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Original article

# Primary aromatic amines (PAAs) in third-hand smoke collected from waterpipe/cigarette cafés: Level and exposure assessment

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A R T I C L E I N F O

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A B S T R A C T

Third-hand smoke (THS) has been recognized as a main exposure route to the chemical content of tobacco products. In the present study, potential exposure of people to primary aromatic amines (PAAs) release from indoor settled dusts in smoking and non-smoking cafés were studied for the first time. Nine compounds of PAAs in the indoor dust samples of waterpipe, cigarettes and non-smoking cafés in Bushehr were measured by using liquid chromatography-mass spectrometry (LC-MS/MS). The mean concentration levels of ∑PAAs released through settled indoor dusts of waterpipe, cigarettes and non-smoking cafés were 728.23, 331.37 and 66.11 ng $g^{-1}$, respectively. The results showed that the mean concentration levels of ∑PAAs were ranked as: waterpipe cafés > cigarette cafés > non-smoking cafés. Among the measured PAAs, aniline (ANL) and 2, 6-dimethylaniline (2, 6-DMA) have the highest levels. The findings also showed that the levels of PAAs had a negative and significant relationship ($P < 0.05$) with “the ventilation rate”, “number of window/doors”, and “café area”, but a positive and significant relationship with “the number of active smokers” and “the time from last painting” ($P < 0.05$). The estimated daily intake (EDI) of PAAs in settled indoor dusts for different age groups (infants, toddlers, children, teenagers, and adults) were ranged from 52.5 to 3832.8 ng $kg^{-1}$-bw $day^{-1}$, and EDI value for toddlers was higher than others groups. Although all obtained EDI values were lower than acceptable exposure values recommended by World Health Organization (WHO) and Environmental Protection Agency (EPA), but chronic exposure can be harmful to health. Hence, more comprehensive studies are needed to evaluate different chemical contents and potential health effects of THS.

## 1. Introduction

Smoking (cigarettes and waterpipe) has a long history and the WHO has introduced smoking as a global epidemic (Ebrahimi Kalan, 2021; Asfar, 2005; Arshad, 2019). According to global report on trends in prevalence of smoking, 1.18 billion people regularly smoke tobacco. It

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was reported that smoking killed about 7 million people worldwide in 2020 (Dai et al., 2022), and tobacco use was the second leading cause of mortality (Al-Numair, 2007). The human health effects of smoking are depended on the amount of chemicals in tobacco smoke and the rate of smoking (Soleimani, 2022; Dobaradaran, 2019; Abadi, 2023). Tobacco smoke contains more than 7000 chemicals that are released into the environment in the form of gas, suspended particles and/or a combination of both (Heydari, 2019; Rodgman and Perfetti, 2013; Dobaradaran, 2022; Akhbarizadeh, 2021; Dobaradaran, 2017; Dobaradaran, 2020; Dobaradaran, 2021; Dobaradaran, 2023; Masjedi, 2020; Masjedi, 2023; Masjedi, 2021; Dobaradaran, 2018; Arfaeinia, 2023). During each smoking, chemical contents of tobacco divided among different smoke components such as mainstream smoke (MS: which the smoker breathes out during the puffs), sidestream smoke (SS: the smoke that is released from the end of a burning cigarette), secondhand smoke (SHS: is made up of SS (~85 %) and exhaled MS (~15 %) (Hang, 2020), and thirdhand smoke (THS: made up of the contaminants that settle indoors after smoking in closed environments) (Hang, 2020; Ding, 2006; Vu, 2021; Counts, 2005; Ajab, 2014. 2014.; Jacob, 2017). The indoor air of any environment is described according to the usage, construction and internal activities, and from this point of view, the indoor air quality of cigarettes and waterpipe cafés is very important due to the presence of high amounts of various chemicals that released into the environment through tobacco smoke (Cobb, 2013). Unfortunately, the smoke of cigarettes and waterpipe remains in the environment and settled on surfaces, and residents are continuously exposed to the chemical contents of them (Soleimani, 2022; Kelley, 2021; Acuff, 2016; Dobaradaran, 2021; Ribeiro, 2022; Soleimani, 2023; Soleimani, 2023). Environmental tobacco smoke (SHS and THS) which contains various chemicals, can cause various health problems including asthma, cardiovascular diseases, and other respiratory problems in smokers and people present in those environments as passive smokers (Drago, 2018). Therefore, it is necessary to assess the people's exposure to various particles and chemicals emitted from tobacco smoke in smoking cafés. Settled indoor dusts in cafés can act as an significant carrier for the transfer of volatile and semi-volatile chemicals such as primary aromatic amines (PAAs) into people's bodies (Mercier, 2011; Chinthakindi and Kannan, 2021). One of the most important and well-known sources of direct contact of people with PAAs is tobacco, cigarette smoke and other related products (Dobaradaran, 2022; Dobaradaran, 2023; Luceri, 1993). The US Food and Drug Administration published a list of potentially dangerous PAAs in tobacco and cigarette smoke including 2, 6-dimethylaniline (2,6-DMA), *ortho*-Toluidine (o-ToL), *ortho*-Anisidine (o-ASD), 1-Naphthylamine (1-NA), 2-Naphthylamine (2-NA), and 4-Aminobiphenyl (4-ABP) (Food and Administration, 2012). These compounds have high reactivity with proteins and DNA, which cause mutagenesis in people (Brauer and Funke, 2002; Norinder et al., 2018). It has been reported that direct contact of people with cigarette smoke and indirect contact of workers in different industries such as paint industries with PAAs increase the prevalence of bladder cancer (Richter and Branner, 2002; Beland, et al., 2012). Therefore, these compounds are considered as a serious threat to human health. Although PAAs have been measured in unsmoked cigarette and freshly smoked cigarette butts (Dobaradaran, 2022) as well as their leachates into water environments (Dobaradaran, 2023), in cigarette smoke (Saha et al., 2009), and waterpipe smoke (Schubert, 2011). But to the best of our knowledge, PAAs have not been measured in settled indoor dusts in cigarettes and waterpipe cafés. Nowadays, due to the increasing prevalence of smoking, it is important to measure the levels of chemicals in settled indoor dusts. For this purpose, in this study, the levels of PAAs in settled indoor dusts emitted from waterpipe and cigarette smoke in cafés have been quantified for the first time. Our work hypothesizes were: 1) the amounts of PAAs compounds in settled indoor dusts from waterpipe and cigarette cafés are considerable. 2) the levels of PAAs in waterpipe cafés is higher than cigarette cafés, and 3) the exposure rate of people present in cafés to PAAs is significant.

## 2. Materials and methods

### 2.1. Study design and selection of sampling places

Fifty-four cafés were randomly selected among available and active eighty-three smoking cafés in Bushehr-Iran, by coding (from 1 to 83) and using a randomization function in Excel software through the following formula (Equation 1):

$$0 \leq 83 \times \text{Rand}\,() \leq 8 \quad (1)$$

Among selected 54 cafés, 35 cafés served waterpipe (waterpipe cafés: WPC) and 19 cafés served only cigarette (cigarette cafés: CC). Besides, 25 smoking-free cafés (SFC) were also selected as the control group.

For each café, the potential effective parameters such as the area, ventilation type, the number of doors/windows, the number of ventilators, the ventilation rates, the number of active waterpipe heads and the type of tobacco (fruit-flavored or traditional tobacco) also recorded via a researcher-made checklist. The indoor settled dust samples (as thirdhand smoke) were collected from each café by using a horsetail brush and a steel dustpan. The weight of each mixed dust sample was ~ 5 g. After transferring to the laboratory, the samples were sieved through a 150 μm sieve to remove extraneous materials/coarse debris and to obtain homogeneous samples (Chinthakindi and Kannan, 2021). Then, obtained samples wrapped in aluminum foil, and stored at 4°C until chromatographic analysis.

### 2.2. Chemicals and reagents

Analytical grade standards of nine studied PAAs were purchased from Sigma–Aldrich. Other required solutions chemicals including methanol, acetonitrile, methyl *tert*-butyl ether (MTBE), hexane, ethyl acetate, dichloromethane (DCM), diethyl ether, formic acid (HCOOH), 30 % ammonium hydroxide in water ($NH_4OH$), and hydrochloric acid (HCl; 37 % v/v) were also purchased from Merck.

### 2.3. Extraction and analysis of samples

In order to extract the PAAs from samples, the proposed method by Chinthakindi et al was used (Chinthakindi and Kannan, 2021). Briefly, 200 mg of settled indoor dust sample was weighed and 10 ng of 5 isotope-labelled PAAs (including aniline-d5, *ortho*-toluidine-$^{13}$C6, *para*-toluidine-d7, 2,6-dimethylaniline-d6 and 4-chloroaniline-$^{13}$C6) were added as internal standards. For extraction, 5 ml MTBE was then added to the samples and ultra-sonicated at room temperature (22°C) with a frequency of 40 kHz for 30 min. This process was repeated to achieve better extraction efficiency. Finally, the samples were centrifuged at 3500 rpm for 10 min and the supernatant was transferred to a polyethylene tube and 15 μL of HCl (0.25 M) was added. The obtained solution was dissolved with 200 μL of a mixture of water and methanol (v:v, 9:1) and finally transferred to a 300 μL vial.

### 2.4. Instrumental and quality assurance

Liquid chromatography with tandem mass spectrometry (LC-MS/MS, (Waters Corporation, USA)) was used to analyze PAAs in the extracted samples. The separation of the target analytes was done with LC attached to the column (100 mm × 2.1 mm, 5 μm) with an injection volume of 5 μL. The mobile phases with a flow rate of 0.3 ml min$^{-1}$ contained 0.1 % formic acid (A) in a mixture of water and methanol (95:5 V:V) and 0.1 % formic acid in methanol (B), respectively. The concentration and time program were as follow: 0.0 min (95 % A), 0.01–2.50 min (95–58 % A), 2.50–6.50 min (58 %-25 % A), 6.50–8.70 min (25–5 % A, hold for 1 min), and 8.70–10.0 min (5–95 % A, hold for 2.50 min). The total time of measuring was 12.5 min and the temperature of the LC column was programmed according to the room temperature (22 °C).

The quality control samples were reagent blanks, procedural blanks, and matrix blanks. HPLC grade water was used in the place of dust for the reagent blank and a settled dust sample collected from a café in Bushehr city was used for procedural and matrix blanks. In order to determine recoveries, the blank samples were stimulated with analytes and passed through whole analytical process. A 9-point matrix matched calibration standard, at concentrations of 0.1–50 ng $mL^{-1}$ with 10 ng $mL^{-1}$ each of internal standards was prepared by stimulating the matrix blanks. The repeatability of sample extraction was determined by 5 replicate analysis of 10 randomly samples. The limit of detection (LOD) was determined according to the lowest acceptable calibration standard. The analytical method validation parameters including retention times (RT), regression coefficient (r) of the calibration curve, limit of detection (LOD) and limit of quantification (LOQ), accuracy and precision are provided in Table S1. The LOD and LOQ values of PAAs were in the range of 0.085–0.15 ng.$g^{-1}$ and 0.32–0.53 ng $g^{-1}$, respectively. The recovery rate and the accuracy of PAAs analysis in indoor dust were in the range of 92.1—–112 % and 1.67—10.2 %, respectively. Excellent correlation coefficient (0.9991–0.9998) was observed for target compounds (Table S1). The chromatograms of PAAs in a sample are depicted in Fig S1. As can be seen, the signal intensity of several PAAs are shown in this chromatogram.

### 2.5. *Assessing the risk of exposure to PAAs through ingestion*

The estimated daily intake (EDI) of PAAs via people present in cigarettes /waterpipe cafés through settled indoor dusts was estimated. The age groups considered to calculate the exposure of people to these compounds were infants (<1 year), toddlers (1–5 years), children (>5–11 years), teenagers (>11–19 years), and adults (≥20 years). EDI (ng $kg^{-1}$-bw $day^{-1}$) was calculated through the following formula (Equation (2):

$$EDI = \frac{C \times DIR}{BW} \tag{2}$$

C is the mean concentration levels of PAAs (ng $g^{-1}$), DIR is the rate of ingestion of settled indoor dusts (mg $d^{-1}$) and BW is the weight of people (kg). The weight of people in the different age groups of infants, toddlers, children, teenagers, and adults were considered as 5, 19, 29, 53, and 63 kg, respectively (Chinthakindi and Kannan, 2021; Zhu and Kannan, 2018). Also, the mean value of DIR for infants, toddlers, children, teenagers, and adults were considered as 20, 100, 50, 50, and 50 mg $day^{-1}$, respectively (Zhu and Kannan, 2018).

### 2.6. *Statistical analyses*

The statistical analysis of the data was done by using SPSS Statistics 22.0-IMB software. The normality of the obtained data was evaluated using the Kolmogorov-Smirnov test and Q-Q plots. One-way analysis of variance (ANOVA) and Tukey Post Hoc tests were used to determine statistically significant differences between PAAs concentrations in different cafes (WPC, CC and SFC). Mann-Whitney, Spearman and Kruskal-Wallis tests were used to investigate the effect of the investigated factors on the PAAs concentration. The p-value of less than 0.05 was considered as a criterion for comparison and significance of differences.

## 3. Results and discussion

### 3.1. *The concentration levels of PAAs in the settled indoor dusts of smoking cafes*

The concentration levels of nine measured PAAs and their total levels in the settled indoor dusts of smoking cafes (WPC, CC and SFC) are shown in Table 1 and Fig. 1. As seen, the concentration levels of ∑PAAs

**Table 1**
Descriptive statistics of primary aromatic amines (PAAs) concentrations (ng/g) in indoor dusts collected from waterpipe café' (WCC, n = 18), cigarette cafés (CC, n = 14) and smoking-free cafés (SFC, n = 18).

| Compound | Abbreviation | Sampling area | Mean ± SD | Percentiles | | | Min | Max | p-value* |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 25th | Median | 75th | | | |
| Aniline | ANL | WPC | 360.96 ± 220.20 | 170.53 | 272.73 | 582.55 | 123.29 | 780.26 | <0.001 |
| | | CC | 225.90 ± 118.55 | 151.38 | 183.76 | 326.92 | 67.35 | 459.77 | |
| | | SFC | 40.11 ± 20.55 | 23.47 | 37.28 | 37.28 | 17.78 | 87.56 | |
| *Ortho*-Toluidine | o-TOL | WPC | 12.82 ± 9.10 | 5.64 | 11.73 | 20.99 | 0.05 | 30.48 | <0.001 |
| | | CC | 8.08 ± 5.90 | 4.09 | 6.76 | 12.44 | 0.05 | 17.83 | |
| | | SFC | 1.97 ± 2.06 | 0.05 | 2.01 | 2.93 | 0.05 | 7.61 | |
| *Para*-Toluidine | p-TOL | WPC | 18.58 ± 11.97 | 8.24 | 17.66 | 27.92 | 0.05 | 45.44 | <0.001 |
| | | CC | 9.70 ± 6.94 | 5.41 | 7.88 | 14.80 | 0.05 | 21.21 | |
| | | SFC | 2.04 ± 1.63 | 0.05 | 2.55 | 2.88 | 0.05 | 490 | |
| *Meta* -Toluidine | m-TOL | WPC | 11.72 ± 9.96 | 4.46 | 8.16 | 15.78 | 0.05 | 34.38 | <0.001 |
| | | CC | 2.86 ± 2.54 | 1.09 | 2.09 | 4.19 | 0.05 | 8.59 | |
| | | SFC | 2.15 ± 2.26 | 0.05 | 2.32 | 3.28 | 0.05 | 8.62 | |
| *Ortho*-Anisidine | o-ASD | WPC | 41.16 ± 30.01 | 19.56 | 31.43 | 57.83 | 0.08 | 109.27 | <0.001 |
| | | CC | 26.20 ± 23.54 | 4.48 | 23.58 | 44.76 | 0.08 | 64.12 | |
| | | SFC | 6.44 ± 6.42 | 0.08 | 5.67 | 12.45 | 0.08 | 17.91 | |
| 2,6-Dimethylaniline | 2,6-DMA | WPC | 211.82 ± 153.53 | 118.15 | 164.22 | 255.00 | 53.29 | 677.26 | <0.001 |
| | | CC | 30.94 ± 8.27 | 21.88 | 36.03 | 61.34 | 9.78 | 124.27 | |
| | | SFC | 18.42 ± 19.77 | 0.05 | 14.33 | 25.23 | 0.05 | 72.20 | |
| 2-Naphthylamine | 2-NA | WPC | 31.15 ± 30.42 | 11.74 | 24.72 | 41.14 | 0.03 | 124.27 | <0.001 |
| | | CC | 5.12 ± 5.03 | 1.75 | 3.62 | 6.90 | 0.03 | 18.55 | |
| | | SFC | 2.15 ± 2.33 | 0.03 | 1.98 | 4.08 | 0.03 | 7.43 | |
| Para-Cresidine | PCD | WPC | 33.52 ± 22.52 | 15.34 | 30.51 | 50.73 | 0.03 | 75.63 | <0.001 |
| | | CC | 9.33 ± 7.48 | 3.96 | 7.66 | 12.79 | 0.03 | 25.21 | |
| | | SFC | 3.42 ± 3.39 | 0.03 | 2.37 | 6.50 | 0.03 | 9.70 | |
| 4-Chloroaniline | 4-CA | WPC | 6.49 ± 7.62 | 2.44 | 4.57 | 6.62 | 0.05 | 32.89 | <0.001 |
| | | CC | 1.47 ± 0.97 | 0.94 | 1.42 | 2.04 | 0.05 | 3.95 | |
| | | SFC | 0.65 ± 0.68 | 0.05 | 0.41 | 0.96 | 0.05 | 2.19 | |
| Total primary aromatic amines | ∑PAAs | WPC | 728.28 ± 377.72 | 395.10 | 620.82 | 927.53 | 315.13 | 1687.83 | <0.001 |
| | | CC | 331.42 ± 129.35 | 232.32 | 303.45 | 413.17 | 150.42 | 596.72 | |
| | | SFC | 66.26 ± 38.02 | 34.69 | 65.12 | 92.40 | 3.83 | 150.11 | |

* Kruskal Wallis test.

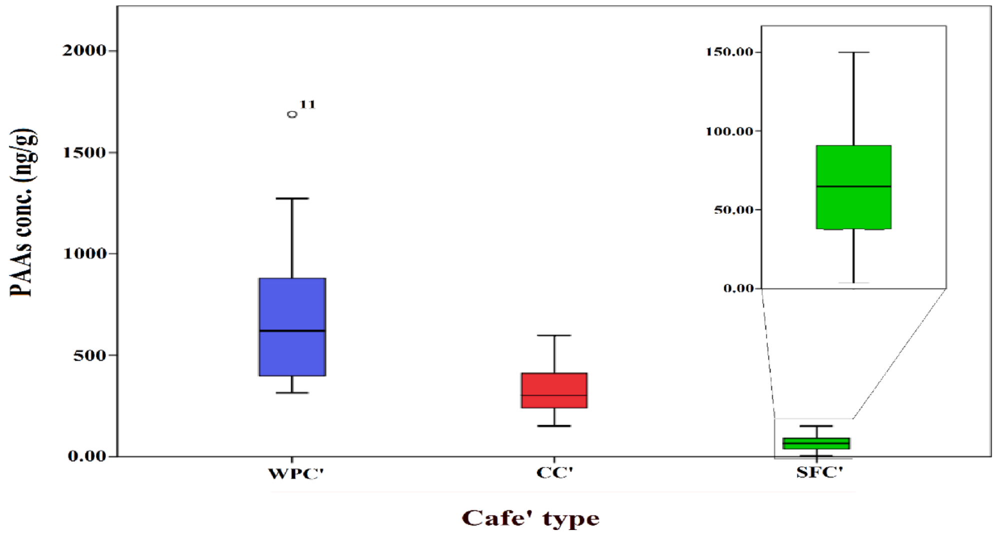


**Fig. 1.** Comparison the concentration levels of total aromatic amines (∑PAAs) in settled indoor dusts of waterpipe cafés (WPC), cigarette cafés (CC) and smoking-free cafés (SFC).

in the settled indoor dusts of cafes were in the order of WPC>CC>SFC with the mean levels of 728.28, 331.42 and 66.26 ng $g^{-1}$ (p-value $<$ 0.001), respectively. The highest level of ∑PAAs was 1687.8 ng $g^{-1}$ (in a WPC café) and the lowest level was 0.03 ng $g^{-1}$ (in a SFC café). The distribution of aniline (ANL) and 2, 6-dimethylaniline (2, 6-DMA) levels were significantly higher than other measured PAAs in the cafes with different uses (Fig. 2). The concentration levels of each measured PAA among different settled indoor dusts of smoking cafes (WPC, CC and SFC) were significantly different (p-value $<$ 0.001) (Table 1). Multiple/Post Hoc group comparisons of PAAs (ng/g) in settled indoor dusts of WPC, CC and SFC are presented in Table S2. In addition, as shown in Table 2, the multiple linear regression models showed significant positive associations between the WCC and CC cafes than SFC cafes for all PAAs (p-value $<$ 0.05).

### *3.2. Factors influencing PAAs level*

The effects of different parameters such as ventilation rate, number of window/door, number of active smoker, café area, café floor, and time from last painting on the indoor dust bounded PAAs level were evaluated by Spearman correlation, Mann–Whitney U and Kruskal–Wallis nonparametric tests. As seen in Tables 3 and 4, ventilation rate and number of windows/doors had a significant and negative correlation with the concentrations of ANL, o-TOL, p-TOL, 2,6-DMA and 2-NA congeners. In other words, with higher number of ventilator and windows & doors in cafes, the concentration of indoor dust bounded of aforementioned PAAs diminished (p-value $<$ 0.05). Based on Spearman's correlation test results (Fig. 3, Table 3), the ∑PAAs level had a negative relationship with ventilation rate (r = -0.549, p-value = 0.001), café area (r = -0.503, p-value = 0.003), and doors/windows numbers (r = -0.532, p-value = 0.001). In addition, there was a significant positive correlation between the number of smokers (r = 0.752, p-value $<$ 0.001) and the concentration of total ∑PAAs (Fig. 3). Indeed, with increase in number of active smokers, the concentration of ∑PAAs increased significantly (p-value $<$ 0.001, Table 3).

Table 4 shows a significant association between the tobacco type and the concentration of m-TOL, 2,6-DMA, 2-NA, PCD, 4-CA and ∑PAAs (p-value $<$ 0.05). Based on the Kruskal Wallis analysis, the mean levels of all PAAs compounds (except for PCD) in the waterpipe cafés with fruit-flavored tobacco was significantly higher than the regular tobacco and cigarette cafés. As well as, a significant differences were observed between floor level (grounded/basement), time of last paint with the mean

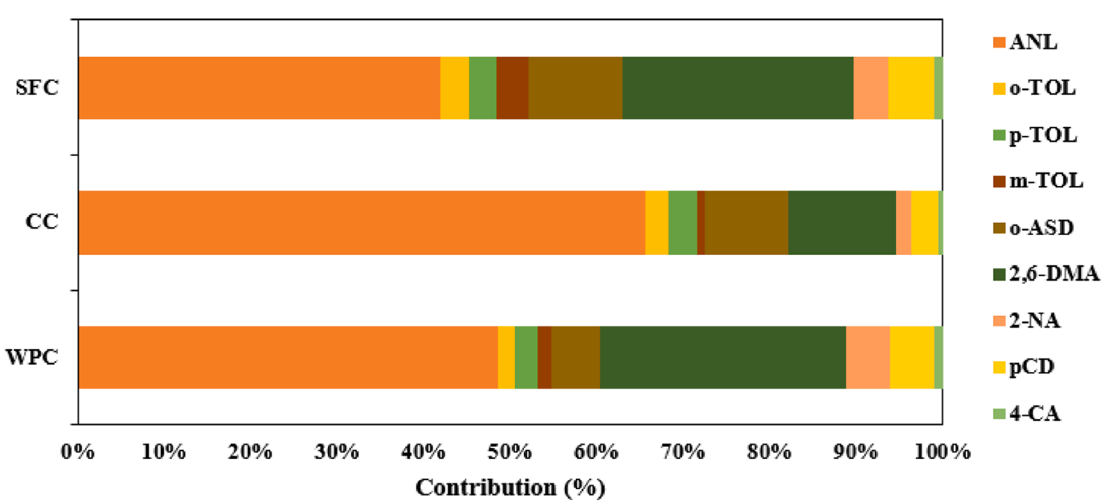


**Fig. 2.** Comparison the distribution rate (%) of primary aromatic amines (PAAs) in indoor dust of waterpipe cafés (WPC), cigarette cafés (CC) and smoking-free cafés (SFC). ANL: Aniline, o-TOL: *ortho*-Toluidine, p-TOL: *para*-Toluidine, m-TOL: meta -Toluidine, o-ASD: *ortho*-Anisidine, 2,6-DMA: 2,6-dimethylaniline, 2-NA: 2-Naphthylamine, pCD: *para*-Cresidine, 4-CA: 4-Chloroaniline.

**Table 2**
Adjusted multiple linear regression models of the association between primary aromatic amines (PAAs) in indoor settled dust and the type of cafe.

| Compound | Sampling area | β (95 % CI) | SE | $R^2$ | p-value |
|---|---|---|---|---|---|
| ANL[a] | SFC | **REF** | – | – | – |
| | WPC | 3.53(2.26 to 4.80) | 0.626 | 0.617 | <0.001 |
| | CC | 3.41(2.10 to 4.71) | 0.646 | | <0.001 |
| o-TOL | SFC | **REF** | – | – | – |
| | WPC | 2.47(1.17 to 3.78) | 0.644 | 0.430 | <0.001 |
| | CC | 2.10(0.76 to 3.45) | 0.664 | | 0.003 |
| p-TOL | SFC | **REF** | – | – | – |
| | WPC | 2.83(1.52 to 4.13) | 0.645 | 0.445 | <0.001 |
| | CC | 1.84(0.50 to 3.19) | 0.665 | | 0.008 |
| m-TOL | SFC | **REF** | – | – | – |
| | WPC | 2.16(0.94 to 3.39) | 0.604 | 0.439 | 0.001 |
| | CC | 1.11(-0.14 to 2.37) | 0.623 | | 0.081 |
| o-ASD | SFC | **REF** | – | – | – |
| | WPC | 3.35(1.94 to 4.76) | 0.697 | 0.473 | <0.001 |
| | CC | 1.34(-0.10 to 2.80) | 0.719 | | 0.473 |
| 2,6-DMA | SFC | **REF** | – | – | – |
| | WPC | 3.41(2.16 to 4.67) | 0.619 | 0.584 | <0.001 |
| | CC | 2.22(0.93 to 3.52) | 0.639 | | 0.001 |
| 2-NA | SFC | **REF** | – | – | – |
| | WPC | 2.91(1.03 to 4.79) | 0.930 | 0.280 | 0.003 |
| | CC | 1.56(-0.37 to 3.50) | 0.959 | | 0.112 |
| PCD | SFC | **REF** | – | – | – |
| | WPC | 2.96(1.38 to 4.54) | 0.782 | 0.439 | 0.001 |
| | CC | 1.57(-0.05 to 3.20) | 0.806 | | 0.058 |
| 4-CA | SFC | **REF** | – | – | – |
| | WPC | 2.49(1.38 to 3.59) | 0.546 | 0.511 | <0.001 |
| | CC | 1.26(0.12 to 2.40) | 0.563 | | 0.030 |
| ∑PAAs | SFC | **REF** | – | – | – |
| | WPC | 2.43(1.98 to 2.88) | 0.223 | 0.810 | <0.001 |
| | CC | 1.80(1.34 to 2.27) | 0.230 | | <0.001 |

[a] Adjusted for number of ventilation, number of window& door, café area,, orientation of the building, floor level and time from last paint., The level of individual PAAs compounds were $\log_{10}$-transformed, REF: this category is set to reference level, Bold values are statistically significantly; *significantly at $p < 0.05$.

levels of all ∑PAAs compounds.

### 3.3. EDI of AAs in settled indoor dusts of smoking cafes

The EDI values of PAAs through settled indoor dusts of smoking cafes for different age groups (infant, toddler, children, teenager, and adult) were determined and the results are summarized in Table 5. The results showed that the age groups are exposed to PAAs in the order of toddlers> infants> children> teenagers> adults. The highest and lowest values of EDI were related to the age group of toddlers when attending WPC (3832.8 ng $kg^{-1}$-bw $day^{-1}$) and adult group in SFC (52.8 ng $kg^{-1}$-bw $day^{-1}$), respectively.

## 4. Discussion

Considering the presence of PAAs in all three types of cafes, especially WPC and CC, it can be said that long time being in these environments can have a high health risk for people. The results of previous studies on the presence of other chemicals such as heavy metals, BTEX (benzene, toluene, ethylbenzene and xylene) and polycyclic aromatic hydrocarbons (PAHs) in the indoor air of WPC and CC are also consistent with our results and have shown a high health risk for people (Heydari, 2020; Arfaeinia, 2022; Rostami, 2019).

Smokers believe that using waterpipe has less health effects than cigarette and is not addictive, therefore the possibility of waterpipe smoking in cafes is more than cigarette smoking (Akl, 2010). As reported before, the number of people visiting waterpipe cafes and the type of tobacco consumed in the cafes are effective in the release of dusts, which increases the release of PAAs (Heydari, 2019; Naddafi, 2019). The distribution of aniline (ANL) and 2, 6-dimethylaniline (2, 6-DMA) levels were significantly higher than other measured PAAs in the cafes with different uses. These two compounds (ANL and 2, 6-DMA) are known with possible carcinogenic effects (group 2A and 2B, respectively); therefore, reducing exposure to these compounds can reduce the potential health effects. The lowest concentration level among all nine measured PAAs in different cafes was related to the 4-chloroaniline (4-CA). In a research, 9 PAAs congeners (m-PDA, ANL, 4,4-ODA, o-ASD, 4-CA, 2-ANP, 1-ANP, 3,5-DCA, and 2-ABP) observed in the waterpipe smoke, and ANL had the highest level (31.3 ng per smoking session) (Schubert, 2011). In a study by Dobaradaran et al., (Dobaradaran, 2023) the levels of PAAs released from cigarette butts in distilled water and river water were 569 and 556 ng/L, respectively. Also, ANL had the highest release rate in both distilled water (525 ng/L) and river (516 ng/L) water samples (Dobaradaran, 2023). Dobaradaran et al. (Dobaradaran, 2022), also reported that the ΣPAAs average concentration in as freshly smoked cigarette butts > aged cigarette butts > unsmoked cigarette with the levels of 3.43, 2.12 μg $g^{-1}$, and 0.28 μg $g^{-1}$, respectively. In a study by Palmiotto et al. (2001), the concentration levels of ANL in indoor and outdoor air were found in the range of 53 ng $m^{-3}$ in office of non-smokers to 1930 ng $m^{-3}$ in discotheque (Palmiotto, 2001).

In Chinthakindi et al. study, ∑10 PAAs were found in > 80 % of the indoor dust samples at concentration ranges of 29.1–19,200 ng $g^{-1}$ and ANL was the predominant detected PAA in all dust samples (Chinthakindi, 2022). In another study in Italy the amounts of 9 PAAs in indoor environments (residential homes, hospitals and offices) were measured. ANL levels ranged from 53 to 1929 ng/$m^3$ in different environments (Palmiotto, 2001). However, no significant difference was observed between the concentration levels of ANL and other measured compounds. The results of the mentioned study also showed that the concentration levels of PAAs in residential houses with smoker (15–33 ng $m^{-3}$) was significantly higher than houses without smokers (5–11 ng $m^{-3}$) (Palmiotto, 2001). In another study, 29 PAAs in indoor settled dust of residential houses in 10 different countries were measured. The results showed that the concentration levels of ANL and 2–6-DMA were

**Table3**
Correlation test between the measured primary aromatic amines (PAAs) of indoor dust and café characteristics (ventilation rate, number of window & door, number of active smokers, and café area).

| PAAs | Ventilation rate | Number of window & Door | Number of active smokers | Café area |
|---|---|---|---|---|
| ANL[a] | −0.434* | −0.296 | 0.633* | −0.361 |
| o-TOL | −0.400* | −0.423* | 0.015 | −0.200 |
| p-TOL | −0.387* | −0.237 | 0.343 | −0.270 |
| m-TOL | −0.325 | −0.645* | 0.562* | −0.301 |
| o-ASD | −0.309 | −0.196 | 0.100 | −0.155 |
| 2,6-DMA | −0.557* | −0.583* | 0.623* | −0.485* |
| 2-NA | −0.350* | −0.354* | 0.446* | −0.154 |
| PCD | −0.203 | −0.227 | 0.362* | −0.422* |
| 4-CA | −0.293 | −0.301 | 0.479* | −0.538* |

*Correlation is significant at the 0.05 level (2-tailed).

**Table 4**
Association between the measured primary aromatic amines (PAAs) of indoor dust and café characteristics (tobacco type, floor level, and the time from last paint).

| Variables | ANL | o-TOL | p-TOL | m-TOL | o-ASD | 2,6-DMA | 2-NA | PCD | 4-CA | ∑PAAs |
|---|---|---|---|---|---|---|---|---|---|---|
| **Type tobacco** Fruit | 406.38 ± 227.58 | 12.53 ± 8.99 | 20.91 ± 11.56 | 11.97 ± 10.45 | 46.06 ± 31.96 | 233.28 ± 166.99 | 32.88 ± 34.23 | 31.13 ± 23.85 | 7.58 ± 8.30 | 802.74 ± 392.18 |
| Regular | 201.98 ± 83.78 | 13.87 ± 10.81 | 10.42 ± 10.90 | 10.85 ± 9.34 | 24.00 ± 13.15 | 136.74 ± 55.45 | 25.09 ± 10.17 | 41.90 ± 16.99 | 2.68 ± 2.29 | 467.55 ± 159.63 |
| Cigarette | 225.90 ± 118.55 | 8.08 ± 5.90 | 9.70 ± 6.94 | 2.86 ± 2.54 | 26.20 ± 23.54 | 42.72 ± 30.94 | 5.12 ± 5.03 | 9.33 ± 7.48 | 1.47 ± 0.97 | 331.42 ± 129.35 |
| **p-value*** | 0.051 | 0.403 | **0.015** | **0.003** | 0.170 | **<0.001** | **0.007** | **0.003** | **0.001** | **<0.001** |
| **Floor level** Grounded | 257.77 ± 167.07 | 8.68 ± 5.28 | 9.95 ± 6.99 | 6.62 ± 8.13 | 27.88 ± 19.14 | 98.42 ± 99.22 | 14.92 ± 19.00 | 16.92 ± 16.06 | 2.79 ± 2.77 | 443.99 ± 264.66 |
| Basement | 386.05 ± 217.64 | 14.71 ± 11.03 | 23.76 ± 11.52 | 10.17 ± 9.87 | 47.47 ± 37.65 | 213.10 ± 186.15 | 29.01 ± 35.70 | 34.42 ± 25.67 | 7.16 ± 9.51 | 765.88 ± 416.43 |
| **p-value**** | **0.042** | 0.190 | **0.001** | 0.165 | 0.204 | **0.034** | 0.292 | **0.047** | 0.084 | **0.020** |
| **Time last paint** | | | | | | | | | | |
| ≤5 years | 219.51 ± 101.32 | 9.70 ± 7.47 | 11.73 ± 8.91 | 6.03 ± 7.88 | 27.68 ± 22.81 | 89.01 ± 63.41 | 14.18 ± 13.93 | 24.96 ± 22.26 | 2.42 ± 2.12 | 405.26 ± 166.63 |
| > 5 years | 459.10 ± 230.44 | 12.75 ± 9.23 | 20.36 ± 12.47 | 11.30 ± 9.72 | 47.84 ± 33.08 | 231.07 ± 203.04 | 30.42 ± 39.51 | 19.08 ± 19.48 | 7.86 ± 9.46 | 839.82 ± 443.23 |
| **p-value**** | **0.007** | 0.321 | 0.054 | **0.020** | 0.088 | **0.034** | 0.512 | 0.538 | **0.022** | **0.004** |

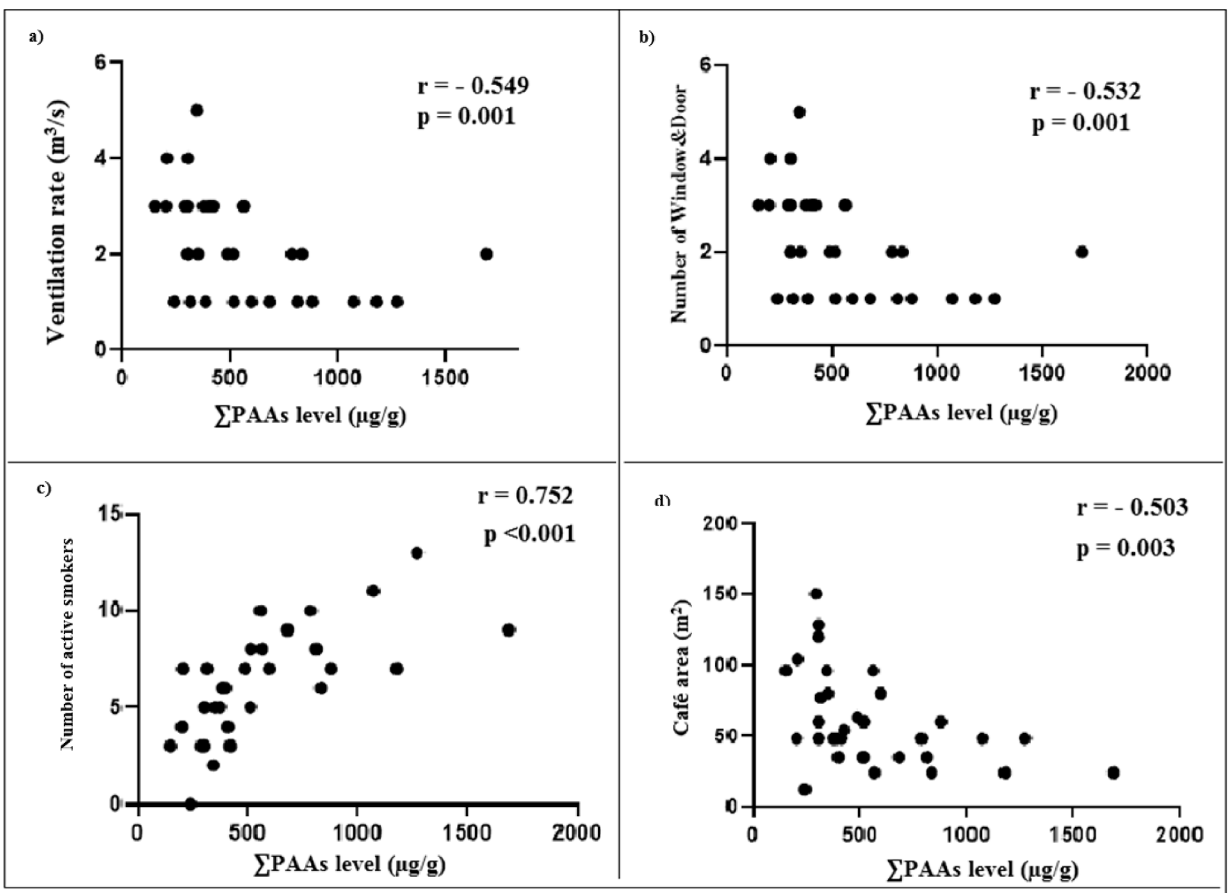


**Fig. 3.** Correlation between the ∑PAAs and café characteristics (Ventilation rate (a), Number of window & door (b), Number of active smokers (c), and Café area (d)).

significantly higher than the other measured PAAs (Chinthakindi and Kannan, 2021). The highest levels of ANL and 2,6-DMA were 334 and 87.5 ng $m^{-3}$, respectively, that were related to the collected samples of suspended particles from South Korea (Chinthakindi and Kannan, 2021), which is lower than the measured levels of these compounds in WPC and CC dust samples in the present study. According to the results of the mentioned study, one of the main sources of the PAAs is smoking cigarette and waterpipe that release these compounds into the indoor air (Chinthakindi and Kannan, 2021). However, it should be noted that PAAs in different environments have various emission sources, which requires more studies to determine the exposure level of people in different environments via different sources of PAAs.

Previous studies have studied different compounds at diverse matrices as THS (Soleimani, 2022; Matt, 2021; Sleiman, 2010; Sleiman,

**Table 5**
The values of daily exposure (EDI) of different age groups to total primary aromatic amines (∑PAAs) through the ingestion of settled indoor dusts in smoking and smoking-free cafes.

| Café type | EDI (ng/kg-bw/day) Age groups | | | | |
|---|---|---|---|---|---|
| | Infants | Toddlers | Children | Teenagers | Adults |
| Waterpipe Cafés (WPC) | 2912.92 | 3832.79 | 1255.569 | 687.01 | 577.96 |
| Cigarette Cafés (CC) | 1325.48 | 1744.05 | 571.33 | 312.61 | 262.99 |
| Smoking-free Cafés (SFC) | 264.44 | 347.95 | 113.98 | 62.37 | 52.47 |

2014; Figueiró et al., 2016). For example, in Figueiró et al study, the concentration level of nicotine in the dust from non-smokers' homes was 10 times lower than in smokers' homes (Figueiró et al., 2016). In another study by Sleiman et al., the levels of tobacco-specific nitrosamines (TSNAs) in indoor surfaces were in the range of 0.00031–5 μg $m^{-2}$ (Sleiman, 2010) and the level of acrolein in smoker's home was 3 times higher than in outdoor air (Sleiman, 2014). The concentration level of nicotine in air samples of smoker cars was 2.2 times higher than non-smoker cars (Matt, 2013) and in the case of surface dust samples, the level of nicotine in smoker cars was 2.7 times higher than non-smoker cars (Matt, 2013). Another study showed that the concentration levels of heavy metals in house dust samples were significantly different depending on the area and nicotine was also identified in all samples and the level of this compound in surface samples was 3.5 times higher than in dust samples (Matt, 2021). Although THS is a main source of exposure to chemical compounds and is counted as a major risk of indoors exposure to tobacco associated chemicals (Sleiman, 2014), but a comprehensive and reliable data about chemical contents of THS is limited. Hence, more studies are needed to evaluate different chemical contents and potential health effects of THS.

The ∑PAAs level had a negative relationship with ventilation rate, café area, and doors/windows numbers. These findings recommend that the ventilation rate could be a key factor for the pollutant levels in indoor air of smoking cafés. Similar results was also reported by Hashemi et al study (Hashemi, 2020). In addition, there was a significant positive correlation between the number of smokers and the concentration of total PAAs. Indeed, with increase in number of active smokers, the concentration of ∑PAAs increased significantly ($p$-value $< 0.001$). In previous studies, it was reported that during the smoking session, PAAs are released into surrounding environment which were present in the first- hand, second hand as well as third-hand smokes (Saha et al., 2009; Smith et al., 2003; Zhang, 2022).

The higher level of PAAs in flavored waterpipe cafés might be justified through the time needed to smoke this type of tobacco. Smoking fruit- flavored tobacco last at least four times more than the regular one (Masjedi, 2019). The possible reason for the higher level of PAAs in flavored waterpipe cafés is that the soft/tasty smoke of flavored tobacco as well as the tendency of young smokers to be more time on smoking of this type of tobacco. In addition, flavored tobaccos contain huge amounts of organic substances, flavoring additives and sweeteners which are added to this types of tobacco during the processing step (Fazlzadeh, 2015). As seen in Table 4, cafés situated in the basement had a higher level of PAAs (e.g., ANL, p-TOL, DMA, and PCD) than those located in the ground floor. Basements are usually confined places with walls without any holes and very limited natural ventilation. Since ventilation is an influential variable in refreshing the indoor air of cafés, the smoking cafés situated in underground floors suffered from more contaminants concentrations, as expected (Heydari, 2019). With regard to last painting of café, it was found that the PAAs concentrations in indoor dust increased with the longer time since the last painting of cafés wall. This means that the painting of cafes walls removes these compounds from the surfaces of the surrounding walls. Although, previous studies reported that the paints utilized for wall painting contain large amounts of aromatic amines and these compounds can be released from freshly painted walls into indoor air as well as indoor dust (Palmiotto, 2001; Zeegers, 2001).

The estimated daily intake (EDI) of PAAs in settled indoor dusts for different age groups (infants, toddlers, children, teenagers, and adults) were ranged from 52.5 to 3832.8 ng $kg^{-1}$-bw $day^{-1}$, and EDI value for toddlers was higher than others groups. The lowest values of EDI were related to the adult group in SFC. One of the reasons for the difference in exposure levels of people is the difference in their body weight and the amount of particulate matter ingestion. Although the probability of the presence of infants and toddlers in WPC and CC is considered lower than other age groups, but nowadays it is possible to use tobacco in some non-smoking cafes and/or restaurants and there is an exposure possibility of this group to pollutants as well. In addition, the presence of smokers in residential houses and other closed environments may expose the infants and toddler groups to PAAs in settled dusts. Acceptable daily intake (ADI) values recommended by WHO for the compound of 4–CA is 2.0 mg $kg^{-1}$-bw $day^{-1}$ (Epa, 1984; Who, 2013). Based on these values, all EDIs calculated for different age groups in this study are lower than the recommended values by WHO. However, exposure to PAAs from other sources should not be ignored because the health risk from PAAs may increase as the release of these compounds increases by other sources as well. Based on our best knowledge, so far, the exposure of people to PAAs in the indoor air of smoking and non-smoking cafes for different age groups has not been investigated. However the level of people's exposure to 29 PAAs in suspended particles has been reported for different age groups in the indoor air of residential houses in ten countries. The highest value of EDI (3.032 ng $kg^{-1}$-bw $day^{-1}$) was related to the group of toddler in South Korea (Chinthakindi and Kannan, 2021) and the lowest value (0.019 ng/kg-bw/day) was related to the group of teenager in Kenya (Chinthakindi, 2022). In another study by Chinthakindi et al, the EDI value of PAAs through dust ingestion ranged from 0.349 for adults to 6.62 ng $kg^{-1}$-bw $day^{-1}$ for toddlers (Chinthakindi, 2022). Naddafi et al. also calculated the excess lifetime cancer risk (ELCR) and hazard quotient (HQ) from inhalation of particulate matters in the indoor air of waterpipes cafes for people aged from 11 to 61 years. Their results showed that the HQ value related to $PM_{2.5}$ for age group of older than 16 years was higher than the acceptable value (HQ>1) (Naddafi, 2019). Also, the ELCR value related to $PM_{2.5}$ ($4.6 \times 10^{-6} - 44.5 \times 10^{-6}$) for all age groups was higher than the recommended range by USEPA ($<1 \times 10^{-6}$) (Naddafi, 2019). Therefore, considering the high carcinogenic risk of suspended particles in the indoor air of WPC, increasing contact with suspended particles with PAAs compounds will increase the health effects caused by them. However, future and additional studies are needed for a complete evaluation of PAAs health effects in settled dusts in smoking cafes as THS.

## 5. Conclusion

In the present study, the concentration levels of PAAs in settled indoor dusts of waterpipe/cigarette cafes and non-smoking cafes, and the levels of people exposure to PAAs in settled indoor dusts as THS for different age groups were investigated for the first time. The results showed that the concentration levels of ∑PAAs in settled indoor dusts of WPC is higher than other cafes (CC and SFC). The results confirmed that settled indoor dusts of waterpipe/cigarette cafes is as a source of THS and should be considered as one of the main sources of PAAs compounds. Among the nine measured AAs compounds in settled indoor dusts of smoking and smoking-free cafes, ANL and 2,6-DMA were the most predominant ones. Moreover, considerably higher concentration of THS-related PAAs was quantified in the waterpipe cafés serving flavored tobacco than those served traditional tobacco. As well as, the EDI value for toddlers was higher than others groups. Finally it's highly necessary in the further studies to focus on the exposure level to PAAs from other sources and diverse contact routes should also be considered. As well as, more comprehensive studies are needed to evaluate the other chemical contents of THS to accurately estimate health effects of this global concern.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.arabjc.2023.105587.

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