Can impurities from soil-contaminated coffees reach the cup?

F. S. Tagliaferro,^{1*} E. A. De Nadai Fernandes,¹ M. A. Bacchi,¹ P. Bode,² E. Joacir De França¹

¹ Centro de Energia Nuclear na Agricultura, Universidade de São Paulo, 13400-970, P.O. Box 96, Piracicaba, SP, Brazil

² Interfaculty Reactor Institute, Delft University of Technology, Mekelweg 15, 2629JB, Delft, The Netherlands

(Received April 13, 2006)

Depending on the harvest conditions, coffee beans can be contaminated by soil when dropped to the ground. It is well known that agricultural soils act as sinks for agrochemicals applied to the crops. While coffee is brewed, substances present in the roasted and ground coffee beans are extracted by hot water, emphasizing the need to assess the possible transfer of impurities from the soil to the beverage. Soil-contaminated samples of roasted coffee beans were split into 2 groups according to the treatments: (a) washed and ground and (b) only ground. Brewing was performed in a household espresso machine for both coffees. The resulting beverage was freeze-dried and the elemental composition determined by instrumental neutron activation analysis (INAA). The mass fractions of the terrigenous elements Fe, La, Sc, Sm and Th in the freeze-dried non-washed coffee beverages were, at least, 2 times higher than in the washed samples. These elements are tracers of the soil, indicating that the impurities from the soil reached the beverage.

Introduction

Coffee plays an important role in the world scenario. Besides its economical and social relevance for producing and consuming countries, the daily habit of drinking coffee represents a significant source of mineral intake. In some countries, like Austria, Belgium-Luxemburg, Denmark, Finland, France, Germany, Greece, Italy, The Netherlands, Norway, Sweden and Switzerland, the per capita consumption of coffee is higher than 5 kg per year,¹ corresponding to approximately 100 liter of beverage ingestion per year. In this context, coffee is not drunk just for pleasure, instead it participates in the human diet.

Efforts have been made to obtain a coffee free of contaminants, following the trend of organically cultivated products, with investments in technology to reduce or even eliminate the use of agrochemicals. Conventional coffees are largely sprayed and based on synthetic fertilizers, causing more impact on the environment, while the organic coffees are expected to be free of pesticides and other agrochemical residues, since the use of these substances is not allowed.

Traditionally, coffee is harvested manually with the cherries dropping to the ground before gathering. The ground can be covered with a canvas to avoid direct contact of the cherries with soil. As this is not frequently done, considerable amounts of agricultural soil are loaded as impurity with the cherries. Previous studies have found up to 2% of soil in commercial roasted and green coffees.^{2,3} Such impurity might depreciate the quality of coffee by increasing the natural levels of some undesirable substances. The coffee flavour chemistry is extremely complex and even a small interference in the coffee composition may result in a bad quality beverage.⁴

Agricultural soils from conventional farming are the sinks for most agrochemicals, of which residues may remain bound to the soil colloids for several years.^{5–9} There is special concern about aldicarb, carbendazim, carbofuran, cypermethrin, deltamethrin, disulfoton, fenamiphos, flucythrinate, hexaconazole, oxamyl, permethrin, prochloraz, propiconazole, terbufos, triadimefon, triadimenol and triazophos that have maximum residue limits (MRL) established for coffee beans by the Codex Alimentarius.¹⁰ These pesticides may be released from soil contaminated coffees during preparation, depending on the coffee brewing technique. Additionally, a range of biological pollutants such as viruses, bacteria and protozoa can also be linked to and transported by the soil.⁸ Consequently, there is a potential risk to human health if harmful substances and/or pathogenic microorganisms from soil reach the cup of coffee. In this work the transfer of impurities from soil-contaminated coffees to the beverage is assessed.

Experimental

The experiment was carried out using a sample of roasted whole beans coffee from the species *Coffea arabica* acquired in the local market of Piracicaba, São Paulo State, Brazil. The material was previously analyzed and an assessment³ using Sc as tracer demonstrated that this material contained high amounts of soil loaded with the beans even though it was available to the consumers.

The sample (1 kg) was homogenized and divided into two portions: one remained contaminated and the other was washed with de-ionized cold water for the removal of the soil. Afterwards, both portions were

* E-mail: fabiotag@cena.usp.br

oven-dried for 24 hours at 60 °C and ground in an iron-free rotor mill producing particle sizes smaller than 0.5 mm. Five subsamples were taken from each portion of the fine coffee powder and the beverage was prepared using the espresso brewing technique in a household espresso coffee machine (Krups). The conditions of extraction were: 400 ml of de-ionised water at 94 °C, 15 g of coffee powder, pressure of 1.5 MPa and percolation time of 50 seconds, resulting in an extracted beverage volume of approximately 300 ml. The beverage was further frozen at -10 °C and freeze-dried for 72 hours, and the dried material (≈ 5.5 g) ground with mortar and pestle. The remaining coffee grounds were oven-dried until constant weight at 60 °C and homogenized.

Instrumental neutron activation analysis (INAA)

Test portions of 500 mg from all prepared samples were placed in special polyethylene capsules for irradiation under neutron fluence of approximately $10^{13} \text{ n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$ in the nuclear research reactor IEA-R1m of Instituto de Pesquisas Energéticas e Nucleares (IPEN), São Paulo. For analytical quality control, the certified reference materials SRM 1515 Apple Leaves and RM 8433 Corn Bran from NIST, V-10 Hay Powder from IAEA and TL-1 Tea Leaves from INCT were irradiated simultaneously to the samples. The induced irradiation was detected in a GMX 50220 HPGe detector (Ortec) after 4, 8 and 15 days of decay time. Thirteen elements were quantified by the k_0 method using the in-house software Quantu.¹¹

Results and discussion

Table 1 shows the mean and standard deviation of Br, Ca, Co, Cs, Fe, K, La, Na, Rb, Sc, Sm, Th and Zn in each of the materials analyzed: powder, grounds and freeze-dried beverage from the soil-contaminated coffee.

Several terrigenous elements, such as Fe, La, Sc, Sm and Th could serve as tracers of soil in plants.^{12–16} The results indicated that the washing process using cold water was efficient for dirt removal. From the enrichment factors of Table 2 it is possible to observe that the mass fractions of terrigenous elements in the non-washed coffee powder were between 7 and 21 times

higher than in the washed coffee. Moreover, the mass fractions of these elements in the washed coffee are comparable to the results of coffee bean analyses found elsewhere.^{2,3,17–19}

Sc can be used to estimate the amount of soil loaded with the coffee beans, since this element is found ubiquitously in soils but its uptake by plants is negligible.¹⁵ Assuming that Sc in Brazilian agricultural soils from the main coffee producing regions range from 5 to 60 mg/kg,³ the amount of soil loaded with the non-washed coffee powder could be estimated to lie between 3 and 40 g of soil per kg of coffee beans.

However, the main subject of this research was the beverage, as this is the portion that is ingested. During the espresso coffee preparation, the beverage is filtered in a metallic filter basket, and most of the soil particulates are expected to be retained with the grounds. Nevertheless, the colloids from soil are very small particles that can be carried by the high-pressure hot water and reach the coffee beverage. The colloids are the most active portion of the soil, usually having a net negative charge, which is responsible for the retention of plant nutrients and other positively charged elements and molecules.²⁰ A review paper⁸ described the adsorption to the mobile particles or colloids as the prevailing mechanism for the movement of pollutants in soils. Pesticides and other agrochemicals, as well as a range of microorganisms such as viruses, bacteria and protozoa are listed among the pollutants that are carried by soil colloids.⁸

The total amounts of the terrigenous elements Fe, La, Sc, Sm and Th found in the coffee beverage prepared from non-washed beans were higher than that from the washed ones (Fig. 1), demonstrating that substances from soil reached the beverage. The largest difference was noticed for Sc, with results 8.5 times higher for the non-washed beans. It is important to note that these terrigenous elements are positively charged, and therefore, easily adsorbed by the surface of the soil colloids. The same reasoning is used for many pesticides molecules that can be adsorbed depending on the properties of soil and the compound.^{5,7–9} The processes involved may be completely reversible by chemical and/or physical variations and the pesticide molecule released.^{5,9,21}

Table 1. Mean and standard deviation (in mg/kg; $n=5$) results for chemical elements in coffee powder, grounds and freeze-dried beverage

Sample	Washed	Br	Ca	Co	Cs	Fe	K	La	Na	Rb	Sc	Sm	Th	Zn
Powder	No	1.47 0.03	1690 100	0.235 0.012	0.133 0.004	617 66	21300 160	1.1 0.3	15 7	34.0 0.6	0.18 0.02	0.14 0.10	0.37 0.15	6.17 0.13
	Yes	1.42 0.03	1310 120	0.159 0.008	0.109 0.003	86 4	20980 290	0.059 0.006	6.41 0.19	31.4 0.4	0.0184 0.0005	0.0070 0.0003	0.022 0.003	6.06 0.16
	No	0.63 0.03	1580 90	0.272 0.012	0.047 0.007	983 65	532 170	1.5 0.6	9.8 1.4	1.4 0.2	0.28 0.02	0.15 0.03	0.47 0.14	7.62 0.19
	Yes	0.58 0.02	1150 50	0.158 0.005	<0.015 –	129 5	770 250	0.082 0.004	2.5 0.6	1.3 0.4	0.0279 0.0017	0.0086 0.0004	0.0278 0.0014	7.4 0.4
Freeze-dried beverage	No	2.81 0.04	1510 70	0.163 0.010	0.291 0.007	51 6	54700 870	0.043 0.006	22 3	86.4 1.7	0.0180 0.0009	0.0069 0.0009	0.037 0.003	3.9 0.2
	Yes	2.84 0.06	1420 20	0.146 0.007	0.269 0.008	23 2	53620 1260	<0.020 –	18 2	81.2 3	0.0021 0.0004	<0.003 –	<0.015 –	4.1 0.2

Table 2. Enrichment factors (non-washed/washed coffees) for powder, grounds and freeze-dried beverage

Element	Powder	Grounds	Freeze-dried beverage
Br	1.0	1.1	1.0
Ca	1.3	1.4	1.1
Co	1.5	1.7	1.1
Cs	1.2	–	1.1
Fe	7.1	7.6	2.2
K	1.0	0.7	1.0
La	18.2	17.9	>2.1
Na	2.4	3.9	1.2
Rb	1.1	1.1	1.1
Sc	9.7	9.9	8.5
Sm	20.6	17.4	>2.3
Th	17.0	16.9	>2.5
Zn	1.0	1.0	1.0

Fig. 1. Total amounts of some terrigenous elements present in 300 ml of non-washed and washed coffees. The values for La, Sm and Th in the washed coffee were estimated on the basis of limits of detection

Conclusions

The terrigenous elements Fe, La, Sc, Sm and Th determined by INAA were successfully employed to trace the soil as impurity in coffee beverage. Substances from soil mixed with coffee beans reached the beverage when using a household espresso machine.

Considering that agricultural soils are sinks for most of the pesticides and other agrochemicals, there is a potential risk for these substances to reach the cup when the coffee beans are soil-contaminated. Thus, the harvest system where the cherries are dropped directly to the ground without any coverage should be avoided, above all in conventionally cultivated fields.

*

The authors wish to thank The State of São Paulo Research Foundation (FAPESP) for the financial support, especially due to a postdoctoral fellowship granted to Dr. Fábio S. TAGLIAFERRO (proc. 03/11528-4).

References

1. FAS/USDA, Horticultural and Tropical Products Division. Per Capita Consumption of Coffee in Selected Importing Countries, <http://www.fas.usda.gov/http/tropical/2004/03-04/coffprcp.pdf>
2. F. S. TAGLIAFERRO, E. A. N. FERNANDES, E. J. FRANÇA, Elemental composition of commercial Brazilian coffee using neutron activation analysis, in: 3rd Intern. Conf. on Isotopes, Vancouver, 2000, p. 277.

3. F. S. TAGLIAFERRO, PhD. Thesis, University of São Paulo, Piracicaba, Brazil, 2002 (in Portuguese).
4. E. ILLY, *Sci. Am.*, 286 (2002) 86.
5. B. GEVAO, K. T. SEMPLE, K. C. JONES, *Environ. Pollut.*, 108 (2000) 3.
6. A. CRAVEN, S. HOY, *Environ. Pollut.*, 133 (2005) 5.
7. L. CITEAU, I. LAMY, F. VAN OORT, F. ELSASS, *Colloid. Surface*, A217 (2003) 11.
8. M. B. MCGECHAN, D. R. LEWIS, *Biosyst. Eng.*, 83 (2002) 255.
9. F. SANNINO, M. T. FILAZZOLA, A. VIOLANTE, L. GIANFREDI, *Chemosphere*, 39 (1999) 333.
10. FAO, Codex Alimentarius Food Quality Control. Pesticide Residues in Food. <http://faostat.fao.org/default.jsp>
11. M. A. BACCHI, E. A. N. FERNANDES, *J. Radioanal. Nucl. Chem.*, 257 (2003) 577.
12. J. J. O'TOOLE, T. E. WESSELS, K. L. MALABY, *J. Plant. Nutr.*, 3 (1981) 397.
13. E. A. N. FERNANDES, *J. Radioanal. Nucl. Chem.*, 168 (1993) 41.
14. T. G. HINTON, P. KOPP, S. IBRAHIM, I. BUBRYAK, A. SYOMOV, L. TOBLER, C. BELL, *Health Phys.*, 68 (1995) 523.
15. T. G. HINTON, J. M. STOLL, L. TOBLER, *J. Environ. Radioact.*, 29 (1995) 11.
16. U. SANSONE, M. BELLI, M. RICCARDI, A. ALONZI, Z. JERAN, J. RADOJKO, B. SMODIS, M. MONTANARI, F. CAVOLO, *Sci. Total Environ.*, 219 (1998) 21.
17. M. J. MARTÍN, F. PABLOS, A. G. GONZÁLEZ, *Anal. Chim. Acta*, 358 (1998) 177.
18. V. KRIVAN, P. BARTH, A. F. MORALES, *Microchim. Acta*, 110 (1993) 217.
19. E. A. N. FERNANDES, F. S. TAGLIAFERRO, P. BODE, A. A. FILHO, *Acred. Qual. Assur.*, 7 (2002) 10.
20. N. C. BRADY, R. R. WEIL, *The Nature and Properties of Soils*, 13rd ed., Prentice Hall, Upper Saddle River, 2002, 960 p.
21. P. BURAUDEL, F. BASSMANN, *Environ. Pollut.*, 133 (2005) 11.