–97.9	64.1 ± 21.9	47.4–97.9	72.8 ± 19.2	31.6–94.2	55.3 ± 22.3
Fe	23 600–70 300	45 300 ± 15 250	50 800–70 300	58 650 ± 6 950	23 600–40 600	31 950 ± 6 400
Mn	190–1 420	775 ± 433	380–1420	1 072 ± 397	190–790	478 ± 211
Cr	30.5–92.8	50.9 ± 18.4	32.2 – 92.8	56.0 ± 23.1	30.5–60.1	45.8 ± 11.7

bonate bedrock. Activities of ^{40}K and ^{137}Cs in both soil types were fairly similar as well as concentrations of Cu, Zn, Pb and Cr.

Concentrations of selected elements and radionuclides in honey are presented in *table II* by honey type (i.e. predominately nectar honey from meadows; mixed meadow nectar honey and honeydew; and honeydew honey from fir and spruce forests). Mean potassium content was lowest in meadow honey: ≅ 0.09 %, followed by mixed honeys: ≅ 0.15 % and highest in honeydew honey: ≅ 0.28 %. Among all studied elements, ^{40}K and potassium comprised 90 % of the total quantity in honey. Strontium and iron uptake into honey was also lowest in meadow honey and highest in honeydew honey. Compared to ^{40}K, the concentrations of Sr and Fe were about three orders of magnitude lower. Without exception, the concentration of all measured elements was significantly higher (at $P < 0.01$, for Zn alone at $P < 0.05$) in honeydew honey compared to meadow nectar honey or mixed honey. The greatest difference in concentrations was found in the cases of ^{137}Cs and Rb. Mean concentrations of these two elements were found to be more than an order of magnitude higher in honeydew honey than in meadow honey.

Transfer factors from soils into the studied honey types (*table III*) were expressed as a percentage, defined as the ratio between element concentration in honey and in soil multiplied by 100. Among the soil macronutrients potassium, iron and calcium, only the potassium (*table III*) shows significant transfer from soil into all of the studied honey types. Calcium transfer from soil into the various honeys was approximately one order of magnitude lower than the transfer of potassium; while the transfer of Fe was about three orders of magnitude lower than potassium transfer. Zn and Mn transfers were very similar in all types of honey, demonstrating a low transfer from soils into honey. Transfer factors for Sr and Fe from soils into all of the honey samples were generally very low. The lowest T_fs were into meadow honey. Only ^{40}K (6.8 9 %) and Pb (1.25 %) showed transfers greater than 1 % into meadow honey, followed by Cu (0.827 %).

4. DISCUSSION

For soils, the mean concentration of elements and radionuclides was based on a limited number of samples ($n = 7$ or 14), each representing a single point composed by depth. Due to this, the soil samples may not accurately represent the true mean for soils across the entire area sampled by the bees. For honey, a similar number of samples would actually represent an average of samples collected at thousands of locations. As such, honey may provide a sample that is a more accurate representative of the entire area.

The majority of sampled honeys were collected from the mixture of silicate and carbonate terrains, but about one third of honey samples originated from well-known, strictly silicate or carbonate terrains. No significant differences were found, at $P < 0.05$, for all studied element concentrations for honeydew honey in relation to the respective soil types from which the honey samples were collected. No significant differences were found in the case of mixed meadow nectar and honeydew honey either. Statistical analyses of meadow nectar honey were not performed owing to a small number of samples collected from strictly silicate or carbonate terrains. Taking into account the aforementioned facts, average element concentrations in all measured soil samples have been taken for transfer factor calculations. This research demonstrated a difference in the uptake dynamics of inorganic chemicals from soils into the nectar of flowers versus into the phloem of fir and spruce coniferous trees and passage through the hindgut of aphids. The honey from meadow plants would have been obtained primarily from blossoms. Another insect feeding on fir and spruce trees produced the honeydew.

Table II. Radionuclide activities (Bq·kg^{-1}) and selected element concentrations (mg·kg^{-1}) in different types of honey from Gorski Kotar.

Element	Meadow honey (n = 16)		Mixed meadow and honeydew honey (n = 22)		honeydew honey (n = 25)	
	Range	Mean ± σ	Range	Mean ± σ	Range	Mean ± σ
^{40}K	8.4–63.6	28.3 ± 15.9	15.9–108.9	45.1 ± 23.3	43.8–143.3	86.9 ± 23.1
^{137}Cs	0.0–1.0	0.44 ± 0.37	0.9–6.8	3.48 ±1.62	4.8–36.2	15.0 ± 8.6
Rb	0.001–0.350	0.063 ± 0.084	0.01–0.80	0.24 ± 0.19	0.52–4.04	1.77 ± 1.17
Ca	7–162	66.3 ± 43.9	20–254	93.8 ± 55.5	131–593	285.8 ± 150.0
Sr	< 0.001–0.028	< 0.006 ± 0.006	< 0.002–0.024	< 0.009 ± 0.006	< 0.01–0.055	< 0.028 ± 0.016
Ni	< 0.005–0.188	< 0.052 ± 0.048	< 0.019–0.211	< 0.076 ± 0.052	< 0.105–0.472	< 0.222 ± 0.111
Cu	0.04–0.78	0.30 ± 0.22	0.1–1.07	0.44 ± 0.29	0.68–2.29	1.40 ± 0.65
Zn	0.03–0.71	0.17 ± 0.16	0.06–0.61	0.24 ± 0.15	0.26–8.93	1.21 ± 1.75
Pb	0.19–2.77	0.80 ± 0.64	0.22–2.62	1.08 ± 0.59	0.84–6.78	3.38 ± 1.55
Fe	0.5 – 11.3	3.9 ± 2.9	1.1 – 15.3	5.3 ± 3.8	5.6 – 34.6	15.9 ± 8.4
Mn	< 0.1–2.5	< 0.77 ± 0.63	< 0.2–3.7	< 1.18 ± 0.88	< 1.4–11.9	< 4.50 ± 2.93
Cr	0.03–0.41	0.16 ± 0.11	0.05–0.83	0.23 ± 0.18	0.28–1.22	0.65 ± .33

Table III. Transfer factor of radionuclides and selected elements from soil (*n* = 14) into dominantly meadow nectar (*n* = 16) honey, mixed (meadow nectar and honeydew; *n* = 22) honey and honeydew (*n* = 25) honey.

Element	Meadow nectar honey	Mixed honey	honeydew honey
^{40}K	6.89 ± 3.86*	11.0 ± 5.67	21.1 ± 6.22
^{137}Cs	0.249 ± 0.208	1.98 ± 0.92	8.51 ± 4.75
Rb	0.051 ±0.068	0.195 ± 0.157	1.43 ± 0.904
Ca	0.572 ± 0.379	0.810 ± 0.479	2.47 ± 1.20
Sr	< 0.008 ± 0.008	< 0.012 ± 0.008	< 0.037 ± 0.020
Ni	< 0.207 ± 0.191	< 0.303 ± 0.208	< 0.880 ± 0.434
Cu	0.827 ± 0.591	2.00 ± 0.775	3.81 ± 1.59
Zn	0.095 ± 0.090	0.130 ± 0.085	0.665 ± 0.958
Pb	1.25 ± 1.01	1.69 ± 0.912	5.28 ± 2.24
Fe	0.009 ± 0.006	0.012 ± 0.008	0.035 ± 0.017
Mn	< 0.099 ± 0.081	< 0.152 ± 0.114	< 0.580 ± 0.362
Cr	0.317 ± 0.210	0.443 ± 0.362	1.27 ± 0.597

* Mean value ± standard deviation of one σ.

Transfer factors of all studied elements were higher into mixed meadow and forest honeys (containing both floral honey and honeydew) than into meadow honey. ^{137}Cs, Rb and Cu showed significantly higher (at $P < 0.001$) T_f into mixed honey compared to honey from meadows, although the T_f for Rb was still very low (0.195 %). Mixed meadow and honeydew honey demonstrated an 11 % transfer of ^{40}K from soil, 1.98 % for ^{137}Cs, 2.00 % for Cu and 1.69 % for Pb. All other elements and radionuclides were considerably below 1 % T_f. Only Ca with a value of 0.810 % was even near the 1 % level. Copper concentrations in honey are very similar to those reported earlier [14, 24] and its seems that T_f for Cu is nearly as high as that found by Jones [14]. Zinc concentrations in honey from Gorski Kotar are several times higher than found by Leita et al. [16], but an order of magnitude lower than was found in nectar and honeydew honey [24]. Lead T_f in Gorski Kotar are an order of magnitude higher than found by Jones [14], but at the same time, Leita et al. [16] and Veleminsky et al. [24] reported very similar lead concentrations in honeys.

Among studied honey types, honeydew honey exhibited the best indicator capabilities for all of the studied elements and radionuclides. By comparison with the aforementioned types of honey, the transfer of ^{137}Cs and Rb into honeydew honey was an order of magnitude higher, with T_fs of 8.51 and 1.57 %, respectively. T_fs for ^{40}K (21.1 %), Pb (5.28 %), Cu (3.81 %), Ca (2.47 %), Cr (1.27 %) and Ni (0.880 %) nearly equalled or exceeded 1 %. On the other hand, the soil macroelement Fe showed a very low T_f (0.035 %) from soils into honeydew honey. Strontium showed a similar behaviour (0.037 %), so it seems that honey could not be used very successfully as an indicator of environmental pollution with strontium radioactive isotopes. In comparison with meadow honeys, honeydew honey showed the highest concentrations of Cs, Rb, Zn and Mn. Potassium concentration increased by a factor of three, while the concentration of all other studied elements was approximately a factor of four higher in honeydew honey than in meadow honey.

Honeydew honey could be used as a pollution indicator for ^{137}Cs, Cu, Rb, Cr and possibly Ni. The ^{137}Cs originated from long-distance transport and fallout resultant from past global activities, including nuclear weapon testing and the Chernobyl nuclear reactor accident. T_f of ^{137}Cs is higher than T_f of Rb, although transfer of rubidium from soils into spruce needles is approximately one order of magnitude higher than transfer of the stable soil microelement caesium [26]. Stable caesium is strongly adsorbed but radioactive pollutant ^{137}Cs is not completely adsorbed and very slowly penetrates into deeper soil layers [4].

Honey bees collect honey, and honeydew from thousands, if not millions, of different single points covering areas of more than 10 km^2. The consequence of this fact is that honey presents probably the best composed sample and most representative values for the average concentrations of bioavailable elements in the given environment. The results of this study indicate that samples of honey, especially honeydew, can indicate the consequences of global pollution events as well as events on a very local scale. In the case of ^{137}Cs, it seems that honeydew honey could be a very good indicator of pollution, even a long time after contamination.

ACKNOWLEDGEMENTS

This research is partly financed by Ministry of Science and Technology, Republic of Croatia, and through US–Croatian science/technology program – project: 'Honey bees and their products as a indicator of environmental caesium pollution'.

Résumé – Radionucléides et éléments traces dans le sol et le miel de Gorski Kotar, Croatie. Cette étude compare le transfert d'un certain nombre d'éléments (^{137}Cs, ^{40}K, Ca, Fe, Rb, Sr, Cu, Zn, Pb, Ni, Mn et Cr) du sol vers différents types de miels : miel de prairie, miel mixte de fleurs et de miellat et miel de miellat des forêts de sapin et d'épicéa dans la région de Gorski Kotar en Croatie. On a analysé les deux principaux types de sols : il s'agit de sols silicatés et de sols carbonatés principalement. Depuis 1993, des échantillons de miel ont été régulièrement prélevés en été et à l'automne dans 12 ruchers fixes et six colonies isolées d'*Apis mellifera*. La *figure 1* donne les lieux d'échantillonnage des sols et des miels. Les types de miels ont été caractérisés par analyse pollinique et par des mesures de conductivité électrique. Les radionucléides ont été mesurés par spectrométrie gamma et les concentrations des autres éléments par fluorescence aux rayons X (XRF).

Les concentrations de tous les éléments, à l'exception de Zn, étaient plus élevés dans les sols carbonatés que dans les sols silicatés (*tableau I*).C'était particulièrement le cas pour Rb, Sr, Mn et Fe à $p < 0{,}01$ et pour Ca et Ni à $p < 0{,}05$. Les activités du ^{40}K et du ^{137}Cs étaient assez semblables dans les deux types de sols, de même que les concentrations en Cu, Zn, Pb et Cr (*tableau I*). Pour tous les éléments analysés, on n'a pas trouvé de différence significative de concentration entre miel de miellat et miel mixte en fonction du type de sol sur lesquels les miels avaient été récoltés.

Le *tableau II* donne les concentrations en éléments et radionucléides par types de miel. La concentration de tous les éléments est significativement plus élevée à $p < 0{,}01$ ($p < 0{,}05$ pour Zn) dans le miel de miellat que dans le miel de prairie ou le miel mixte. Les facteurs de transfert (T_f) des sols vers les types de miels étudiés sont exprimés par un pourcentage défini comme le rapport entre la concentration de l'élément dans le miel et sa concentration dans le sol ×100. Le *tableau III* donne les T_f de chaque élément et de chaque radionucléide. Parmi les macroéléments du sol que sont K, Fe et Ca, seul K présente un transfert significatif du sol vers tous les types de miels (*tableau III*). Le transfert de Ca est environ dix fois inférieur à celui de K. Les transferts de Zn et de Mn sont semblables, ceux de Sr et Fe en général très faibles, quel que soit le type de miel. Les T_f les plus faibles ont été trouvés pour le miel de prairie et le plus fort (21,1 ± 6,22 %

pour ^{40}K) pour le miel de miellat. Le T_f du ^{137}Cs était trois fois plus élevé vers le miel de miellat que vers le miel de prairie (*tableau III*). Des résultats semblables existent pour Rb. Les T_f de Cu et Pb vers le miel de miellat sont eux aussi relativement élevés; ceux de Fe et de Sr sont faibles.
Cette étude montre une différence de la dynamique d'extraction des éléments chimiques des sols selon qu'elle se fait vers le nectar des fleurs ou vers le phloème des conifères à travers l'intestin postérieur des pucerons. Parmi les différents types de miels étudiés, le miel de miellat reflète le mieux les polluants inorganiques biodisponibles et persistants dans le milieu. Le miel de miellat pourrait être utilisé comme indicateur de pollution pour le ^{137}Cs, Cu, Rb et Cr et peut-être pour le Ni. Les abeilles récoltent le nectar et le miellat en milliers, si ce n'est millions, de points qui couvrent des surfaces supérieures à 10 km^2. La conséquence en est que le miel représente probablement le meilleur échantillon et les valeurs les plus représentatives pour des concentrations moyennes d'éléments biodisponibles dans un environnement donné.

radionucléide / élément trace / miel / sol / transfert / indicateur biologique

Zusammenfassung – Radionuklide und ausgewählte Elemente im Boden und im Honig in Gorski Kotar, Kroatien. In dieser Untersuchung wurde der Transfer von ^{137}Cs, ^{40}K, Ca, Fe, Rb, Sr, Cu, Zn, Pb, Ni, Mn und Cr aus dem Boden in verschiedene Honigsorten verglichen: 1. Honig von Wiesenblumen, 2. gemischter Blüten/Honigtau-Honig und 3. reiner Honigtau-Honig aus Weiβtannen- und Fichtenwäldern der Region um Gorski Kotar in Kroatien. Zwei häufige Bodenarten wurden analysiert, Böden mit überwiegend Silikat- und Böden mit überwiegend Karbonatanteilen. Seit 1993 wurden Honigproben im Sommer und frühen Herbst gesammelt. Es standen 12 permanente Bienenstände und sechs einzelne Völker von *Apis mellifera* zur Verfügung. Die Verteilung der Probennahmen von Böden und Honig ist in *Abbildung 1* dargestellt. Die Honigsorten (Blütenhonig, gemischter Blüten-/Honigtau-Honig und reiner Honigtau-Honig) wurden durch Pollenanalyse und elektrische Leitfähigkeit bestimmt. Die Radionuklide wurden durch Gammastrahlspektrometrie bestimmt, die Konzentration der anderen Elemente mit X-Strahlen Fluoreszenz (XRF).
Bis auf Zn waren die Konzentrationen aller gemessenen Elemente in Karbonatböden höher als in Silikatböden (*Tabelle I*). Das war besonders deutlich bei Rb, Sr, Mn und Fe ($p < 0,01$), aber auch bei Ca und Ni ($p < 0,05$). Die Strahlung von ^{40}K und ^{137}Cs war in beiden Bodentypen etwa gleich, das gilt auch für die Konzentrationen von Cu, Zn, Pb und Cr. In Bezug auf die Böden konnte kein signifikanter Unterschied für die Konzentrationen der Elemente in Honigtau-Honig und gemischtem Honig nachgewiesen werden, bei $p < 0,05$.
Die Konzentrationen von ausgewählten Elementen und Radionukliden in Honigen sind in *Tabelle II* dargestellt. Die Konzentrationen sind im Honigtau-Honig signifikant höher ($p < 0,01$, Zn: $p < 0,05$) als im Blüten- oder Mischhonig.
Die Transfer Faktoren (T_f) von Böden in den Honig wurde als Prozent angegeben, definiert als Verhältnis der Konzentrationen der Elemente von Honig zu Boden, multipliziert mit 100. Transfer Faktoren für jedes Element bzw. Radionuklid vom Boden in den Honig sind in *Tabelle III* dargestellt. Unter den biologisch wichtigen Ionen des Bodens K, Fe und Ca zeigt nur K (*Tabelle III*) einen deutlichen Transfer vom Boden in alle untersuchten Honige. Der Ca Transfer war etwa eine Gröβenordnung geringer, während von Fe sogar 3 Gröβenordnungen weniger aufgenommen wurde als K. Der Transfer von Zn und Mn war in allen 3 Honigsorten ähnlich, der von Sr und Fe in allen sehr gering. Die kleinsten Transfer Faktoren gab es beim Blütenhonig, die höchsten im

Honigtau-Honig für ^{40}K (21,1 ± 6,22 %). Der T_f von 8,51 ± 4,75 % für ^{137}Cs im Honigtau-Honig war mehr als 30 mal höher als der im Wiesenblütenhonig (0,249 ± 0,208 %), die Werte für Rb liegen ähnlich. Die T_f für Kupfer und Blei waren im Honigtau-Honig ebenfalls recht hoch. Eisen dagegen hatte einen kleinen T_f (0,035 ± 0,017 %) für Honigtau-Honig, wie auch Sr.
Diese Untersuchungen zeigen einen Unterschied in der Aufnahmedynamik von anorganischen Substanzen vom Boden in den Nektar der Blüten im Vergleich zum Phloem der Nadelbäume und der Passage durch den Darm von Blattläusen. Honigtau-Honig zeigt von allen untersuchten Honigsorten am deutlichsten eine dauerhafte Kontamination des anorganischen Nährsubstrats in der Umwelt an. Honigtau-Honig könnte deshalb als Indikator für ^{137}Cs, Cu, Rb, Cr und wahrscheinlich Ni genutzt werden. Bienen sammeln Nektar und Honigtau von Tausenden, wenn nicht Millionen unterschiedlichen Stellen und decken dabei ein Gebiet von mehr als 10 km^2 ab. Deshalb handelt es sich bei Honig wahrscheinlich um eine Probe, die am besten durchmischt ist und die dadurch repräsentative Werte für durchschnittliche Konzentration von biologisch verwerteten Elementen in einem bekannten Gebiet geben kann.

Radionuclide / Spurenelemente / Boden / Honig / Transfer / Bioindikator

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