Study of $^{238}$U, $^{232}$Th, $^{222}$Rn and $^{220}$Rn contents in various samples by using solid state nuclear track detector

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Coffee and green tea drinks as well as sugar are widely consumed by Moroccan population. $^{238}$U, $^{232}$Th, $^{222}$Rn and $^{220}$Rn contents have been measured inside different soil, sugar beet and table sugar material samples collected in different areas of Morocco by using CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs). The transfer of contents $^{238}$U, $^{232}$Th and $^{222}$Rn between soil and sugar beet and that between sugar beet and table sugar has been measured. To explore the exposure pathway of $^{238}$U, $^{232}$Th and $^{222}$Rn to the organs and tissues of consumers from the ingestion of coffee and green tea drinks, contents of these radionuclides have been measured in the drinks. The effect of the nature water and pollution on the concentrations of these radionuclides in coffee and green tea has been investigated. Annual committed effective doses due to $^{238}$U, $^{232}$Th and $^{222}$Rn from the ingestion of table sugar and coffee and green tea drinks by the members of the general public and workers have been determined. The maximum total committed effective dose due to $^{238}$U, $^{232}$Th and $^{222}$Rn from the ingestion of tea drinks by the members of the Moroccan rural population was found to be equal to 0.13 mSv y$^{-1}$.

Keywords: Nuclear track detector, Uranium, Thorium, Radon, Thoron, Radiation dose assessment

1 Introduction

Naturally occurring radionuclides of terrestrial origin exist ubiquitously in the environment and contribute significantly to external and internal doses to the population. Among them, of particular importance are the solid radionuclides belonging to the $^{238}$U and $^{232}$Th series. These radionuclides enter the human body mainly through ingestion and by inhalation to considerably smaller degree. Due to their presence in soil and phosphate fertilizers, primordial radionuclides and their progeny are transferred via water to sugar beet and sugar cane and then to table sugar, which is ingested by individuals. Because of the fact that table sugar is widely consumed by people in sweets, pastry products and coffee and green tea drinks it is necessary to measure the radionuclide content of table sugar and coffee and green tea drinks samples to assess potential radiation doses and, if necessary, to take action to avoid the exposure of consumers to radiation. $^{238}$U and $^{232}$Th concentrations have been measured in various food and drink samples by using gamma-ray spectrometry. $^{40}$K, $^{226}$Ra, and $^{222}$Th contents have been determined in various soils in Slovenia and different Nile river sediments in upper Egypt by using gamma spectrometry. Simultaneous determination of $^{238}$U and $^{232}$Th in some biological reference materials has been performed by using neutron activation analysis and radiochemical separation. However, this technique is both destructive (chemical agents are added to the material sample) and expensive. $^{238}$U and $^{232}$Th have been analysed in different food samples using inductively coupled plasma mass spectrometry (ICP-MS) which is also destructive. $^{222}$Rn is a chemically inert and very mobile gaseous decay product of $^{238}$U which is found in all rocks and soils. Inhalation and ingestion of radon and its progeny represent the main source of exposure to ionizing radiation for population in most countries.

In this work, we used a method based on calculating the detection efficiencies of the CR-39 and LR-115 type II solid state nuclear track detectors (SSNTDs) for alpha-particles emitted by $^{238}$U and $^{232}$Th series to evaluate $^{238}$U, $^{232}$Th, $^{222}$Rn and $^{220}$Rn concentrations in various soil, sugar beet and table sugar material samples as well as in coffee and green tea drinks. The annual committed effective doses from intakes of $^{238}$U, $^{232}$Th and $^{222}$Rn in the human body of consumers from the ingestion of the studied table sugars and coffee and green tea drinks, have also been determined.
2 Method of Study

2.1 Determination of $^{238}$U, $^{232}$Th, $^{222}$Rn and $^{220}$Rn concentrations

Sugar beet is mainly cultivated in the Tadla, Moulouya, Doukkala and Loukkous regions as shown in Fig. 1. Different soil, sugar beet and table sugar material samples were collected from these regions. Green tea and coffee drinks have been prepared by adding tea, coffee and sugar to boiled water.

Disk shaped CR-39 (manufactured by Pershore Mouldings Ltd, UK) and LR-115 type II (manufactured by Kodak Pathé, France and marketed by Dosirad, France) solid state nuclear track detectors (SSNTDs) of radius $q=2$ cm have been separately placed in close contact with soil, sugar beet, table sugar and coffee drinks samples in hermetically sealed (using glue and a sellotape) HDPE (high-density polyethylene) cylindrical plastic containers for 30 days as shown in Fig. 2. During this exposure, alpha-particles emitted by the nuclei of the $^{238}$U and $^{232}$Th series inside the considered material samples bombarded the SSNTD films. After the irradiation, the exposed films were etched in two NaOH solutions at optimal conditions of etching, ensuring good sensitivities of the SSNTDs and a good reproducibility of the registered track density rates: 2.5 normality at 60°C for 120 min for the LR-115 II films and 6.25 normality at 70°C for 7 h for the CR-39 detectors. After this chemical treatment, the track densities registered on the CR-39 and LR-115 II detectors were found to be identical within the statistical uncertainties. There are three main factors which disturb the radioactive secular equilibrium between $^{238}$U and its progeny and between $^{232}$Th and its daughters: the transformation of the material sample, escape of $^{222}$Rn and $^{220}$Rn gases and exposure time if it is smaller than 25 days. As the HDPE containers have a thickness of 5 mm and are well closed by using glue and sellotape (there is no escape of $^{222}$Rn and $^{220}$Rn) and the exposure time was 30 d, one can assume radioactive secular equilibrium between $^{238}$U and each of its decay products and between $^{232}$Th and each of its progeny.

For our experimental etching conditions, the residual thickness of the LR-115 type II detectors measured by means of a mechanical comparator is $5 \times 10^{-6}$ m. This thickness defines the lower ($E_{\text{min}} = 1.6$ MeV) and upper ($E_{\text{max}} = 4.7$ MeV) energy limits for registration of tracks of alpha-particles in LR-115 type II films. All alpha-particles emitted by the $^{238}$U and $^{232}$Th series that reach the LR-115 detector at an angle lower than its critical angle of etching $\theta_C$ with a residual energy between 1.6 and 4.7 MeV are registered as bright track-holes.
The CR-39 detector is sensitive to all alpha-particles reaching its surface at an angle smaller than its critical angle of etching $\theta_c$. The critical angles of etching $\theta'_c$ and $\theta_c$ have been calculated by using a method described in detail by Misdag et al\(^\text{13}\).

The global track density rates (tracks cm\(^{-2}\) s\(^{-1}\)), due to alpha-particles emitted by the \(^{238}\text{U}\) and \(^{232}\text{Th}\) series inside a material sample, registered on the CR-39 ($\rho_{\text{CR}}^\text{G}$) and LR-115 II ($\rho_{\text{LR}}^\text{G}$) detectors, after subtracting the corresponding backgrounds, are respectively given in Ref. (10):

$$\rho_{\text{CR}}^\text{G} = \frac{\pi q^2}{2 S_d} C(U) d_s \left[ A_t \sum_{j=1}^{8} k_j R_j \varepsilon_j^\text{CR} + A_{\text{th}}^{\text{Th}} \frac{C(\text{Th})}{C(U)} \sum_{j=1}^{2} k_j R_j \varepsilon_j^\text{CR} \right]$$

... (1)

and

$$\rho_{\text{LR}}^\text{G} = \frac{\pi q^2}{2 S_d} C(U) d_s \left[ A_t \sum_{j=1}^{8} k_j R_j \varepsilon_j^\text{LR} + A_{\text{th}}^{\text{Th}} \frac{C(\text{Th})}{C(U)} \sum_{j=1}^{2} k_j R_j \varepsilon_j^\text{LR} \right]$$

... (2)

where $S_d$ and $S_d'$ are the surface areas of the CR-39 and LR-115 II films, respectively, $C(U)$ [ppm (10\(^{-6}\) g/g)] and $C(\text{Th})$ (ppm(10\(^{-6}\) g/g)) are the \(^{238}\text{U}\) and \(^{232}\text{Th}\) concentrations of the material sample, $A_t(Bq/g) = 0.0123$ and $A_{\text{th}}(Bq/g) = 0.0041$ are the specific activities of a material sample for a \(^{238}\text{U}\) content of 1ppm and a \(^{232}\text{Th}\) content of 1ppm, respectively, $d_s$ is the density of the material sample (g cm\(^{-2}\)), $R_j$ and $R'_j$ are the ranges in the sample of an alpha-particle of index $j$ and initial energy $E_j$ emitted by the nuclei of the \(^{238}\text{U}\) and \(^{232}\text{Th}\) series, respectively, $k_j$ and $k'_j$ are the branching ratios corresponding to the disintegration of the nuclei of the \(^{238}\text{U}\) and \(^{232}\text{Th}\) series, respectively and $\varepsilon_j^\text{CR}$, $\varepsilon_j^\text{CR}'$, $\varepsilon_j^\text{LR}$ and $\varepsilon_j^\text{LR}'$ are the detection efficiencies of the CR-39 and LR-115 II detectors for the emitted alpha-particles, respectively. The first terms (right of Eqs 1 and 2) correspond to the number of alpha-particles emitted by the \(^{238}\text{U}\) family (8 alpha-emitting nuclei), whereas the second terms correspond to the number of alpha-particles emitted by \(^{232}\text{Th}\) series (7 alpha-emitting nuclei).

Combining Eqs (1 and 2), measuring $\rho_{\text{CR}}^\text{G}$ and $\rho_{\text{LR}}^\text{G}$ track density rates and calculating $\varepsilon_j^\text{CR}$, $\varepsilon_j^\text{CR}'$, $\varepsilon_j^\text{LR}$ and $\varepsilon_j^\text{LR}'$, one can evaluate the \(^{238}\text{U}\) [C(U)] and \(^{232}\text{Th}\) (C(Th)) contents inside the considered soil, sugar beet, table sugar, coffee and green tea drinks samples.

According to one of our previous paper\(^1\text{4}\) when we place the SSNTDs directly on the soil, sugar beet, table sugar, coffee and green tea drinks samples studied (Fig. 1) and assume a secular radioactive equilibrium between \(^{238}\text{U}\) and \(^{222}\text{Rn}\) on one hand and between \(^{232}\text{Th}\) and \(^{220}\text{Rn}\) on the other hand, track densities due to alpha-particles emitted by the \(^{238}\text{U}\) and \(^{232}\text{Th}\) series inside these samples and registered on the CR-39 ($\rho_{\text{CR}}^\text{G}$) and LR-115 type II ($\rho_{\text{LR}}^\text{G}$) films are given by:

$$\rho_{\text{CR}}^\text{G} = \frac{\pi q^2}{2 S_d} C(U) d_s \left[ A_{\varepsilon}^{(222\text{Rn})} \sum_{j=1}^{8} k_j R_j \varepsilon_j^\text{CR} + A_{\varepsilon}^{(220\text{Rn})} \sum_{j=1}^{2} k_j R_j \varepsilon_j^\text{CR} \right]$$

... (3)

and

$$\rho_{\text{LR}}^\text{G} = \frac{\pi q^2}{2 S_d} C(U) d_s \left[ A_{\varepsilon}^{(222\text{Rn})} \sum_{j=1}^{8} k_j R_j \varepsilon_j^\text{LR} + A_{\varepsilon}^{(220\text{Rn})} \sum_{j=1}^{2} k_j R_j \varepsilon_j^\text{LR} \right]$$

... (4)

where $A_{\varepsilon}^{(222\text{Rn})}$ (in Bq cm\(^{-3}\)) and $A_{\varepsilon}^{(220\text{Rn})}$ (in Bq cm\(^{-3}\)) are the \(^{222}\text{Rn}\) and \(^{220}\text{Rn}\) alpha-activities inside a soil/sugar beet/table sugar/ coffee drink/ green tea drink sample, respectively.

Combining Eqs (3 and 4), the following relationship between track density rates and \(^{220}\text{Rn}\) to \(^{222}\text{Rn}\) ratios is obtained:

$$A_{\varepsilon}^{(222\text{Rn})} = \frac{S_d}{S_d'} \sum_{j=1}^{8} k_j \varepsilon_j^\text{CR} R_j - \frac{\rho_{\text{CR}}^\text{G}}{\rho_{\text{LR}}^\text{G}} \sum_{j=1}^{8} k_j \varepsilon_j^\text{LR} R_j$$

... (5)

The \(^{222}\text{Rn}\) alpha-activity of a soil/sugar beet/table sugar/coffee drink/green tea drink sample is given by Eq. 4:

$$A_{\varepsilon}^{(222\text{Rn})} = \frac{2 S_d' \rho_{\text{LR}}^\text{G}}{\pi q^2 d_s} \left[ \sum_{j=1}^{8} k_j \varepsilon_j^\text{LR} R_j + \frac{A_{\varepsilon}^{(220\text{Rn})}}{A_{\varepsilon}^{(222\text{Rn})}} \sum_{j=1}^{2} k_j' \varepsilon_j^\text{LR}' R_j' \right]$$

... (6)

The ranges of the emitted alpha-particles in soil, sugar beet, table sugar, coffee and green tea drinks and SSNTDs were calculated by using a TRIM
2.2 Determination of the alpha-activity due to $^{238}$U, $^{232}$Th and $^{222}$Rn in the human body

Alpha-activities of $^{238}$U and $^{232}$Th in the different compartments of the human body from the ingestion of a table sugar/coffee and green tea drinks sample by a consumer are obtained by solving the differential equation system representing the rates of change of these activities by using a Maple 8 code providing that at $t=0$ these activities are equal to zero except that in the stomach. Indeed, for the $n^{th}$ compartment, we have\textsuperscript{15}:

$$A_n^U(U)(t)=I_U \sum_{i=1}^{18} a_i^U e^{-\gamma_i^U t} \quad \ldots \quad (7)$$

for $^{238}$U and

$$A_n^U(Th)(t)=I_{Th} \sum_{i=1}^{19} a_i^U e^{-\gamma_i^U t} \quad \ldots \quad (8)$$

for $^{232}$Th.

where $I_U$ (in Bq y$^{-1}$) and $I_{Th}$ (in Bq y$^{-1}$) are the uranium and thorium intakes due to the ingestion of a table sugar/coffee drink/green tea drink sample during one year, $a_i^U$ and $a_i^U$ are constants and $\gamma_i^U$ and $\gamma_i^U$ are rate constants expressed in d$^{-1}$.

According to the International Commission on Radiological Protection dosimetric model for the gastrointestinal system\textsuperscript{19} each of the four sections of this system consists of a single compartment: the stomach (St), small intestine (Si), upper large intestine (Uli) and lower large intestine (Lli). There are two pathways out of the Si: one leads to the Uli and the other to blood (B) as shown in Fig. 3.

Alpha-activities due to $^{222}$Rn in the different tissues of the gastrointestinal system from the ingestion of various table sugar and coffee and green tea drinks samples by the members of the public and workers are obtained by the differential equation system representing the rates of change of these activities by using a Maple 8 code\textsuperscript{17} providing that at $t=0$ these activities are equal to zero except that in the stomach. Assuming that all the ingested radon from table sugar and coffee and green tea drinks appears in the stomach, the radon alpha-activity in a tissue T of the gastrointestinal tract is given by\textsuperscript{20}:

$$A_T^R(\text{Rn})(t)=I(\text{Rn}) \sum_{i=1}^{18} a_i^R e^{-k_i^R t} \quad \ldots \quad (9)$$

where $I(\text{Rn})$ (in Bq y$^{-1}$) is the radon intake from the ingestion of a table sugar/coffee drink/green tea drink sample, $a_i^R$ is a constant and $b_i^R$ is a rate constant expressed in h$^{-1}$.

2.3 Evaluation of annual committed effective doses due to $^{238}$U, $^{232}$Th and $^{222}$Rn in the human body

Alpha-equivalent dose rate (Sv s$^{-1}$) in the tissue T of the human body due to $^{238}$U and $^{232}$Th from the ingestion of a table sugar/coffee drink/green tea drink sample by the members of the public and workers are respectively given by:

$$H_r(U)(t)=A_T^U(U)(t) D_{sp}(U) W_R \quad \ldots \quad (10)$$

and

$$H_r(Th)(t)=A_T^U(Th)(t) D_{sp}(Th) W_R \quad \ldots \quad (11)$$

where $A_T^U(U)(t)$ (Bq) is the alpha-activity, at time t, due to $^{238}$U in the tissue T of the human body. $A_T^U(U)(t)$ is the alpha-activity, at time t, due to $^{232}$Th in the tissue T of the human body. $D_{sp}(U)$ is the specific alpha-dose (Gy) deposited by alpha-particles emitted by 1Bq of $^{238}$U in the tissue T. $D_{sp}(Th)$ is the specific alpha-dose (Gy) deposited by alpha-particles emitted by 1Bq of $^{232}$Th in the tissue T. $W_R$ is the radiation weighting factor which is equal to 20 for alpha-particles\textsuperscript{21}.

The $D_{sp}^T(U)$ and $D_{sp}^T(Th)$ specific alpha-doses\textsuperscript{22} are respectively given by:

$$D_{sp}^T(U)=k \frac{K_f R_f S_f}{m_t} \quad \ldots \quad (12)$$

and

$$D_{sp}^T(Th)=k \frac{K_f R_f S_f}{m_t} \quad \ldots \quad (13)$$

where $m_t$ is the mass of the target tissue T (in kg)\textsuperscript{23}. $K_f$ is the branching ratio for $^{238}$U disintegration. $K_f$ is the branching ratio for $^{232}$Th disintegration, $R_f$ is the range of the alpha-particles emitted by $^{238}$U, in the tissue of the target organ (g cm$^{-2}$), $R_f$ is the range of the alpha-particles emitted by $^{232}$Th, in the tissue of the target organ (g cm$^{-2}$). $k = 1.6 \times 10^{-15}$ (J MeV$^{-1}$) is a
conversion factor, $S_T$ is the stopping power of the tissue $T$ for the alpha-particles emitted by $^{238}\text{U}$ (MeV cm\(^2\) g\(^{-1}\)). $S_T$ is the stopping power of the tissue $T$ for the alpha-particles emitted by $^{232}\text{Th}$ (MeV cm\(^2\) g\(^{-1}\)). $R_T$, $R_T'$, $S_T$ and $S_T'$ were calculated by using a TRIM programme\(^{15}\).

The committed equivalent doses due to $^{238}\text{U}$ and $^{232}\text{Th}$ in the tissue $T$ from the ingestion of a table sugar/green tea drink/coffee drink sample are given by:

\[
H_T(\text{U}) = \int_0^T H_T(\text{U})\, dt \quad \text{... (14)}
\]

and

\[
H_T(\text{Th}) = \int_0^T H_T(\text{Th})\, dt \quad \text{... (15)}
\]

where $T$ is the integration time (in years) following intake. $T$ is equal to 50y for adults and 70y for infants and children.

The annual committed effective doses due to the $^{238}\text{U}$ and $^{232}\text{Th}$ radionuclides from the ingestion of a table sugar/green tea drink/coffee drink sample are given by:

\[
E_\text{U} = \sum W_T H_T(\text{U}) \quad \text{... (16)}
\]

and

\[
E_\text{Th} = \sum W_T H_T(\text{Th}) \quad \text{... (17)}
\]

where $W_T$ is the tissue weighting factor.

These annual committed effective doses are also evaluated by using the following relationships:

\[
E_\text{U} = I_\text{U} e(\text{g})_\text{U} \quad \text{... (18)}
\]

and

\[
E_\text{Th} = I_\text{Th} e(\text{g})_\text{Th} \quad \text{... (19)}
\]

where $I_\text{U}$ (Bq y\(^{-1}\)) and $I_\text{Th}$ (Bq y\(^{-1}\)) are the $^{238}\text{U}$ and $^{232}\text{Th}$ intakes, respectively, and $e(\text{g})_\text{U}$ (SV Bq\(^{-1}\)) and $e(\text{g})_\text{Th}$ (SV Bq\(^{-1}\)) are the ICRP ingestion dose coefficients for the $^{238}\text{U}$ and $^{232}\text{Th}$ radionuclides, respectively.

Assuming that only 1\% of the energy of the alpha-particles is included in computing the effective energies for the GI tract\(^{23}\), the alpha-equivalent dose rate (Sv s\(^{-1}\)) in a tissue $T$ of the human gastrointestinal system due to $^{222}\text{Rn}$ from the ingestion of a table sugar/green tea drink/coffee drink sample by the members of the Moroccan rural and urban populations is given by:

\[
H_T(\text{Rn})(t) = 10^{-2} D_{\text{sp}}^T(\text{Rn}) A_T(\text{Rn})(t) W_T \quad \text{... (20)}
\]

where $A_T(\text{Rn})$ is the alpha-activity due to $^{222}\text{Rn}$ in the tissue $T$ of the gastrointestinal system and $D_{\text{sp}}^T(\text{Rn})$ is the specific alpha-dose (Gy) deposited by alpha-particles emitted by 1Bq of $^{222}\text{Rn}$ in the tissue $T$.

The $D_{\text{sp}}^T(\text{Rn})$ specific alpha-dose is given by:

\[
D_{\text{sp}}^T(\text{Rn}) = \frac{K_T R_T S_T}{m_T} \quad \text{... (21)}
\]

where $m_T$ is the mass of the target tissue $T$. $K_T$ is the branching ratio for $^{222}\text{Rn}$ disintegration. $R_T$ is the range of the alpha-particle emitted by $^{222}\text{Rn}$. $S_T$ is the stopping power of the tissue $T$ for the alpha-particle emitted by $^{222}\text{Rn}$. $k = 1.6 \times 10^{-13}$ (J MeV\(^{-1}\)) is a conversion factor.

The committed equivalent dose due to $^{222}\text{Rn}$ in the tissue $T$ from the ingestion of a table sugar/green tea drink/coffee drink sample is given by:

\[
H_T(\text{Rn}) = \int_0^T H_T(\text{Rn})(t)\, dt \quad \text{... (22)}
\]

where $t_i$ is the exposure time.

The committed effective dose due to $^{222}\text{Rn}$ from the ingestion of a table sugar/green tea drink/coffee drink sample is given by:

\[
E_{\text{Rn}} = \sum W_T H_T(\text{Rn}) \quad \text{... (23)}
\]

3 Results and Discussion

The validity of our method has been already tested by using different instrumental methods such as neutron activation analysis and isotope dilution mass spectrometry\(^{10,26}\) and also by analyzing different uranium nitrate standard solutions\(^{20}\).

The $^{238}\text{U}[A_c(\text{U})]$, $^{232}\text{Th}[A_c(\text{Th})]$, $^{222}\text{Rn}[A_c(\text{Rn})]$ and $^{220}\text{Rn}[A_c(\text{Rn})]$ concentrations were measured inside different soil, sugar beet, and table sugar collected from the Tadla, Moulouya, Doukkala and Loukous regions (Eqs1, 2, 5 and 6). Data obtained are shown in Table 1(a). Since the track detectors utilized were etched in two NaOH solutions at optimal conditions of etching, ensuring good sensitivities of
Table 1a — Data obtained for $^{238}$U, $^{222}$Th and $^{222}$Rn concentrations inside soil, sugar beet and table sugar samples

<table>
<thead>
<tr>
<th>Region</th>
<th>Soil $^{238}$U (mBq/kg)</th>
<th>Soil $^{238}$Th (mBq/kg)</th>
<th>Soil $^{222}$Rn (mBq/kg)</th>
<th>Sugar beet $^{238}$U (mBq/kg)</th>
<th>Sugar beet $^{238}$Th (mBq/kg)</th>
<th>Sugar beet $^{222}$Rn (mBq/kg)</th>
<th>Table sugar $^{238}$U (mBq/kg)</th>
<th>Table sugar $^{238}$Th (mBq/kg)</th>
<th>Table sugar $^{222}$Rn (mBq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tadla</td>
<td>65±4</td>
<td>26±1</td>
<td>177±11</td>
<td>72±5</td>
<td>6.6±0.3</td>
<td>2.2±0.1</td>
<td>12.5±0.5</td>
<td>4.2±0.2</td>
<td>5.4±0.3</td>
</tr>
<tr>
<td>Doukkala</td>
<td>54±4</td>
<td>23±1</td>
<td>103±7</td>
<td>43±3</td>
<td>6.2±0.3</td>
<td>2.4±0.1</td>
<td>9.4±0.4</td>
<td>3.5±0.2</td>
<td>5.1±0.3</td>
</tr>
<tr>
<td>Gharb</td>
<td>78±6</td>
<td>20±1</td>
<td>215±14</td>
<td>58±4</td>
<td>7.9±0.4</td>
<td>1.8±0.1</td>
<td>18±1</td>
<td>4.8±0.3</td>
<td>6.9±0.4</td>
</tr>
<tr>
<td>Moulouya</td>
<td>48±3</td>
<td>30±1</td>
<td>88±6</td>
<td>54±4</td>
<td>7.1±0.4</td>
<td>2.2±0.1</td>
<td>7.8±0.4</td>
<td>2.2±0.1</td>
<td>6.7±0.4</td>
</tr>
<tr>
<td>Loukous</td>
<td>57±4</td>
<td>27±1</td>
<td>111±7</td>
<td>53±4</td>
<td>5.2±0.3</td>
<td>2.5±0.1</td>
<td>9.5±0.4</td>
<td>4.6±0.3</td>
<td>4.5±0.3</td>
</tr>
</tbody>
</table>

Table 1b — Data obtained for $^{238}$U, $^{222}$Th and $^{222}$Rn transfer coefficients between soil and sugar beet ($\text{TC}^{\text{SuB/So}}^\text{U}$, $\text{TC}^{\text{SuB/So}}^\text{Th}$ and $\text{TC}^{\text{SuB/So}}^\text{Rn}$) and between sugar beet and table sugar ($\text{TC}^{\text{SuB/Tab}}^\text{U}$, $\text{TC}^{\text{SuB/Tab}}^\text{Th}$ and $\text{TC}^{\text{SuB/Tab}}^\text{Rn}$).

<table>
<thead>
<tr>
<th>Region</th>
<th>Transfer coefficients between soil and sugar beet</th>
<th>Transfer coefficients between sugar beet and table sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\text{TC}^{\text{SuB/So}}^\text{U}$ (%)</td>
<td>$\text{TC}^{\text{SuB/So}}^\text{Th}$ (%)</td>
</tr>
<tr>
<td>Tadla</td>
<td>10±1</td>
<td>8.0±0.7</td>
</tr>
<tr>
<td>Doukkala</td>
<td>12±1</td>
<td>9±1</td>
</tr>
<tr>
<td>Gharb</td>
<td>10±1</td>
<td>9±1</td>
</tr>
<tr>
<td>Moulouya</td>
<td>15±1</td>
<td>7.2±0.8</td>
</tr>
<tr>
<td>Loukous</td>
<td>9.0±0.6</td>
<td>9±1</td>
</tr>
</tbody>
</table>

The SSNTDs and a good reproducibility of the measured global track density rates registered on these films placed in direct contact with the studied material samples determined by means of the same optical microscope with magnification 40x, only the statistical uncertainty on track counting is predominant. Indeed, from the statistical uncertainty on track counting one can determine the uncertainty on track density production per unit time and then evaluate the uncertainty of the $^{238}$U, $^{222}$Th, $^{222}$Rn concentrations determination which is of 8%.

Table 1(b) presents the uranium transfer coefficient $\text{TC}^{\text{U}}_{\text{SuB/So}}$, thorium transfer coefficient $\text{TC}^{\text{Th}}_{\text{SuB/So}}$ and radon transfer coefficient $\text{TC}^{\text{Rn}}_{\text{SuB/So}}$, which are defined as the ratios of the sugar beet (SuB) to soil (So) $^{238}$U, $^{222}$Th and $^{222}$Rn concentrations, and the transfer coefficients $\text{TC}^{\text{U}}_{\text{SuB/So}}$, $\text{TC}^{\text{Th}}_{\text{SuB/So}}$ and $\text{TC}^{\text{Rn}}_{\text{SuB/So}}$, which are defined as the ratios of the $^{238}$U, $^{222}$Th and $^{222}$Rn concentrations of the sugar (Su) to sugar beet $^{238}$U, $^{222}$Th and $^{222}$Rn concentrations. We noted that 7% to 14% of $^{238}$U, $^{222}$Th and radon are transferred from soil to sugar beet and 69% to 95% are transferred from sugar beet to sugar. Wide ranges for $^{222}$Th and $^{238}$U transfer coefficients were reported for various countries reflecting all kinds of soils and plants. $^{238}$U transfer coefficient ranged from 0.2 to 6.4% for different plants in Syria $^{27}$. $^{222}$Th and $^{222}$Rn transfer factors were found equal to 0.049 % and 0.11% for melon, respectively $^{28}$. $^{238}$U transfer factor was found equal to 0.37% for watermelon in Italy $^{28}$. $^{222}$U transfer factor was found equal to 6.3% for roots and 2.4% for stalk of tomato plants in Germany $^{29}$.

The $^{238}$U, $^{222}$Th and $^{222}$Rn concentrations were measured inside eleven table sugar samples imported from different countries (Table 2). We noted that the uranium activity concentration is higher than that of thorium for all the table sugar samples studied (Table 2). Annual $^{238}$U (I$_{\text{U}}$), $^{222}$Th (I$_{\text{Th}}$) and $^{222}$Rn (I$_{\text{Rn}}$) intakes by adult members of the public belonging to the considered countries from the ingestion of table sugar material samples were determined (Table 2) by using intake masses given in the OCDE/FAO report $^{30}$. The relative uncertainty on the $^{238}$U, $^{222}$Th and $^{222}$Rn annual intakes determination is 8%. $^{238}$U, $^{222}$Th, $^{222}$Rn and $^{222}$Rn concentrations have been measured inside different green tea and coffee drinks, prepared by adding tea, coffee and sugar to boiled potable water, consumed by adult members of the Moroccan urban population (Table 3). These radionuclides were also measured inside various green tea and coffee drinks, prepared by adding tea, coffee and sugar to boiled water collected from wells, consumed by the members of the...
Moroccan rural population (Table 4). We noted that the $^{238}$U and $^{232}$Th concentrations are higher in the tea and coffee drinks consumed by the members of the rural population than in those consumed by the members of the urban population. This is because potable water used by urban consumers for preparing tea and coffee drinks contains less $^{238}$U and $^{232}$Th uranium and thorium than water collected from wells and used by the rural population. A census of the consumption of green tea and coffee drinks by the members of the Moroccan urban and rural populations was taken (Tables 5 and 6).
Table 5—Data obtained for the annual committed effective doses due to \(^{220}\)U (\(I_{\text{U}}\)), \(^{232}\)Th (\(I_{\text{Th}}\)), \(^{222}\)Rn (\(I_{\text{Rn}}\)) and \(^{222}\)Rn (\(I_{\text{Rn}}\)) from the ingestion of different green tea and coffee drinks by adult members of the Moroccan urban population. \(I_{\text{U}}\), \(I_{\text{Th}}\), and \(I_{\text{Rn}}\) are respectively the \(^{238}\)U, \(^{232}\)Th and \(^{222}\)Rn intakes from the ingestion of the studied green tea and coffee drinks by adult members of the Moroccan urban population.

<table>
<thead>
<tr>
<th>City (number of individuals)</th>
<th>Drink preparation</th>
<th>Intake mass (I(_{\text{y}}) per person)</th>
<th>(I_{\text{U}}) (mBq/L)</th>
<th>(I_{\text{Th}}) (mBq/L)</th>
<th>(I_{\text{Rn}}) (Bq/L)</th>
<th>(E_{\text{U}}) (10(^{-9})Sv.y(^{-1}))</th>
<th>(E_{\text{Th}}) (10(^{-9})Sv.y(^{-1}))</th>
<th>(E_{\text{Rn}}) (10(^{-9})Sv.y(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marrakech (5,232)</td>
<td>Tea</td>
<td>225±4</td>
<td>1.24±0.1</td>
<td>0.76±0.07</td>
<td>1339±91</td>
<td>4.3±0.4</td>
<td>18±1</td>
<td>1.07±0.06</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>132±3</td>
<td>0.68±0.05</td>
<td>0.42±0.03</td>
<td>709±54</td>
<td>2.5±0.2</td>
<td>9.9±0.7</td>
<td>0.57±0.03</td>
</tr>
<tr>
<td>Rabat (3,827)</td>
<td>Tea</td>
<td>149±3</td>
<td>0.83±0.06</td>
<td>0.45±0.03</td>
<td>875±59</td>
<td>3.0±0.3</td>
<td>10.7±0.8</td>
<td>0.7±0.05</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>152±4</td>
<td>0.77±0.06</td>
<td>0.43±0.04</td>
<td>813±51</td>
<td>2.8±0.2</td>
<td>10.2±0.8</td>
<td>0.65±0.05</td>
</tr>
<tr>
<td>Casablanca (4164)</td>
<td>Tea</td>
<td>210±5</td>
<td>0.39±0.03</td>
<td>0.65±0.05</td>
<td>412±28</td>
<td>1.5±0.1</td>
<td>15.7±1.4</td>
<td>0.33±0.03</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>163±3</td>
<td>0.34±0.02</td>
<td>0.47±0.03</td>
<td>362±24</td>
<td>1.3±0.1</td>
<td>11±1</td>
<td>0.29±0.02</td>
</tr>
<tr>
<td>Mohamadia (2,875)</td>
<td>Tea</td>
<td>256±5</td>
<td>0.41±0.03</td>
<td>1.12±0.08</td>
<td>433±33</td>
<td>1.5±0.1</td>
<td>27±2</td>
<td>0.35±0.02</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>146±3</td>
<td>0.18±0.01</td>
<td>0.61±0.03</td>
<td>190±12</td>
<td>0.66±0.06</td>
<td>15±1</td>
<td>0.15±0.01</td>
</tr>
<tr>
<td>Fes (3,721)</td>
<td>Tea</td>
<td>175±3</td>
<td>1.24±0.1</td>
<td>0.70±0.05</td>
<td>1300±115</td>
<td>4.4±0.3</td>
<td>17±1</td>
<td>0.10±0.07</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>118±3</td>
<td>0.80±0.05</td>
<td>0.45±0.03</td>
<td>846±55</td>
<td>2.9±0.2</td>
<td>10.9±0.9</td>
<td>0.68±0.05</td>
</tr>
<tr>
<td>Beni-Mellal (2,315)</td>
<td>Tea</td>
<td>228±5</td>
<td>1.06±0.08</td>
<td>0.68±0.05</td>
<td>1129±84</td>
<td>3.8±0.3</td>
<td>16±1</td>
<td>0.9±0.06</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>123±3</td>
<td>0.53±0.03</td>
<td>0.34±0.02</td>
<td>561±42</td>
<td>1.9±0.1</td>
<td>8.1±0.6</td>
<td>0.45±0.03</td>
</tr>
<tr>
<td>Agadir (2,901)</td>
<td>Tea</td>
<td>192±4</td>
<td>1.34±0.1</td>
<td>0.17±0.01</td>
<td>140±121</td>
<td>4.7±0.4</td>
<td>4.1±0.4</td>
<td>1.12±0.08</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>105±3</td>
<td>0.70±0.06</td>
<td>0.10±0.01</td>
<td>739±56</td>
<td>2.6±0.2</td>
<td>1.8±0.1</td>
<td>0.59±0.04</td>
</tr>
<tr>
<td>Dakhla (1,824)</td>
<td>Tea</td>
<td>354±10</td>
<td>2.7±0.02</td>
<td>0.39±0.02</td>
<td>2906±183</td>
<td>10.3±0.8</td>
<td>9.5±0.7</td>
<td>2.3±0.2</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>96±3</td>
<td>0.71±0.05</td>
<td>0.11±0.01</td>
<td>751±49</td>
<td>2.6±0.2</td>
<td>2.1±0.2</td>
<td>0.6±0.03</td>
</tr>
<tr>
<td>Laayoune (2,082)</td>
<td>Tea</td>
<td>376±10</td>
<td>3.1±0.2</td>
<td>0.62±0.05</td>
<td>3286±2223</td>
<td>11.6±0.8</td>
<td>14±1</td>
<td>0.6±0.02</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>82±2</td>
<td>0.66±0.05</td>
<td>0.12±0.01</td>
<td>695±60</td>
<td>2.4±0.2</td>
<td>3.0±0.3</td>
<td>0.56±0.04</td>
</tr>
<tr>
<td>Oujda (3,457)</td>
<td>Tea</td>
<td>217±5</td>
<td>0.53±0.04</td>
<td>1.05±0.07</td>
<td>566±37</td>
<td>1.9±0.1</td>
<td>26±2</td>
<td>0.45±0.04</td>
</tr>
<tr>
<td></td>
<td>Coffee</td>
<td>124±3</td>
<td>0.26±0.02</td>
<td>0.57±0.04</td>
<td>275±20</td>
<td>0.94±0.07</td>
<td>14±1</td>
<td>0.22±0.01</td>
</tr>
</tbody>
</table>

\((I_{\text{Rn}})\) and \((I_{\text{Rn}})\) intake of the Moroccan urban (adults) and rural (different age groups) population from the ingestion of green tea and coffee drinks were determined (Tables 5 and 6). The relative uncertainty on the \(^{238}\)U and \(^{232}\)Th annual intake determination is of 10%. Building and farm workers usually prepare at workplaces their green tea drinks without cleaning their hands. Thus, amounts of building material, phosphate, and fertilizer dusts adhere to tea and sugar materials and are consequently introduced in the prepared tea drinks. In order to study the influence of the dusts of different pollutants, \(^{238}\)U, \(^{232}\)Th, and \(^{222}\)Rn concentrations were measured inside polluted tea drinks (Table 7). From results presented in Table 7 we showed that the \(^{238}\)U, \(^{232}\)Th, and \(^{222}\)Rn concentrations inside polluted tea drinks without cleaning their hands. Thus, amounts of building material, phosphate, and fertilizer dusts adhere to tea and sugar materials and are consequently introduced in the prepared tea drinks. In order to study the influence of the dusts of different pollutants, \(^{238}\)U, \(^{232}\)Th, and \(^{222}\)Rn concentrations were measured inside polluted tea drinks (Table 7). From results presented in Table 7 we showed that the \(^{238}\)U, \(^{232}\)Th, and \(^{222}\)Rn concentrations inside polluted tea
drinks are more important than inside the unpolluted ones because cement, granite, clay, phosphates, and marbles contain more $^{238}$U and $^{232}$Th. The tea drink sample polluted by phosphates shows higher $^{238}$U concentration than those polluted by cement, granite, clay and marble. This is because the former material contains more $^{238}$U than the latter's.

The tea drink sample polluted by clay dusts shows higher $^{232}$Th concentration than the others. This is due to the fact that clay dusts show higher $^{232}$Th concentration than the other pollutants.

Annual committed effective doses due to $^{238}$U (E$_U$), $^{232}$Th (E$_{Th}$) and $^{222}$Rn [E($^{222}$Rn)] from the ingestion of different table sugar samples were evaluated in the human body of adult consumers belonging to various countries (Table 2). The statistical relative uncertainty of the committed equivalent dose determination is of 10%. Global committed effective doses due to $^{238}$U,
That the global committed effective dose due to $^{238}$U, $^{232}$Th and $^{222}$Rn from the ingestion of tea drinks is higher for all age groups belonging to the Argub and Echdera rural localities (southern Morocco) than those belonging to the other Moroccan rural localities. This is because populations in Saharian zones (southern Morocco) consume more tea drink than those living in the other Moroccan rural zones (Table 8). A maximum value of the total committed effective dose due to $^{238}$U, $^{232}$Th and $^{222}$Rn from the ingestion of tea drinks by the members of the Moroccan rural population was found equal to (0.13 ± 0.01) m Sv y$^{-1}$ (obtained for the members of the 12-17 years age group living in the Aargoub locality) which is lower than the mean world values for ingestion (ranging from 0.2 to 0.8 m Sv y$^{-1}$) [36]. Committed effective doses due to $^{238}$U and $^{232}$Th from the ingestion of tea drinks by adult members of the Moroccan rural population were determined by using our method and the ICRP ingestion dose coefficient [36]. Data obtained by the two methods are in good agreement with each other (Table 9). Committed effective doses due to radon from the ingestion of tea drinks by adult consumers were evaluated by using our method and the UNSCEAR ingestion dose coefficient [36]. The difference between data obtained by the two methods is due to the fact that we evaluated the committed

$^{232}$Th and $^{222}$Rn ranged from 6.77 $10^{-8}$ to 47.59 $10^{-8}$ Sv y$^{-1}$.

Committed effective doses due to $^{238}$U, $^{232}$Th and $^{222}$Rn were determined for adult members of the Moroccan urban population, belonging to different cities from the ingestion of tea and coffee drinks (Table 5). We noted from results shown in Table 5 that the global committed effective dose due to $^{238}$U, $^{232}$Th and $^{222}$Rn from the ingestion of both tea and coffee drinks is higher for consumers belonging to the cities of Laayoune and Dakhla (Southern Morocco) than for those belonging to the other Moroccan cities. This is due to the fact that the first consumers drink especially more tea drink than the latter’s (Table 5). A maximum value of 3.16 $10^{−1}$ for the 12-17 years age group than for the other age groups. This is due to the fact that children belonging to the 12-17 years age group consume more tea drinks than those belonging to the other age groups (Table 8). It is to be noted that the

![Table](indianjpureandapplphys/50/10/694/table8.jpg)

Table 8—Data obtained for the annual committed effective doses due to $^{238}$U $(E_U)$, $^{232}$Th $(E_{Th})$ and $^{222}$Rn $(E(222Rn))$ from the ingestion of tea drinks by different age groups of the Moroccan rural population.

<table>
<thead>
<tr>
<th>Tea drink(location)</th>
<th>7-12 years age group</th>
<th>12-17 years age group</th>
<th>Adults (&gt;17 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E_U$ $(\mu$Sv.y$^{-1})$</td>
<td>$E_{Th}$ $(\mu$Sv.y$^{-1})$</td>
<td>$E(222Rn)$ $(\mu$Sv.y$^{-1})$</td>
</tr>
<tr>
<td>Tea + sugar + WW1</td>
<td>0.18±0.02</td>
<td>0.76±0.06</td>
<td>83±7</td>
</tr>
<tr>
<td>(Ait Ourir)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tea + sugar + WW2</td>
<td>0.14±0.01</td>
<td>0.66±0.05</td>
<td>40±3</td>
</tr>
<tr>
<td>(Ain Aouda)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tea + sugar + WW3</td>
<td>0.12±0.01</td>
<td>0.59±0.05</td>
<td>35±2</td>
</tr>
<tr>
<td>(Sidi Hajjai)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tea + sugar + WW4</td>
<td>0.18±0.01</td>
<td>1.21±0.09</td>
<td>49±4</td>
</tr>
<tr>
<td>(Ben Yarkhlef)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tea + sugar + WW5</td>
<td>0.13±0.01</td>
<td>0.35±0.02</td>
<td>34±3</td>
</tr>
<tr>
<td>(Menzeh)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tea + sugar + WW6</td>
<td>0.33±0.02</td>
<td>1.01±0.07</td>
<td>90±7</td>
</tr>
<tr>
<td>(Dar ouled Zidouh)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tea + sugar + WW7</td>
<td>0.2±0.02</td>
<td>0.90±0.06</td>
<td>56±4</td>
</tr>
<tr>
<td>(Douar el Kodia)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tea + sugar + WW8</td>
<td>0.34±0.02</td>
<td>0.63±0.06</td>
<td>96±7</td>
</tr>
<tr>
<td>(Aargub)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tea + sugar + WW9</td>
<td>0.34±0.03</td>
<td>1.08±0.07</td>
<td>99±8</td>
</tr>
<tr>
<td>(Echdera)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tea + sugar + WW10</td>
<td>0.15±0.01</td>
<td>1.06±0.08</td>
<td>42±3</td>
</tr>
</tbody>
</table>
effective dose only in the gastrointestinal tract whereas the UNSCEAR ingestion dose coefficient is for the whole human body (Table 9). Global committed effective dose due to $^{238}\text{U}$, $^{232}\text{Th}$ and $^{222}\text{Rn}$ was determined for rural adult workers consuming polluted tea drinks (Table 7). A maximum value was found to be equal to 0.69 mSv y$^{-1}$ which is within the interval of the mean world values for ingestion (ranging from 0.2 to 0.8 mSv y$^{-1}$).

### 4 Conclusions

It has been shown by this study that by using both CR-39 and LR-115 II solid state nuclear track detectors (SSNTDs), one can determine $^{238}\text{U}$ and $^{232}\text{Th}$ concentrations as well as alpha activities per unit volume due to $^{222}\text{Rn}$ and $^{228}\text{Rn}$ inside different table sugar and tea and coffee drink samples. It has been shown that $^{238}\text{U}$, $^{232}\text{Th}$ and $^{222}\text{Rn}$ are mostly transferred from sugar beet to table sugar. It is concluded that pollution due to building material and phosphate dust may increase radiation dose to the consumers of tea drinks. Therefore, building material and farm workers should clean their hands before preparing their tea drinks at workplaces to avoid significant exposure to radiation. This SSNTDs’ technique which has the advantage of being inexpensive, non-destructive, sensitive, and accurate and does not need the use of any standard for its calibration, is a good tool for assessing radiation-dose risk due to the ingestion of sweeties and tea and coffee drinks.

### Funding

This work was realized under an URAC-15 research contract with the CNRST, Rabat, Morocco.

### References


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Table 9—Committed effective doses due to $^{238}\text{U}$ ($E_U$), $^{232}\text{Th}$ ($E_{Th}$) and $^{222}\text{Rn}$ ($E_{222}\text{Rn}$) from the ingestion of green tea drinks by adult members of the Moroccan rural population.

<table>
<thead>
<tr>
<th>Tea drink (locality)</th>
<th>This method</th>
<th>ICRP ingestion dose coefficient</th>
<th>UNSCEAR Ingestion dose coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E_U$ (µSv.y$^{-1}$)</td>
<td>$E_{Th}$ (µSv.y$^{-1}$)</td>
<td>$E_{222}\text{Rn}$ (µSv.y$^{-1}$)</td>
</tr>
<tr>
<td>Tea + sugar + WW1 (Ait Ouir)</td>
<td>0.18±0.01</td>
<td>0.95±0.06</td>
<td>52±4</td>
</tr>
<tr>
<td>Tea + sugar + WW2 (Ain Aouda)</td>
<td>0.13±0.01</td>
<td>0.76±0.06</td>
<td>36.5±2.4</td>
</tr>
<tr>
<td>Tea + sugar + WW3 (Sidi Hajjaj)</td>
<td>0.11±0.01</td>
<td>0.63±0.05</td>
<td>30.3±1.7</td>
</tr>
<tr>
<td>Tea + sugar + WW4 (Ben Yakhlef)</td>
<td>0.15±0.01</td>
<td>1.21±0.09</td>
<td>40.8±3.6</td>
</tr>
<tr>
<td>Tea + sugar + WW5 (Menzeh)</td>
<td>0.11±0.01</td>
<td>0.38±0.03</td>
<td>30.5±2.6</td>
</tr>
<tr>
<td>Tea + sugar + WW6 (Dar ouled Zidouh)</td>
<td>0.24±0.02</td>
<td>0.91±0.07</td>
<td>65.6±5.1</td>
</tr>
<tr>
<td>Tea + sugar + WW7 (Douar el Kodia)</td>
<td>0.17±0.01</td>
<td>0.92±0.07</td>
<td>48±3.3</td>
</tr>
<tr>
<td>Tea + sugar + WW8 (Aargub)</td>
<td>0.29±0.02</td>
<td>0.67±0.06</td>
<td>83.5±5.6</td>
</tr>
<tr>
<td>Tea + sugar + WW9 (Echderia)</td>
<td>0.26±0.02</td>
<td>1.04±0.08</td>
<td>74±5</td>
</tr>
<tr>
<td>Tea + sugar + WW10 (Jouadra)</td>
<td>0.12±0.01</td>
<td>1.10±0.08</td>
<td>33.6±2.2</td>
</tr>
</tbody>
</table>
17 Maple version 8.0, Waterloo Maple Software, 450 Philip Street, Waterloo, Ontario, N2L-5J2, Canada (2002).