Biomonitoring PAH levels in domestic kitchens using commonly grown culinary herbs

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Abstract

Cooking is a significant source of polycyclic aromatic hydrocarbon (PAH) emissions in indoor environments. A biomonitoring study was carried out in previously selected rural Hungarian kitchens to evaluate cooking-related PAH concentrations in 4 common kitchen vegetables such as basil, parsley, rocket and chives. After 1 month exposure, PAH accumulation pattern in tested plants clearly indicated differences in cooking methods and cooking oils used in the selected households. Use of lard and animal fats in general resulted in the high concentrations of higher molecular weight (5- and 6-ring) PAHs, while olive oil usage could be associated with the emission of 2- and 3-ring PAHs. Culinary herbs, however, accumulated carcinogenic PAHs such as benzo[a]anthracene, benzo[b]fluoranthene and chrysene which might question their safe use.

Introduction

Indoor air quality has become a crucial issue (WHO 2010), especially considering the fact that people spend around 90% of their time indoors in Europe (González-Martín et al. 2021). Cooking is a major indoor source of polycyclic aromatic hydrocarbons (PAHs) (Zhai and Albritton 2020); some authors even argue that it has a significant contribution to urban outdoor PAH concentrations (Li et al. 2003). PAHs are listed by the EU Directive 2004/107/EC (EU 2004) among the contaminants of emerging environmental concern.

PAH emissions generated from the various cooking practices differ considerably, depending on cooking methods, as well as materials used (See and Balasubramanian 2006). Deep-frying is the most common procedure to prepare food (Ganesan and Xu 2020), as deep-fried items usually have attractive color and texture (Bordin et al., 2013). However, deep-frying is reportedly generating the highest amount of PAHs as a result of the high oil temperatures used (Abdullahi et al. 2013). In the experiments of Yao et al., average oil temperature measured during deep-frying was 203°C, in comparison to the temperature during frying (139°C). Oil temperatures determine PAH emissions in cooking fumes as PAHs move from the oil into the air when heated (Moret and Conte 2000). An additional problem associated with deep-frying is that vegetable oils are often re-used mainly to reduce costs. During repeated use, nutritional value and safety decrease (Ng et al. 2014). Manzoor et al. (2022) reported that only 20% of the in-use frying oil and 10% food products were safe for consumption in street vendors in Kashmir. Chen et al. (2007) measured gaseous and particulate emissions in Chinese restaurants and reported that deep frying produced the highest amount of total gaseous PAHs, with the dominance of naphthalene ranging between 67–89%.

There are a wide range of studies analysing PAH emission during different cooking activities and in different environments. Nevertheless, in case of chemical monitoring, sampling is done for a very limited duration, mostly covering the time of the experimental cooking (e.g. Yao et al. 2015, Li et al. 2022, Zhang et al. 2017). On the contrary, using biomonitors, integrated exposure of pollutants can be assessed for a pre-chosen continuous or semi-continuous exposure (Mukhopadhyay et al. 2020). Plants provide an excellent tool for PAH biomonitoring as they are exposed to PAHs both from gas-phase air and solid particles suspended in the air (Wieczorek et al. 2015). Light molecular weight (LMW) PAHs are characteristic in gas phase due to their volatile nature while higher molecular weight (HMW) compounds are less volatile and occur mostly in the airborne particulate form (Kameda, 2011).

Different plant species have been widely used to capture information about the level of PAH pollution in outdoor environments like urban settings (e.g. Klingberg et al. 2022), industrial areas (e.g. Wannaz et al. 2013) or agricultural lands (e.g. Capozzi et al. 2017). Although more scarcely, indoor applications have also been documented. Rzepka et al. (2010) evaluated genotoxic properties of indoor air applying comet assay on Scindapsus aureus (pothos). Nap levels were monitored by the Tradescantia pallida cv. Purpurea micronucleus assay in the study of Alves et al. (2008). Transplanted lichens have been the most widely used in indoor studies (Canha et al. 2012, 2019, Paoli et al. 2019, Protano et al. 2017, Sujetovienė and Česynaitė 2021). However, houseplants such as Dieffenbachia amoena, Dracena marginata, Ficus elastica or Yucca massengena were used to monitor emissions from tobacco smoke in the study of Ghoma et al. (2022). Tobacco smoke was also monitored by the moss Pleurozium schreberi in the study of Świsłowski et al. (2022).

The main question in the present study was to find out if PAH emissions generated during different cooking habits can be indicated by bioaccumulation experiments. Also, we wanted to examine to what extent common culinary herbs typically grown in
kitchen environments can be used for bioaccumulation studies.

**Material and Methods**

**Household selection**

3 households were selected sharing some important characteristic features (Table 1.). They have similar size, 2 adults + 2 children. Also, they are situated in small villages, not affected by heavy traffic or any outdoor pollution source. As several studies have shown that infiltration of outdoor air pollutants could be influencing indoor air quality in case of traffic-impacted sites (e.g. Tong et al. 2016), this criterion was of crucial importance.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Description of the surveyed households</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH1</td>
<td>HH2</td>
</tr>
<tr>
<td>Number of inhabitants</td>
<td>4</td>
</tr>
<tr>
<td>Cooking frequency per day</td>
<td>usually 2</td>
</tr>
<tr>
<td>Material used</td>
<td>lard app. 95%</td>
</tr>
<tr>
<td></td>
<td>butter app. 5%</td>
</tr>
<tr>
<td>Cooking method</td>
<td>Boiling 30%</td>
</tr>
<tr>
<td></td>
<td>Deep-frying 10%</td>
</tr>
<tr>
<td></td>
<td>Pan-frying 40%</td>
</tr>
<tr>
<td></td>
<td>Oven 20%</td>
</tr>
</tbody>
</table>

**Pot experiment**

Commonly grown kitchen vegetables have been selected for the study as follows: *Eruca sativa* Mill. (rocket) (Family Brassicaceae); *Ocimum basilicum* L. cv. Genovese (basil) (Family Lamiaceae); *Petroselinum crispum* var. neapolitanum (Mill.) Fuss (leaf parsley) (Family Apiaceae) and *Allium schoenoprasum* L. (chives) (Family Amaryllidaceae). As such, the test battery involved 3 dicot (*E. sativa, O. basilicum, P. crispum*) and 1 monocot species (*A. schoenoprasum*). These species can be easily kept indoors, in fact, they are recommended for indoor environments by gastroblogs. Leaf surface absorption is the main transport pathway of PAHs from the air in leafy vegetables (Zhang et al. 2020).

Test plants were purchased from a local retainer than acclimatized for 1 month before exposure. Acclimatization was carried out in uncontaminated commercial soil (pH: 6.8 ± 0.5; N (m/m%): min 0.3; P₂O₅ (m/m%): min 0.1; K₂O (m/m%): min 0.3) in a greenhouse.

Exposure took one month, between 1 June and 30 June. Summer period was chosen to avoid potential cross-pollution from heating. Also, during summer holidays children mostly lunch at home, which increases cooking frequency. During exposure, plants were provided with enough water to prevent water stress.

After 1 month exposure healthy leaves were cut with pre-washed scissors. New leaves (younger than 1 month) were discarded. Samples were immediately taken to the laboratory, washed, ground and homogenized (Wang et al. 2021). Prior to analysis, they were kept in the freezer (~ 20°C).

**Determination of the PAH content**
Detailed description of plant material preparation and analytical procedures are given in Hubai et al. (2022). Shortly, 10 g of each vegetable sample was grinded followed by extraction with 20 mL n-hexane. The extract was spiked with 100 µl of 0.01 µg/mL deuterated PAH surrogate mixture than concentrated to 1 mL using dry nitrogen stream. Solid phase silica gel and alumina oxide sample clean-up was performed than 100 µl of 0.01 µg/mL Internal standard mixture (2-floro-biphenyl, and p-terphenyl-d14) was added to the clean sample. Analyses were performed by Agilent 6890GC 5973E MSD GC-MS, following the protocol based on MSZ (Hungarian Standard) EN 15527:2009 (Characterization of waste. Determination of polycyclic aromatic hydrocarbons (PAH) in waste using gas chromatography mass spectrometry). All data were corrected for the average value of the blanks. The limit of PAH detection (LOD) in plant samples 0.1 µg/kg dry plant material. Analytical determinations were performed by the courtesy of the Laboratory of the ELGOSCAR-2000 Environmental Technology and Water Management Ltd. accredited by the (Hungarian) National Accreditation Authority, registration number NAH-1-1278/2015.

**Statistical analysis**

In order to examine compositional differences among samples, principal component analysis (PCA) has been performed which generally reduces the set of variables into two major principle components. PCA has been extensively used to evaluate PAH accumulation pattern in different plant matrices (e.g. Kodnik et al. 2015; Capozzi et al. 2017). Statistical analyses were performed using the RStudio (RStudio Desktop 1.4.1106) program, ggfortify package (https://CRAN.R-project.org/package=ggfortify).

**Results and Discussion**

**Accumulation pattern**

Accumulated PAHs are given in Table 2, grouped by households. Except for parsley grown in HH2, accumulation of PAHs in each household was dominated by the 2-ring Naphthalene, regardless of the vegetable species used (Table 2), in concordance with other studies (e.g. Zhu and Wang 2003, Sharma and Jain 2020). Jia et al. (2019) modelled PAH accumulation in different leafy vegetables and found that gas-phase absorption contributed to app. 90% of total uptake. Nap typically occurs in the gas phase. Generally, higher temperatures lead to higher gas phase PAH concentrations while in cold temperature high level of PAHs in the particulate phase can be expected (Li et al. 2006). Nap production, however, seems to be independent from cooking styles: Huang et al. (2021) measured PAH emission during frying, steaming and grilling in Chinese commercial kitchens and found similar Nap emissions.
Table 2
Concentration of PAHs in the vegetables, grouped by households.

<table>
<thead>
<tr>
<th>PAH</th>
<th>Basil HH1</th>
<th>Rocket HH1</th>
<th>Parsley HH1</th>
<th>Chives HH1</th>
<th>Basil HH2</th>
<th>Rocket HH2</th>
<th>Parsley HH2</th>
<th>Chives HH2</th>
<th>Basil HH3</th>
<th>Rocket HH3</th>
<th>Parsley HH3</th>
<th>Chives HH3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nap</td>
<td>86</td>
<td>87.4</td>
<td>274</td>
<td>273</td>
<td>73.5</td>
<td>142</td>
<td>&lt;0.01</td>
<td>25.4</td>
<td>72.4</td>
<td>144</td>
<td>68.8</td>
<td>85.4</td>
</tr>
<tr>
<td>Methy-Nap</td>
<td>34.8</td>
<td>4.5</td>
<td>19.1</td>
<td>9.4</td>
<td>10</td>
<td>14.1</td>
<td>0.92</td>
<td>9.9</td>
<td>10</td>
<td>10.1</td>
<td>10.1</td>
<td>9.2</td>
</tr>
<tr>
<td>Me-Nap</td>
<td>24</td>
<td>2.8</td>
<td>13.1</td>
<td>6.6</td>
<td>6.2</td>
<td>8.5</td>
<td>7.8</td>
<td>5.8</td>
<td>7.12</td>
<td>7.2</td>
<td>0.72</td>
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<tr>
<td>Acl</td>
<td>19</td>
<td>2.9</td>
<td>7.2</td>
<td>2.3</td>
<td>1.8</td>
<td>11.4</td>
<td>3</td>
<td>1.7</td>
<td>6.2</td>
<td>5</td>
<td>1</td>
<td>2.1</td>
</tr>
<tr>
<td>Ace</td>
<td>1.42</td>
<td>2.66</td>
<td>3</td>
<td>1.5</td>
<td>1.5</td>
<td>2.3</td>
<td>1.9</td>
<td>1</td>
<td>2.1</td>
<td>1</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Flu</td>
<td>3.14</td>
<td>9.3</td>
<td>17.1</td>
<td>6.3</td>
<td>6.6</td>
<td>11.5</td>
<td>7.6</td>
<td>10.4</td>
<td>6</td>
<td>5.2</td>
<td>0.4</td>
<td>0.4</td>
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<tr>
<td>Phe</td>
<td>1.24</td>
<td>1.16</td>
<td>62</td>
<td>45</td>
<td>24.7</td>
<td>28.9</td>
<td>2.4</td>
<td>4.7</td>
<td>32.1</td>
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<td>7.8</td>
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<td>5</td>
<td>5.4</td>
<td>3.4</td>
<td>4.5</td>
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<tr>
<td>Flt</td>
<td>11.4</td>
<td>8.4</td>
<td>23</td>
<td>12.7</td>
<td>22.5</td>
<td>3.7</td>
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<td>54.2</td>
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<td>20</td>
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<tr>
<td>Pyr</td>
<td>8.86</td>
<td>11.2</td>
<td>15.8</td>
<td>7.1</td>
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<td>2.1</td>
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<td>3.4</td>
<td>1.7</td>
<td>6.2</td>
<td>10.1</td>
</tr>
<tr>
<td>BaA</td>
<td>7.06</td>
<td>7.7</td>
<td>7.4</td>
<td>4.9</td>
<td>9.8</td>
<td>11.9</td>
<td>9</td>
<td>8.5</td>
<td>1.8</td>
<td>0.8</td>
<td>4.2</td>
<td>5.05</td>
</tr>
<tr>
<td>Cry</td>
<td>16.5</td>
<td>8.04</td>
<td>14.1</td>
<td>6</td>
<td>14.1</td>
<td>20.1</td>
<td>10.2</td>
<td>12.1</td>
<td>2.9</td>
<td>0.92</td>
<td>4</td>
<td>0.62</td>
</tr>
<tr>
<td>BbF</td>
<td>1.12</td>
<td>5.9</td>
<td>13.5</td>
<td>4.4</td>
<td>13.8</td>
<td>13.2</td>
<td>8.4</td>
<td>1.29</td>
<td>0.28</td>
<td>1.1</td>
<td>9.2</td>
<td>10.1</td>
</tr>
<tr>
<td>BkF</td>
<td>8.5</td>
<td>4.00</td>
<td>6.7</td>
<td>2.6</td>
<td>7</td>
<td>8.9</td>
<td>4.4</td>
<td>0.6</td>
<td>19</td>
<td>0.6</td>
<td>3.2</td>
<td>5</td>
</tr>
<tr>
<td>BeP</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>6.74</td>
<td>3</td>
<td>8.2</td>
<td>8.8</td>
<td>4.4</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BaP</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>5.7</td>
<td>1.6</td>
<td>3.7</td>
<td>3.1</td>
<td>3.1</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>DahA</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>6.6</td>
<td>6.1</td>
<td>5.6</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ind</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>3.5</td>
<td>&lt;0.01</td>
<td>1.6</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BghiP</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>7.6</td>
<td>&lt;0.01</td>
<td>6.2</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Total</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>238</td>
<td>301.3</td>
<td>108.87</td>
<td>113.49</td>
<td>222</td>
<td>224</td>
<td>159</td>
<td>182</td>
</tr>
</tbody>
</table>

Of 3-ring PAHS, Phe was found in the highest concentrations in the majority of the samples, reaching as much as 62 µg/kg (parsley, HH1). Masuda et al. measured 12 PAHs in cooking exhaust gas, phenanthrene (2100 ng m$^{-3}$), fluorene (630 ng m$^{-3}$), and anthracene (200 ng m$^{-3}$) were detected at the highest concentrations. Sun et al. (2020) also reported the dominance of Phe when emissions in Sichuan style restaurant were measured. Sichuan cuisine is generally characterised by quick frying, high-temperature cooking and large oil consumption, which favours to PAH production. Phen was however measured at high concentrations when emissions from water-based cooking activities were studied in Chinese kitchens (Zhao et al. 2019).

Considering 4-ring PAHs, Flt and Pyr have been reported as being abundant/dominant in cooking-related emissions (Sun et al. 2020). In our samples, however, no clear pattern was shown. Accumulation of Flt seems to be depending on the vegetable tested: in general, high concentrations were found in basil, parsley and chives but definitely lower accumulation was found in case of rocket. Even less clear tendency was found for Pyr. Cry, however, was found in some samples in higher concentrations than
reported by the literature: in HH2 in the range of 10.2 (parsley) and 20.1 (rocket) and also reaching high values in HH1, 16.5 µg/kg in basil and 14.1 µg/kg in parsley.

More clear differences can be seen between households when ratio of different molecular weight PAHs is analysed. Figure 1 shows the distribution pattern of PAHs in vegetables/households grouped by the number of rings.

Characteristic differences between the households are represented by the distribution of HMW PAHs. The differences are especially clear when 6-ring PAHs are addressed: their concentration in HH2 was 11.1 in basil and 7.8 in parsley, and 10.4 in parsley in HH1. On the contrary, in HH1 no 6-ring PAH was detected. HH2 uses animal fat (lard) in app. 40% of its cooking activities and HH1 relies exclusively on the use of animal fats: lard app. 95% and butter app. 5%. The use of lard is negligible in HH3, 5%. Lard is extensively used in Hungary, Rurik and Antal (2003) reported that lard was used by 44% of subjects when cooking habits of elderly people was studied. Literature studies concerning emissions generated by animal fat usage as cooking material are extremely rare. Zhu and Wang (2003) compared PAH content of lard and vegetable oil fumes and found that lard fumes released more PAHs when heated at the same temperature. Jing et al. (2022) reported higher PAH emission and resulting incidence of cancers when animal fat was used, in comparison to vegetable oil use.

More studies have dealt with emissions generated during usage of raw materials with high animal fat content. Li et al. (2018) found that fat contents in raw materials can also be an important factor influencing PAH emission. Rogge et al. (1991) demonstrated that PAH emissions increased with increasing fat content of meat prepared. Of HMW PAHs, BghiP was detected in high concentrations when hamburgers with high fat content were grilled (McDonald et al. 2003). Alves et al. (2021) compared PAH emissions during cooking different typical Latin meals such as stuffed chicken, fried mackerel, fried and grilled pork. Emissions generated during preparation of grilled pork contained HMW PAHs in high concentrations, including IP, D(a,h) a and B(g,h,i,j) p.

PCA has been a widely used tool to identify possible emission sources of PAHs (Slezakova et al. 2013, Jia et al. 2018). In our study, PCA is based on the PAH content of different vegetables and the cooking behaviour of the three households. It explains 79.01% of the variance in the data in a single two-dimensional model (Fig. 2). Four groups were determined, high correlation was found between I. frequency of using olive oil, 2 ring and 3 ring PAHs, II. frequency of using butter or lard and pan frying; III. 4, 5, 6 ring PAHs; IV. frequency of using sunflower oil, deep frying and baking in oven.

Olive oil usage seems to be associated with the emission of 2- and 3-ring PAHs. It was used in only one household (HH2) at relatively high frequency (app. 5%). Chiang et al. (2022) measured total, gaseous-phase and particle-phase PAH emission rates when different vegetable oils (soybean oil, palm oil, and olive oil) were used for deep-frying. Of gaseous-phase PAHs, naphthalene amounted to 87% in olive oil. Comparing the three different oils, palm oil emitted significantly higher particle-phase PAHs than the other two.

HMW (4–6 ring) PAHs form another group, without clear relationship with potential sources. In general, frying operations such as stir- and deep-frying have been associated with the production of higher molecular weight compounds (See et al. 2006, Yao et al. 2015). These operations are reported for all three households being present in the study.

**Potential health hazards**

Concerning carcinogenicity of PAHs, different classification systems exist (reviewed by Sampaio et al. 2021). 13 PAHs were classified as genotoxic and carcinogenic by the Joint FAO/WHO Expert Committee on Food Additives: BaA, Chr, CPP (Cyclopenta[cd]pyrene), BbF, BaP, 5-MC (5-Methylchrysene), BjF (Benzo[j]fluoranthene), BkF, DBA, IP, DeP (Dibenzo[a,e]pyrene), DiP (Dibenzo[a,i]pyrene), and dibenzo[a,h]pyrene. Of them, four PAHs (BaA, Chr, BbF, and BaP) were identified as occurring in food and being good indicators of toxicity (EFSA 2008).

BbF was detected in all samples, reaching the highest values (above 13 µg/kg) in basil and rocket samples of HH1 (13.8 µg/kg and 13.2 µg/kg, respectively) and in the parsley sample of HH1 (13.5 µg/kg) (Table 1). BaA also occurred in every sample, with the highest concentrations in all HH2 samples: 9.8 µg/kg in basil, 11.9 µg/kg in rocket, 9.0 µg/kg in parsley and 8.5 µg/kg in
chives (Table 1). Cry was also detected in every vegetable sample, reaching outstandingly high concentration, 20.1 µg/kg, in the rocket sample in HH2.

Finally, BaP occurred in 5 samples, in the range of 1.6 µg/kg (chives, HH1) and 5.7 µg/kg (parsley, HH1). BaP is ubiquitous in heat-treated foods (Rose et al., 2015). Yao et al. (2015) found B(a)P emission characteristic during deep frying. Hu et al. (2021) measured concentrations of 8 PAHs including BaP in sunflower oil during deep-frying under simulated frying conditions and demonstrated an increase with increasing frying time.

**Conclusions**

Accumulation of PAHs was assessed in 3 Hungarian kitchens using common culinary herbs over 1 month exposure. Households participating in the study were of similar size and they were located in villages not affected by heavy traffic but they were representing different cooking practices, using different cooking oils. PAH profiles in the test plants could be associated to cooking habits of these households. Culinary herbs used in our study are often recommended for cultivation and use in kitchens. However, many of the test plants accumulated carcinogenic PAHs such as benzo[a]anthracene, benzo[b]fluoranthene and chrysene which might question their safe use.

**Abbreviations**

PM  
particulate matter  
PAH - polycyclic aromatic hydrocarbon  
LMW - low molecular weight  
HMW  
high molecular weight  
Naphthalene  
Nap  
Acenaphthylene  
Acy  
Acenaphthene  
Ace  
Fluorene  
Flu  
Phenanthrene  
Phen  
Anthracene - Ant  
Fluoranthene- Flt  
Pyrene  
Pyr  
Benzo[a]anthracene - B(a)a  
Chrysene  
Cry  
Benzo[b]fluoranthene  
B(b)f  
Benzo[k]fluoranthene  
B(k)f  
Benzo[e]pyrene  
B(e)p  
Benzo[a]pyrene  
B(a)p
Indeno[1,2,3-cd]pyrene
IP
Dibenzo[a,h]anthracene
D(a,h)a
Benzo[g,h,i]perylene
B(g,h,i)p

Declarations

Ethics approval and consent to participate.
Not relevant.

Consent for publication
Not relevant.

Availability of data and materials
All data generated or analysed during this study are included in this published article.

Competing interests
The authors declare no conflicts of interest.

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Authors’ contributions
All authors contributed to the study conception and design. Conceptualization was performed by KH; data collection and analysis were performed by KH, NK, BEV and GT. The first draft of the manuscript was written by NK and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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References


Figures
Figure 1

PAH isomers in the vegetable samples grouped by households
Figure 2

PCA diagram of the samples based on PAH isomers and cooking habits/materials used.