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# Estimation of the Dietary Exposure of Polycyclic Aromatic Hydrocarbons in Syria and Their Health Risks Assessment

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**Abstract**

In this work, the exposure of people, through their diet, to polycyclic aromatic hydrocarbons (PAHs) has been assessed for the urban, rural, and general populations in Syria. The food categories consumed have been divided into major groups, and the health risk assessment on dietary exposure of PAHs determined in each food category. For this purpose, two approaches were used: incremental lifetime cancer risk (ILCR) and margin of exposure approach (MOE). The results showed that each of the following food categories: oils and fats, meat and meat products, vegetables, and cereals dominantly contribute in the dietary exposure of PAHs. Also their MOE values are the lowest. Additionally, they have higher ILCR values. Therefore, these groups are a main risk source to health. On the other hand, the dietary exposure of PAHs in each of urban, rural and general populations was of low health concern, whereas their ILCR values reached to 10E-05 in total food categories, nevertheless it remains lower than serious risk level (ILCR > 10E-04). This work is the first study that is dealing with dietary exposure of PAHs and their health risk assessment in Syria.

***Keywords:*** Polycyclic aromatic hydrocarbons; Benzo[a]pyrene; Dietary exposure; Health risks assessment; Incremental lifetime cancer risk; Margin of exposure

## 1 Introduction

Polycyclic aromatic hydrocarbons (PAHs) are well-known ubiquitous organic pollutants that belong to the group of persistent organic pollutants (Halfadji, Touabet, Portet-Koltalo, Le Derf & Machour, 2017). They consist of carbon and hydrogen with two or more fused aromatic rings. PAHs are primarily formed and released from the incomplete combustion or pyrolysis of organic matter, during industrial, geochemical processes and other human activities (Yebra-Pimentel, Fernandez-Gonzalez, Martinez-Carballo & Simal-Gandara, 2015). Most PAHs have lipophilic and hydrophobic characteristics with low water solubility (Domingo & Nadal, 2015) and are generally found throughout the environment in air, water, soils, and sediments in the form of complex mixtures (Falco et al., 2003).

In toxicological studies, several PAHs have been demonstrated to be genotoxic and carcinogenic to humans. On the other hand, other PAHs that have not been found to be carcinogenic may act as synergists (Poster, Schantz, Sander & Wise, 2006). PAHs classification is based on their toxicity and a list of 16 PAHs issued by the U.S. Environmental Protection Agency (EPA) have been described as priority pollutants. The International Agency for Research on Cancer (IARC)

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has classified some of these PAHs as human carcinogens (International Agency for Research on Cancer, 2016). In the EU, a list of 15+1 EU priority PAHs was recently established. The Scientific Committee on Food (SCF) prioritized 15 PAHs and the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (EFSA, 2008) identified one additional PAH.
Food consumption is by far the major source of exposure of humans to PAHs (Phillips, 1999). This contamination by PAHs is due to environmental pollution and/or as result of certain food processing methods (Gomez-Ruiz, Cordeiro, Lopez & Wenzl, 2009). On the other hand, the dietary intake of PAHs depends on both the contaminant concentration in food and the nutritional habits of the examined population. The presence of PAHs has been reported extensively in various food samples including: vegetable oils, fish and seafood, meats, bread, cereals, sweets, tea, coffee, chesses, milk, fruits and vegetables (Bansal & Kim, 2015; Phillips, 1999; Plaza-Bolanos, Garrido Frenich & Martinez Vidal, 2010; Zelinkova & Wenzl, 2015). However, studies concerning health risk assessment on dietary exposure of PAHs are quite limited (Bansal & Kim, 2015; Domingo & Nadal, 2015; Yebra-Pimentel et al., 2015). Two approaches were used to determine the health risk assessment on dietary exposure of PAHs. The first is the incremental lifetime cancer risk (ILCR). This classification was developed by the EPA and provides the cancer risk estimate for PAH mixtures relative to benzo[a]pyrene (BaP). The second approach is the margin of exposure (MOE), adopted by European Food Safety Authority (EFSA), which is the ratio between the no-observed-adverse-effect level or benchmark dose lower confidence limit (BMDL) for the critical effect to the theoretical, predicted, or estimated dose or concentration of human intake. Dietary exposure to PAHs and the corresponding health risk assessment have been reported in some countries. Among them and for this purpose, in Spain, series of surveys have been carried out in 2000, 2006, 2010, and 2012 (Falco et al., 2003; Marti-Cid, Llobet, Castell & Domingo, 2008; Martorell et al., 2012; Martorell et al., 2010). In the frame of the second French Total Diet Study (TDS), the 15+1 EU PAHs were analysed in 725 foodstuffs habitually consumed by the French population (Veyrand et al., 2013). Recently, the content of PAHs in most common consumed foodstuffs was determined in a market basket study made at the National Food Agency in Sweden (Abramsson-Zetterberg, Darnerud & Wretling, 2014). Furthermore in Korea, 27 different food commodities frequently consumed were analysed for the profile of 14 PAH congeners (Yoon, Park, Lee, Yang & Lee, 2007). While in China, 25 kinds of seven categories of foods were analysed for determination of the concentrations of 16 PAHs (Xia et al., 2010). In another study, 16 PAHs in 24 duplicate-diet samples were also determined (Nie et al., 2014). In Azerbaijan, due to lack of PAHs concentration data from middle-Eastern countries, only data from European countries were adopted (Nwaneshiudu et al., 2007). Finally, in recent study, cancer risks of long-term exposure to PAHs through consumption of major food categories in India for eight societal groups were evaluated (Singh & Agarwal, 2018). Notable absence of such data from big countries such as Australia, Canada, Germany, or Japan (for example), among many others has been highlighted (Domingo & Nadal, 2015). On the other hand, in previously studies, the levels of 16 EPA PAHs in medicinal plants from Syria and in Syrian olive oils have been reported (Krajian & Odeh, 2013, 2014). In addition, the levels of 15+1 EU PAHs in different edible oils, available on the Syrian market, were determined (Krajian & Odeh, 2018). However, there is no study dealing with health risk assessment on dietary exposure of PAHs in Syria. The current work will investigate the health risk assessment on dietary exposure of PAHs in Syria. The dietary exposure of PAHs was estimated, for both urban and rural populations and the incremental lifetime cancer risks were calculated. The margin of exposure was evaluated to observe whether the local levels posed any potential health problem for Syrian consumers.

## 2 Materials and Methods

### 2.1 Dietary exposure estimates

Target population was divided into three main groups (urban, rural, and general). Food categories included: meat and meat products, fish and shellfish, vegetables, tubers, fruits, eggs, milk, dairy products, cereals, pulses, oils and fats, and industrial bakery. The PAHs studies were the 16 EPA PAHs namely: naphthalene (NAP), acenaphthylene (ACY), acenaphthene (ACP), fluorene (FLR), phenanthrene (PHE), anthracene (ANT), fluoranthene (FLT), pyrene (PYR), benz[a]anthracene (BaA), chrysene (CHR), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), BaP, dibenz[a,h]anthracene (DahA), benzo[ghi]perylene (BgP), and indeno[1,2,3-cd]pyrene (IcP). Data on food consumption, for the year of 2009, was obtained from the Syrian State Central Bureau of Statistics. PAHs concentration data for each food category were obtained from other study (Martorell et al., 2010) due the lack of such data from Syria. The body weight for a typical Syrian individual (67.4 kg) was obtained from the study by Walpole et al. (2012). Dietary exposures to PAHs (the sum of 16 EPA PAHs), PAH8 (the sum of eight genotoxic PAHs), PAH4 (the sum of the four PAHs namely: CHR, BaA, BaP, and BbF), PAH2 (the sum of CHR and BaP), and BaP were estimated for each food category. The exposure levels were obtained by multiplying the corresponding concentration of each PAHs by the amount of food consumption by individuals per day (expressed in units of mass per unit time, or mass per unit time normalized to body weight).

## 2.2 Cancer risk estimates

The BaP equivalent value for individual PAHs ($BaP_{eqi}$) was calculated for each PAH from its concentration in each food category multiplied by its toxic equivalency factor as proposed by Nisbet and Lagoy (1992). The BaP equivalent value for the mixture of 16 EPA PAHs ($BaP_{eq}$) was calculated as the sum of the $BaP_{eqi}$ values in each food category. Dietary exposures of $BaP_{eq}$ for each food category (Ei) were calculated in the same way as described previously. The incremental lifetime cancer risk (ILCR) of each population groups in Syria were estimated to express the risk caused by PAHs dietary exposure using the following equation (1):

$$ILCR = \frac{Ei \times ED \times EF \times SF}{(BW \times AT)} \quad (1)$$

where: ED is the exposure duration (43 year), EF is the exposure frequency (365 days $year^{-1}$), SF is the oral cancer slope factor of BaP (4.5, 5.9, 9.0, and 11.7, with a geometric mean of 7.3 mg $kg^{-1}$ $day^{-1}$), BW is the body weight (kg), and AT is the average lifespan for carcinogens (25550 days) (Xia et al., 2010).

## 2.3 Margin of exposure

The risk associated with the dietary exposure of PAHs was evaluated using the approach based on the margin of exposure (MOE). MOE values of BaP, PAH2, PAH4, and PAH8 were calculated using the ratio between the EFSA $BMDL_{10}$ corresponding values (benchmark dose lower confidence limit for a 10 % increase in the background incidence of tumors in bearing animals) and dietary exposure of BaP, PAH2, PAH4, and PAH8. The $BMDL_{10}$ values for BaP, PAH2, PAH4 and PAH8 are 0.07, 0.17, 0.34 and 0.49 mg $kg^{-1}$ bw $day^{-1}$, respectively (EFSA, 2008).

## 2.4 Statistical analysis

Statistical analyses were performed using OriginPro 9.2 software. The non-parametric Kruskal-Wallis test was applied to assess statistically significant differences in ILCR's results relative to exposure for different food categories among urban, rural, or general populations. A $p$-value of $< 0.05$ was considered statistically significant.

# 3 Results and Discussion

The food categories consumed have been divided into major groups as shown in Table 1, where we also derived the average amount of food categories consumption per capita for the urban, rural, and general populations of Syria. Table 2 shows the concentration values of PAHs (the sum of 16 EPA PAHs), PAH8 (the sum of eight genotoxic PAHs), PAH4 (the sum of the four PAHs namely: CHR, BaA, BaP, and BbF), PAH2 (the sum of

Table 1: Food categories and their average consumption per capita for urban, rural, and general populations of Syria

| Food Category | Average consumption per capita (g day$^{-1}$) | | |
|---|---|---|---|
| | Urban | Rural | General |
| Meat and meat products | 71 | 65 | 68 |
| Fish and shellfish | 22 | 24 | 23 |
| Vegetables | 326 | 350 | 338 |
| Tubers | 87 | 111 | 99 |
| Fruits | 108 | 91 | 100 |
| Eggs | 24 | 22 | 23 |
| Milk | 40 | 53 | 47 |
| Dairy products | 107 | 94 | 101 |
| Cereals | 470 | 564 | 517 |
| Pulses | 30 | 33 | 31 |
| Oils and fats | 66 | 76 | 71 |
| Industrial bakery | 10 | 8 | 9 |
| Total | 1361 | 1491 | 1427 |

Table 2: Concentrations values of studied PAHs in the studied food categories

| Food Category | PAHs Concentrations (ng g$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | BaP | PAH2 | PAH4 | PAH8 | PAHs | $BaP_{eq}$ |
| Meat and meat products | 0.14 | 0.69 | 1.45 | 1.70 | 39.0 | 0.33 |
| Fish and shellfish | 0.07 | 0.26 | 0.57 | 0.86 | 2.85 | 0.16 |
| Vegetables | 0.07 | 0.12 | 0.23 | 0.36 | 1.19 | 0.11 |
| Tubers | 0.02 | 0.04 | 0.08 | 0.16 | 0.75 | 0.05 |
| Fruits | 0.02 | 0.04 | 0.08 | 0.16 | 0.78 | 0.05 |
| Eggs | 0.10 | 0.20 | 0.40 | 0.80 | 3.68 | 0.25 |
| Milk | 0.01 | 0.02 | 0.04 | 0.08 | 0.45 | 0.02 |
| Dairy products | 0.05 | 0.10 | 0.20 | 0.40 | 7.61 | 0.13 |
| Cereals | 0.03 | 0.06 | 0.12 | 0.24 | 1.24 | 0.07 |
| Pulses | 0.04 | 0.08 | 0.16 | 0.32 | 1.52 | 0.1 |
| Oils and fats | 0.49 | 0.98 | 1.96 | 3.92 | 18.8 | 1.21 |
| Industrial bakery | 0.03 | 0.06 | 0.13 | 0.25 | 1.38 | 0.08 |
| Total | 1.07 | 2.65 | 5.42 | 9.25 | 79.3 | 2.56 |

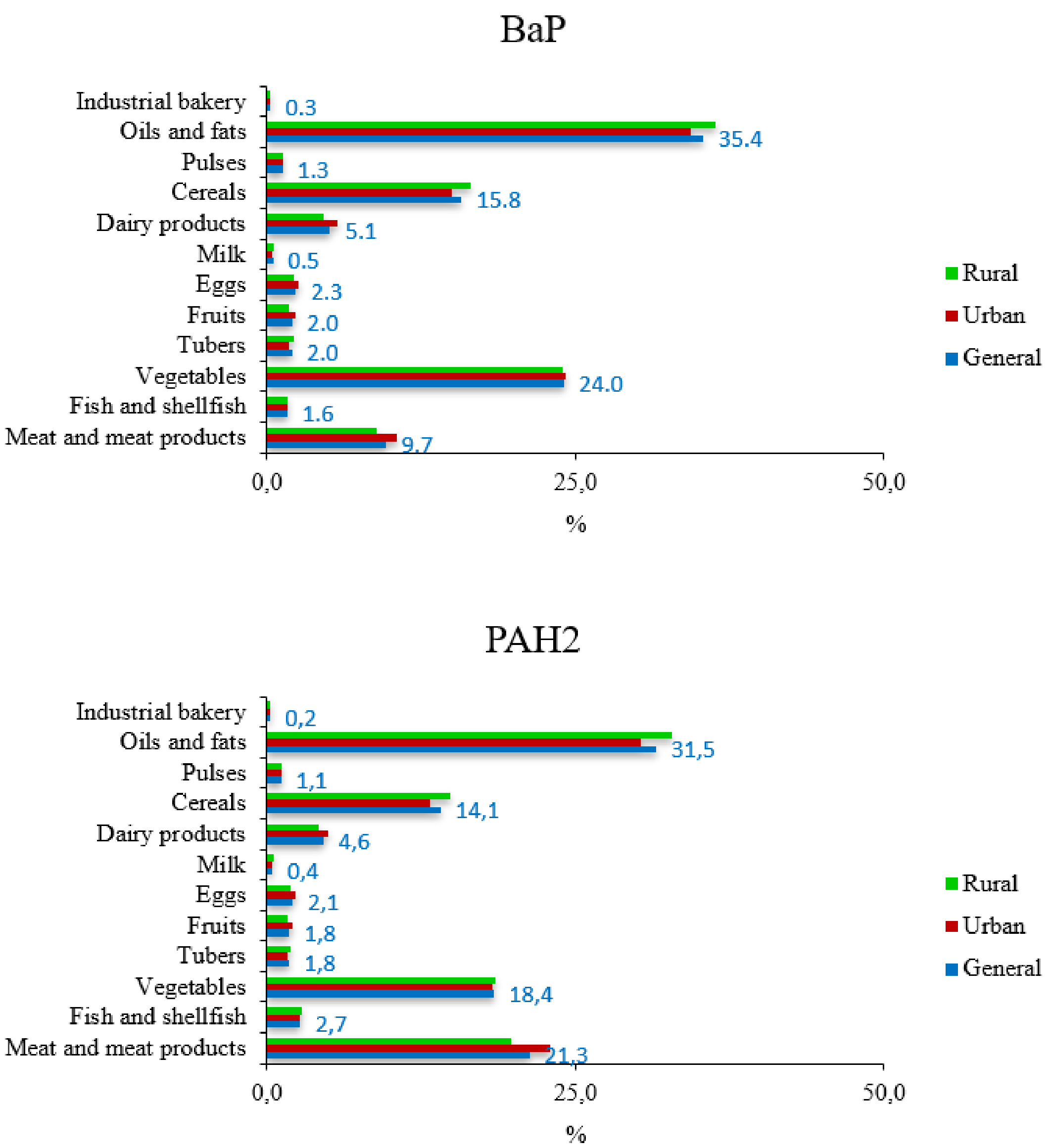


Figure 1: Contribution ratios of dietary exposures to studied BaP and PAH2 in the food categories for urban, rural, and general populations in Syria

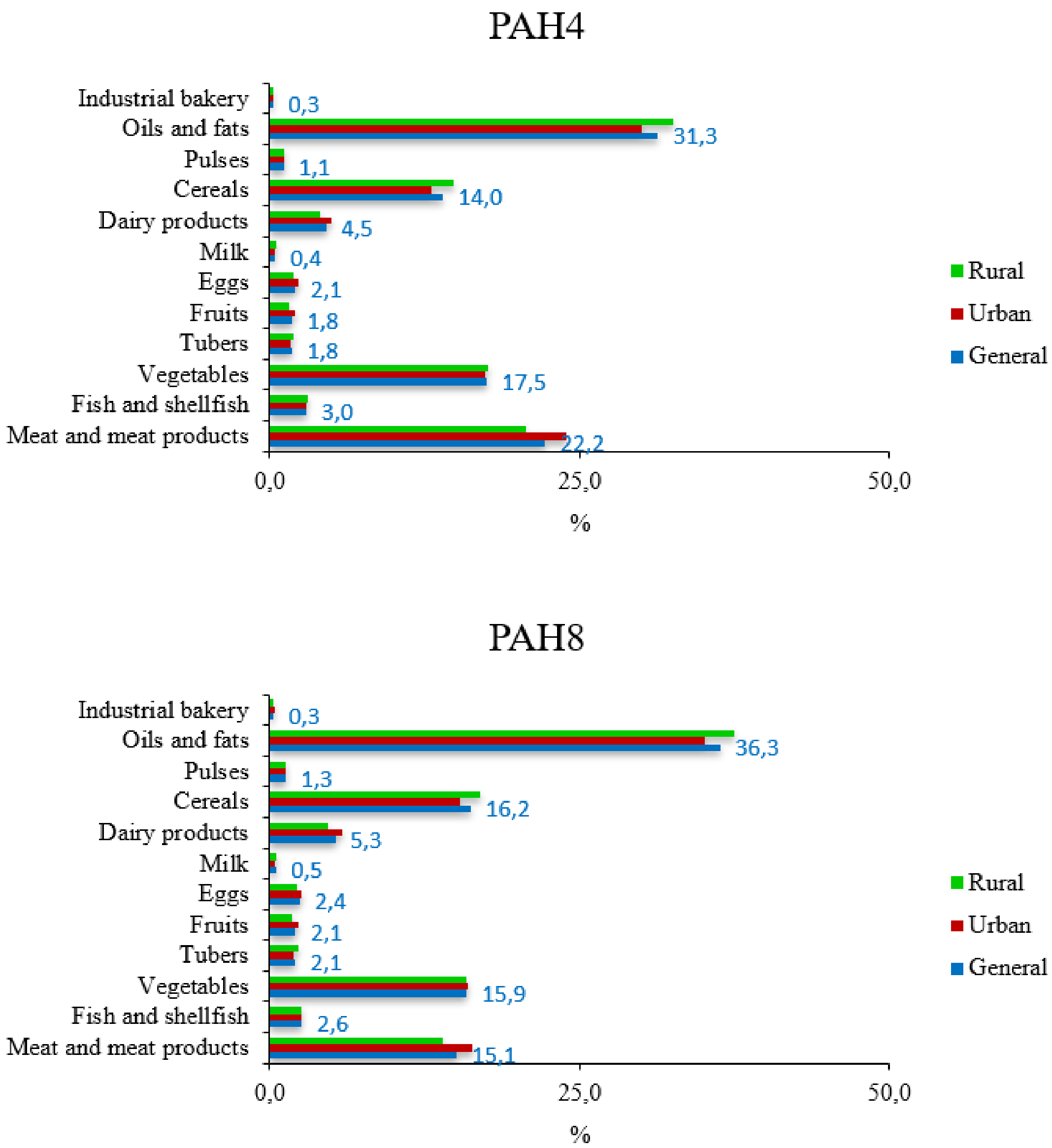


Figure 2: Contribution ratios of dietary exposures to studied PAH4 and PAH8 in the food categories for urban, rural, and general populations in Syria

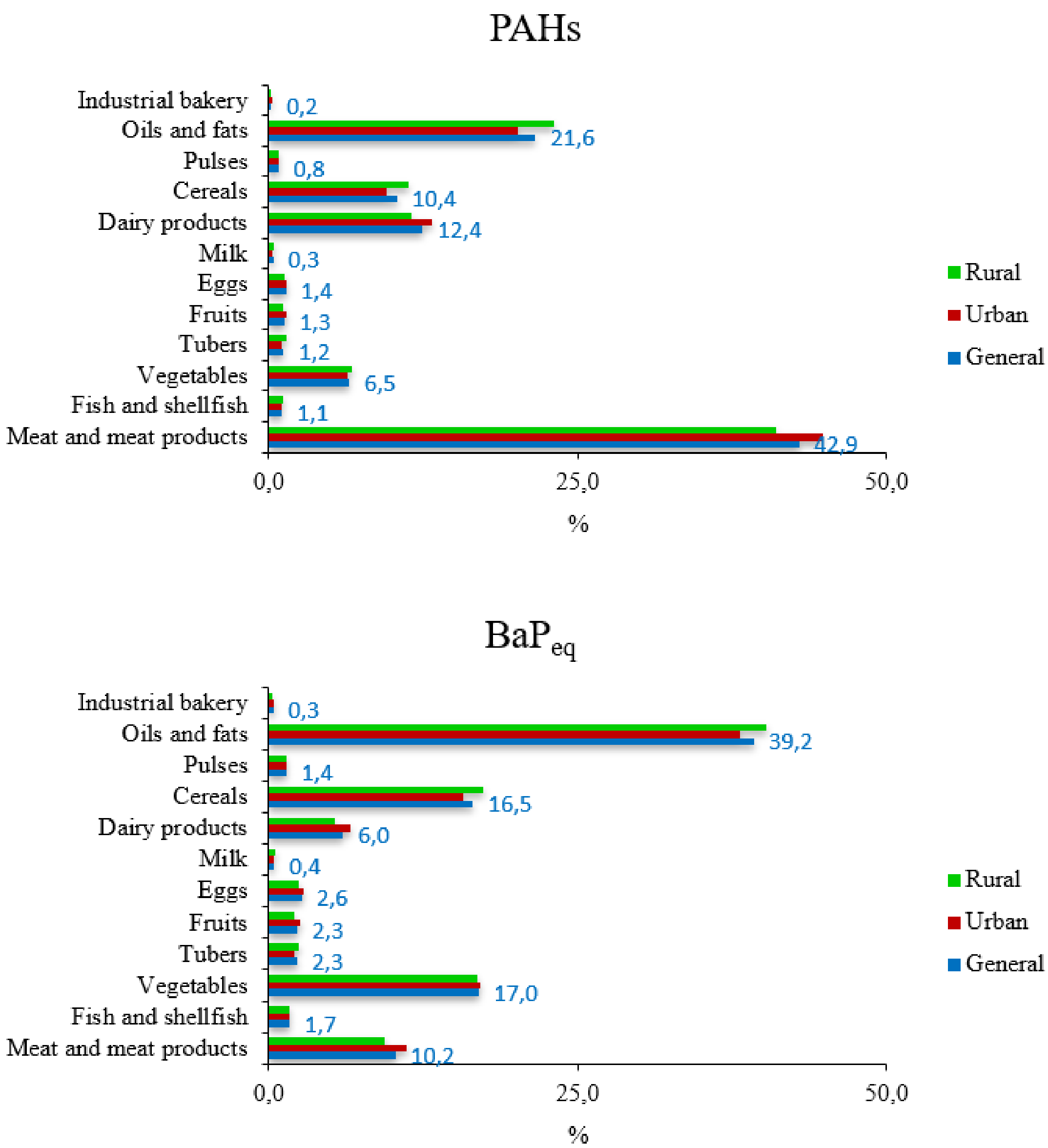


Figure 3: Contribution ratios of dietary exposures to studied PAHs and $BaP_{eq}$ in the food categories for urban, rural, and general populations in Syria

Table 3: Dietary exposure to studied PAHs for urban population in Syria

| Food Category | Dietary exposure of PAHs ng day$^{-1}$ (ng kg$^{-1}$ bw day$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | BaP | PAH2 | PAH4 | PAH8 | PAHs | BaPeq |
| Meat and meat products | 10 (0.15) | 49 (0.73) | 103 (1.53) | 121 (1.79) | 2767 (41.1) | 23 (0.35) |
| Fish and shellfish | 2 (0.02) | 6 (0.08) | 13 (0.19) | 19 (0.28) | 63 (0.93) | 4 (0.05) |
| Vegetables | 23 (0.34) | 39 (0.58) | 75 (1.11) | 117 (1.74) | 388 (5.76) | 36 (0.53) |
| Tubers | 2 (0.03) | 3 (0.05) | 7 (0.10) | 14 (0.21) | 65 (0.97) | 4 (0.06) |
| Fruits | 2 (0.03) | 4 (0.06) | 9 (0.13) | 17 (0.26) | 84 (1.25) | 5 (0.08) |
| Eggs | 2 (0.04) | 5 (0.07) | 10 (0.14) | 19 (0.28) | 88 (1.31) | 6 (0.09) |
| Milk | <1 (0.01) | 1 (0.01) | 2 (0.02) | 3 (0.05) | 18 (0.27) | 1 (0.01) |
| Dairy products | 5 (0.08) | 11 (0.16) | 21 (0.32) | 43 (0.64) | 814 (12.1) | 14 (0.21) |
| Cereals | 14 (0.21) | 28 (0.42) | 56 (0.84) | 113 (1.67) | 583 (8.65) | 33 (0.49) |
| Pulses | 1 (0.02) | 2 (0.04) | 5 (0.07) | 10 (0.14) | 46 (0.68) | 3 (0.04) |
| Oils and fats | 32 (0.48) | 65 (0.96) | 129 (1.92) | 259 (3.84) | 1239 (18.4) | 80 (1.18) |
| Industrial bakery | <1 (<0.01) | 1 (0.01) | 1 (0.02) | 3 (0.04) | 14 (0.20) | 1 (0.01) |
| Total | 94 (1.40) | 214 (3.17) | 431 (6.39) | 737 (10.93) | 6169 (91.5) | 210 (3.11) |

CHR and BaP), BaP, and $BaP_{eq}$ (BaP equivalent value for the mixture of 16 EPA PAHs) in the studied food categories. These values were calculated based on the data of PAHs in the study of Martorell et al. (2010). According to the food categories (Table 2) the oils and fats have the highest concentration values of PAH8, PAH4, PAH2, BaP, and $BaP_{eq}$. The only exception noticed is for PAHs, where the meat and meat products category has the highest concentration values followed by the oils and fats food categories. The contributions of the oils and fats in total studied food categories ranged between 23.7 % for PAHs to 47.3 % for $BaP_{eq}$. On the other hand, the milk category has the lowest concentration values with average contribution of 0.8 %. The high concentrations of PAHs in oils and fats food category might be due to the lipophilic nature of PAHs and consequently, this food category can be easily contaminated by PAHs either directly or indirectly as an ingredient in food (Dennis et al., 1991; Krajian & Odeh, 2018). Tables 3, 4, and 5 report the dietary exposures to BaP, PAH2, PAH4, PAH8, BaP, PAHs, and $BaP_{eq}$ for urban, rural, and general populations in Syria, respectively. It was noticed that there are some comparable values of PAHs dietary exposures between urban and rural populations. Indeed, the total PAHs dietary exposures for the rural population are relatively higher than for urban population, taking into account that the differences in the values of

Table 4: Dietary exposure to studied PAHs for rural population in Syria

| Food Category | Dietary exposure of PAHs ng day$^{-1}$ (ng kg$^{-1}$ bw day$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | BaP | PAH2 | PAH4 | PAH8 | PAHs | BaPeq |
| Meat and meat products | 9 (0.14) | 45 (0.67) | 94 (1.40) | 111 (1.64) | 2533 (37.6) | 21 (0.32) |
| Fish and shellfish | 2 (0.02) | 6 (0.09) | 14 (0.20) | 21 (0.31) | 68 (1.01) | 4 (0.06) |
| Vegetables | 25 (0.36) | 42 (0.62) | 81 (1.19) | 126 (1.87) | 417 (6.18) | 39 (0.57) |
| Tubers | 2 (0.03) | 4 (0.07) | 9 (0.13) | 18 (0.26) | 83 (1.24) | 6 (0.08) |
| Fruits | 2 (0.03) | 4 (0.05) | 7 (0.11) | 15 (0.22) | 71 (1.05) | 5 (0.07) |
| Eggs | 2 (0.03) | 4 (0.07) | 9 (0.13) | 18 (0.26) | 81 (1.20) | 6 (0.08) |
| Milk | 1 (0.01) | 1 (0.02) | 2 (0.03) | 4 (0.06) | 24 (0.35) | 1 (0.02) |
| Dairy products | 5 (0.07) | 9 (0.14) | 19 (0.28) | 38 (0.56) | 715 (10.6) | 12 (0.18) |
| Cereals | 17 (0.25) | 34 (0.50) | 68 (1.00) | 135 (2.01) | 699 (10.4) | 39 (0.59) |
| Pulses | 1 (0.02) | 3 (0.04) | 5 (0.08) | 11 (0.16) | 50 (0.74) | 3 (0.05) |
| Oils and fats | 37 (0.55) | 74 (1.11) | 149 (2.21) | 298 (4.42) | 1427 (21.2) | 92 (1.36) |
| Industrial bakery | <1 (<0.01) | <1 (0.01) | 1 (0.02) | 2 (0.03) | 11 (0.16) | 1 (0.01) |
| Total | 102 (1.52) | 227 (3.37) | 457 (6.78) | 795 (11.8) | 6180 (91.7) | 228 (3.38) |

dietary exposures between urban and rural populations in this study were caused by variations in the average amount of food categories consumption per capita. These values could change if the concentrations of PAHs in food categories for urban and rural were taken into account. Generally, high values of dietary exposure to PAHs in Syria were observed (6178 ng day$^{-1}$). For comparison, in UK it was equal to 3700 ng day$^{-1}$ (Phillips, 1999), while in China it was equal to 1830 ng day$^{-1}$ (Yu et al., 2015), whereas in Korea it was equal to 198 ng day$^{-1}$ (Yoon et al., 2007). Moreover, the dietary exposure to BaP were equal to 76, 13, and 2 ng day$^{-1}$ in Spain (Martorell et al., 2010), France (Veyrand et al., 2013), and China (Nie et al., 2014), respectively, against 98 ng day$^{-1}$ in this study (Syria). Concerning PAH4, it was equal to 104 ng day$^{-1}$ in France (Veyrand et al., 2013) against 444 ng day$^{-1}$ in this study (Syria). Finally, for BaP$_{eq}$, it was equal to 572 ng day$^{-1}$ in China (Xia et al., 2010), while in this study (Syria) it was equal to 219 ng day$^{-1}$ . The contribution ratios of dietary exposures to studied PAHs in the food categories for urban, rural, and general populations in Syria are highlighted in Figure 1, 2 and 3. We found that the oils and fats category has the highest contribution in dietary exposures to BaP, PAH2, PAH4, PAH8, BaP, and BaP$_{eq}$ but not for PAHs (the meat and meat products 42.9 %), followed by the meat and meat products, the vegetables, and cereals categories. The sum of these food

Table 5: Dietary exposure to studied PAHs for general population in Syria

| Food Category | Dietary exposure of PAHs ng day$^{-1}$ (ng kg$^{-1}$ bw day$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | BaP | PAH2 | PAH4 | PAH8 | PAHs | BaP$_{eq}$ |
| Meat and meat products | 10 (0.14) | 47 (0.70) | 99 (1.46) | 116 (1.72) | 2650 (39.3) | 22 (0.33) |
| Fish and shellfish | 2 (0.02) | 6 (0.09) | 13 (0.19) | 20 (0.29) | 66 (0.97) | 4 (0.05) |
| Vegetables | 24 (0.35) | 41 (0.60) | 78 (1.15) | 122 (1.81) | 402 (5.97) | 37 (0.55) |
| Tubers | 2 (0.03) | 4 (0.06) | 8 (0.12) | 16 (0.24) | 74 (1.10) | 5 (0.07) |
| Fruits | 2 (0.03) | 4 (0.06) | 8 (0.12) | 16 (0.24) | 78 (1.16) | 5 (0.07) |
| Eggs | 2 (0.03) | 5 (0.07) | 9 (0.14) | 18 (0.27) | 85 (1.26) | 6 (0.09) |
| Milk | <1 (<0.01) | 1 (0.01) | 2 (0.03) | 4 (0.06) | 21 (0.31) | 1 (0.01) |
| Dairy products | 5 (0.07) | 10 (0.15) | 20 (0.30) | 40 (0.60) | 769 (11.4) | 13 (0.19) |
| Cereals | 16 (0.23) | 31 (0.46) | 62 (0.92) | 124 (1.84) | 641 (9.51) | 36 (0.54) |
| Pulses | 1 (0.02) | 2 (0.04) | 5 (0.07) | 10 (0.15) | 47 (0.70) | 3 (0.05) |
| Oils and fats | 35 (0.52) | 70 (1.03) | 139 (2.06) | 278 (4.13) | 1333 (19.8) | 86 (1.27) |
| Industrial bakery | <1 (<0.01) | 1 (0.01) | 1 (0.02) | 2 (0.03) | 12 (0.18) | 1 (0.01) |
| Total | 98 (1.46) | 221 (3.27) | 444 (6.59) | 766 (11.4) | 6178 (91.7) | 219 (3.25) |

categories contributes to more than 80 % of the total dietary exposures. Whereas, the proportion of each milk and the industrial bakery categories do not exceed 0.5 %. Similar results have been obtained in other studies (Martorell et al., 2010; Phillips, 1999; Veyrand et al., 2013). The incremental lifetime cancer risk (ILCR) of each population groups in Syria through consumption of each studied food categories were calculated (Table 6) in order to study the risk caused by PAHs dietary exposure. According to the EPA, a one in a million chance of additional human cancer over a 70 year lifetime (ILCR = 10E-06) is the level of risk considered acceptable or inconsequential, whereas additional lifetime cancer risk of one in ten thousand or greater (ILCR = 10E-04) is considered serious. We noticed that the ILCR values for all studied food categories for all population groups fell within the range 10E-06 to 10E-08, where they exceeded the acceptable or inconsequential risk level (ILCR > 10E-06) in each of the oils and fats, the cereals, the vegetables, and the meat and meat products categories. Whereas, it reached 10E-05 in total food categories. However, it remained lower than serious risk level (ILCR > 10E-04). On the other hand, there are no statistically significant differences in ILCR's results relatively to exposure for different food categories among urban, rural, or general populations with relatively higher risk values for rural population. Comparing the risk values in this study with

Table 6: Incremental lifetime cancer risk (ILCR) in each studied food categories through dietary exposures to PAHs for urban, rural, and general populations in Syria

| Food Category | Incremental lifetime cancer risk (ILCR)[a] | | |
|---|---|---|---|
| | Urban | Rural | General |
| Meat and meat products | 1.58x10E-06 | 1.45x10E-06 | 1.52x10E-06 |
| Fish and shellfish | 2.38x10E-07 | 2.60x10E-07 | 2.49x10E-07 |
| Vegetables | 2.33x10E-06 | 2.50x10E-06 | 2.42x10E-06 |
| Tubers | 2.86x10E-07 | 3.65x10E-07 | 3.26x10E-07 |
| Fruits | 3.55x10E-07 | 3.00x10E-07 | 3.29x10E-07 |
| Eggs | 3.94x10E-07 | 3.62x10E-07 | 3.78x10E-07 |
| Milk | 6.61x10E-08 | 8.76x10E-08 | 7.77x10E-08 |
| Dairy products | 9.21x10E-07 | 8.09x10E-07 | 8.69x10E-07 |
| Cereals | 2.32x10E-06 | 2.79x10E-06 | 2.56x10E-06 |
| Pulses | 1.97x10E-07 | 2.17x10E-07 | 2.04x10E-07 |
| Oils and fats | 5.32x10E-06 | 6.13x10E-06 | 5.72x10E-06 |
| Industrial bakery | 5.02x10E-08 | 4.02x10E-08 | 4.52x10E-08 |
| Total | 1.41x10E-05 | 1.53x10E-05 | 1.47x10E-05 |

[a]The ILCRs relatively to exposure for different food categories among urban, rural, or general populations are not significantly different ($p$>0.05)

other studies in different parts of the world, similar trends were observed. The risk of PAHs exposure from ingested food in Azerbaijan ranged between 9.34x10E-05 to 3.67x10E-04 (Nwaneshiudu et al., 2007). The cancer risk faced by Indian population through their complete diet ranged from 7.63x10E-10 to 5.05 (Singh & Agarwal, 2018). The duplicate-diet study in China has estimated cancer risk values of 9.07x10E-04 to 1.12x10E-04 (Nie et al., 2014). Whereas, in Spain the cancer risk of 4.5x10E-06 was calculated for male adults (Martorell et al., 2010). Finally in Korea, the cancer risk posed by food ingestion was reported as 2.3x10E-05 (Yoon et al., 2007). The risk associated with the dietary exposure of PAHs was evaluated following the approach based on the margin of exposure (MOE). The EFSA used the MOE as a new approach to risk assessment for genotoxic and carcinogenic PAHs (EFSA, 2008). The values of MOEs that are close to or less than 10000 indicate a potential concern for consumer health and a possible need for risk management action. For total dietary exposures, the MOE values of BaP, PAH2, PAH4, and PAH8 were equal to (50000, 53600, 53200, and 44800) for urban population, (46000, 50400, 50100, and 41600) for rural population, and (47900, 51900, 51600, and 43100) for general population, respectively. The lowest MOE values of BaP, PAH2, PAH4, and PAH8 for all population groups were observed for oils and fats category followed by the vegetables, the cereals, and the meat and meat products categories. On the other hand, the MOE values for urban population were higher than those for rural population. However, the results of MOE values in this study (> 10000) indicated that the dietary exposure of PAHs for urban, rural, and general populations was considered a low concern for consumer health. Again, similar trends were observed when comparing the values of MOEs with the results from other studies in different parts of the world. The MOE values for PAH4 calculated for exposure of the French population to PAHs through the whole diet were 150000 for children and 230000 for adults (Veyrand et al., 2013). In a market basket study carried out at the National Food Agency in Sweden, the MOE value of BaP was about 100000 (Abramsson-Zetterberg et al., 2014).

The results obtained from both approaches (ILCR and MOE) highlighted that the following categories namely: oils and fats, cereals, vegetables, and the meat and meat products have the major contribution in the dietary exposure of PAHs. The reason is due to the high concentrations of PAHs in the oils and fats and the meat and meat products categories, while in the cereals and the vegetables categories are resulting from high amount of consumption. Consequently, these categories have the highest ILCR values and the lowest MOE values, indicating that they represent the main risk source to health.

## 4 Conclusions

This is the first study dealing with dietary exposure of PAHs and their health risk assessment in Syria. The results indicated that the dietary exposure of PAHs for urban, rural, and general populations was of low concern for consumer health. The cancer risk values reached 10E-05 in total food categories remaining lower than serious risk level (ILCR > 10E-04). However, future studies should be carried out to monitor the PAHs levels in food product samples from local markets, which are absent in Syria. Furthermore, the dietary exposure of PAHs and the associated risk values for children and adults are needed to establish maximum limits or guideline levels for PAHs in food products. These values should be included in the national standards, to reduce health risks posed by dietary exposure of PAHs in the Syrian population.

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