

DISTRIBUTION AND HEALTH RISKS OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) IN SMOKE AEROSOLS FROM BURNING OF SELECTED GARDEN WASTES

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Abstrak

Satu kajian telah dijalankan bagi mencirikan sebatian polisiklik aromatik hidrokarbon yang dibebaskan daripada pembakaran lima jenis sisa laman iaitu daun Bachang, Mempelam, Nangka dan Jambu Air yang luruh dan sejenis Rumpit. Sampel-sampel ini telah dibakar sehingga membara dan zarah asap yang terhasil ketika proses pembakaran disampel menggunakan alat pensampelan berisipadu tinggi yang dimuat dengan penapis gentian kaca. Polisiklik aromatik hidrokarbon (PAHs) diekstrak menggunakan campuran diklorometana-methanol (3:1) sebagai pelarut dan hasil ekstrak yang diperolehi dipisahkan dengan menggunakan turus silika-alumina. Penentuan dan kuantifikasi unsur PAHs dijalankan dengan menggunakan GC-MS. Keputusan menunjukkan pembakaran menghasilkan kuantiti PAHs yang banyak dalam semua sampel; jumlah keseluruhan unsur PAHs yang dibebaskan adalah dalam julat 0.41 to 42.2 $\mu\text{g}/\text{m}^3$. Majoriti unsur PAHs yang hadir dalam semua zarah asap sampel adalah PAHs bergelang tiga ke empat (e.g. fluorantina dan pirina) diikuti dengan jumlah yang sedikit bagi lima ke enam gelang (e.g. benzo(a)pirina dan benzo(g,h,i) perilina) dan dua ke tiga gelang (e.g. acenaphthylina). Keputusan kesetaraan BaP menunjukkan kemungkinan potensi risiko ke atas kesihatan daripada zarah asap sisa laman adalah amat ketara; nilai keseluruhan kesetaraan BaP adalah dalam julat 5.60 E+04 pg/m^3 – 4.98 E+06 pg/m^3 dengan zarah asap Jambu Air menunjukkan potensi risiko ke atas kesihatan yang paling tinggi.

Abstract

A study has been carried out to characterize polycyclic aromatic hydrocarbons emitted from the burning of five types of typical garden wastes viz, Bachang, Mango, Jackfruit, Jambu Air litter fall and a type of Grass. The samples were burned to the ember and respective smoke aerosols emitted during the burning period were sampled using high volume filtration on a pre-cleaned glass fibre filters. Polycyclic aromatic hydrocarbons (PAHs) were extracted using dichloromethane-methanol (3:1) as solvent and the extracts fractionated on silica-alumina column. Detection and quantification of PAHs compounds were carried out using GC-MS. Results indicated that burning resulted in the formation of significant amount of PAHs compounds in all samples; total PAHs compounds emitted were in the range of 0.41 to 42.2 $\mu\text{g}/\text{m}^3$. The major PAHs compound exhibited in all smoke samples were three to four rings PAHs (e.g. fluoranthene and pyrene) with lesser amount of five to six rings (e.g. benzo(a)pyrene and benzo(g,h,i) perylene) and two rings PAHs (e.g. acenaphthylene). The BaP equivalency results showed that the potential health risk from these garden wastes smoke were very significant; total BaP equivalency values were in the range of 5.60 E+04 pg/m^3 – 4.98 E+06 pg/m^3 with Jambu Air smoke exhibited the highest potential health risk.

Keywords: smoke aerosols, biomass burning, polycyclic aromatic hydrocarbons, environmental health risks, toxic equivalency factors.

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) are a multi-ringed organic compounds encountered ubiquitously and widely distributed in the environment generated by incomplete combustion and/or pyro-synthesis of organic material arising, in part, from biomass burning, natural forest fires and volcanic eruption. Biomass burning is an important primary source of many trace substances which are reactants in atmospheric chemistry and of soot particulate matter that decreases visibility and absorbs incident radiation [1]. Open burning is often used as a rapid and inexpensive method for disposing of crop or garden biomass residues, releasing nutrients for the next growing cycle and clearing land, especially in plantation areas and gardens but very often this actually could cause severe air pollution problem in many countries. For example, the haze episodes that occurred in Malaysia in September–October 1991, August–October 1994 and September–October 1997 have been attributed to suspended smoke particulate matter from biomass burning in southern Sumatra and Kalimantan, Indonesia [2].

Among the formed air pollutants are large amounts of volatile and gaseous carbonaceous compound, for example CO, CH₄, C₂H₄ and HCN, including the carcinogenic and mutagenic polycyclic aromatic hydrocarbons (PAHs). The characterization of PAHs emitted from different biomass burning has been well studied worldwide [3-5]. Abas *et al.* [6] reported that *n*-alkanes, *n*-alkan-2-ones, *n*-alkanols, *n*-alkanoic acids, levoglucosan and PAHs are among the dominant organic components found in aerosol particulate matter during a haze episode in Kuala Lumpur, Malaysia.

The presence, PAHs in air could pose possible health risks to the public due to their mutagenicity and carcinogenicity, thus many regulations on PAHs emission have been proposed. In California, the technical exposure limit for benzo[a]pyrene (BaP) in air is 1.1 ng/m³ and the exposure limit for 70 years lifetime is 1.1-3.3 ng/m³ [7]. The US EPA has proposed a reference concentration (Rfc) of naphthalene in ambient air of 3 µg/m³ to prevent harmful respiratory tract, ocular, and blood effects [8]. Therefore, the chemical composition data of smoke aerosols is important for understanding the organic component contribution of biomass burning emissions to atmospheric chemistry and in assessing their health risk exposures associated to the smoke aerosols.

In Terengganu, the practice of burning garden waste in residential compound is a very common practice among the residents with the adults and children can easily be exposed to these smoke as they go about doing their chores, e.g. adding new waste to the existing burn fire or continue with weeding activities weekly and playing in the garden, respectively without any thought of possible health risks arising from inhalation of these smoke. Consequently, this study has been carried out to characterize the polycyclic aromatic hydrocarbons (PAHs) profile and content, in the aerosols emitted from the burning of five selected garden wastes, viz. Bachang, Mango, Jackfruit, and Jambu Air and a garden Grass sample in an effort to assess the health risk associated with exposure to smoke aerosols PAHs from the samples studied.

Materials and methods

Sampling of garden wastes samples

Five different kinds of garden waste samples were chosen for analysis that is Bachang (*Mangifera foetida*), Mango (*Mangifera indica*), Jackfruit (*Artocarpus heterophyllus*), and Jambu Air (*Eugenia aquea*) litter fall and Grass (*Panicum repens*). These samples were chosen because they are the common types of trees grown by the villagers and the grass is the common weed that grows around their garden or residential compounds in this area. The dry litter falls of Bachang, Mango, Jackfruit, Jambu Air were taken from a resident house at Kg. Telaga Papan, Kuala Terengganu and the fresh leaves of Grass were taken at Kg. Wakaf Tembusu, Gong Badak, Kuala Terengganu which located a few kilometers from roadside. All samples were placed separately in boxes lined with aluminium foil and sealed to avoid contamination during transportation. The litter fall samples were allowed to dry over a two week period in open air until further analysis. Grass sample was separated into two portions; one portion was left to dry in a similar manner to the litter fall samples before burning (dry burnt grass) whilst the other was burnt immediately after sampling (fresh burnt grass) as discuss in section below. This procedure was carried out in order to investigate the differences in PAHs compounds (if any) emitted in the smoke aerosols from fresh and dry burnt grass as it is also a practice by the residents to burn fresh grass or often these grass were left to dry before burning.

Sampling of garden wastes smoke aerosols

Each litter fall and grass sample was burnt completely to the ember. The smoke emitted throughout the burning period were collected using a high-volume air sampler (HVS) fitted with a pre-cleaned glass fibre filter, placed approx. 1m diagonally above and to the side of the flames in the smoke plume.

Extraction and fractionation

PAHs compounds were extracted from the glass filter using ultrasonic agitation with mixture of dichloromethane-methanol (3:1v/v) as solvent. Before extraction, aromatic internal standards of perylene d-₁₂ for aromatic fraction (fraction 2) were spiked into the filter paper for recovery assessment. The extracts were concentrated to about 1 mL using rotary evaporator. The concentrated extracts were then fractionated into subfractions on 5% deactivated silica (230-400 mesh)-2% deactivated alumina (70-230 mesh) columns. PAHs compounds were eluted using a combination of 30mL of 10% dichloromethane in hexane followed by 20ml of 50% dichloromethane in hexane.

GC/MS analysis

Identification and quantification of the 17 priority PAHs compounds were carried out using Shimadzu-QP2010 GC-MS. The compounds determined for the 17 priority PAHs compounds were as follows: naphthalene (Nap), acenaphthylene (Acy), acenaphthene (Ace), fluorene (Flu), phenanthrene (Ph), anthracene (An), fluoranthene (Fla), pyrene (Py), benz[a]anthracene (B[a]A), Chr (chrysene), benzo[b]fluoranthene (B[b]F), benzo[k]fluoranthene (B[k]F), benzo[a]pyrene (B[a]P), benzo[e]pyrene (B[e]P), indeno[1,2,3-cd]pyrene (Ind), dibenz[a,h]anthracene (D[ah]A), benzo[g,h,i]perylene (B[ghi]P). The sum of these 17 PAHs compounds are known as total identified PAHs (TIP). The GC-MS operating conditions are summarized in Table 1. Verification of peaks was carried out based on key fragment ions, retention times compared to those of external aliphatic hydrocarbons and PAHs standards, and/or mass spectra.

Table 1: Description on GCMS chromatographic condition

| No. | Parameter | Description |
|-----|-------------------------------|--|
| 1 | Mode | Full-scan GCMS |
| 2 | Column | DB-5 5% diphenyldimethylpolysiloxane (30m long, 0.25 mm I.D., 0.25µm film thickness) |
| 3 | Carrier gas | Helium (purity 99.999%) |
| 4 | Initial flow | 2.0 mL/min |
| 5 | Nominal initial pressure | 32.2 kPa |
| 6 | Average velocity | 51.3 cm/sec |
| 7 | Injection mode | Splitless (1 min) (1.0-1.4µL; hot needle technique) |
| 8 | Temperature of injector | 290°C |
| 9 | Temperature of oven | 50°C (held for 1 min), then up to 140°C at 5°C/min, then up to 300°C at 4°C/min and held isotherm for 15 min |
| 10 | Temperature of transfer line | 300°C |
| 11 | Data for qualitative analysis | Acquired in the electron impact (EI) mode (70eV), scanning from 50-650 mass units |

Recovery blanks

The recovery of the multi-step procedure for perylene-d₁₂ ranged from 81-101%. Appropriate corrections were made to the measured concentrations. Procedural blanks as well as solvent blanks were analysed and quantified to ensure that there were no significant background interferences; no PAHs compounds of interest were detected in these blanks.

Calculation of benzo[a]pyrene equivalency (BaP_{eq}) concentration

The BaP equivalency concentration is a calculation that sums together carcinogenic PAHs compound based on the individual PAHs compound toxic equivalency factors (TEFs), using BaP as a reference value of 1. The individual PAHs TEFs value was adapted from Nisbet and Lagoy [9] as these TEFs have been demonstrated to be a better reflection of the actual state of knowledge on the toxic potency of each individual PAH species relative to BaP [10]. The equation for BaP_{eq} concentration is shown in Equation 1 where it is calculated by summing together each species concentration multiplies by its respective TEFs.

$$BaP_{eq} = \sum_{i=1}^n TEF_i \times [PAH_i] \dots\dots \text{Equation 1}$$

Where: BaP_{eq} = Benzo[a]pyrene equivalency
 TEF = Toxic equivalency factor
 n = number of TEF / PAH compounds in calculation
 i = individual TEF / PAH compounds in calculation

Results and discussion

It should be noted that results obtained from this study are preliminary because only one burning test was conducted for each sample included in this study. It must be conceded that distributions and abundances of PAHs compound in all smoke aerosol samples constituents are strongly dependent on combustion conditions (e.g. smouldering versus flaming, duration) and although attempt has been made in this study to sample aerosols throughout the flaming and smouldering conditions, uncertainty remains with respect to the duration of each combustion phase. Thus, the values reported in this study should not be used as absolute value but as a relative chemical fingerprints for each vegetation sample.

PAHs distribution from garden wastes smoke

PAH compounds are generally formed by thermal decomposition of any organic matter containing C and H atom through either incomplete combustion (pyrolysis) or carbonisation process. All biomass fires are pyrolysis processes; PAHs are formed from either the process of high temperature thermal alteration of natural product precursors in the source organic matter or process of recombination of molecular fragment in the smoke. Figure 1 shows the distribution of individual priority PAHs and Figure 2 shows the ring number distribution of PAHs present the samples studied. 17 PAHs were quantified in this study, but not all the PAHs were detected in smoke particulate in the samples analyzed. 14 PAHs out of the 17 selected PAHs were detected from the burning of Mango leaves and dry burnt Grass. For Bachang leaves smoke and fresh burnt Grass, 15 PAHs were detected whereas 16 PAHs were detected in Jambu Air leaves smoke. In Jackfruit leaves smoke only 13 out of 17 PAHs were detected. The major PAHs emitted are fluoranthene, pyrene and benzo[g,h,i]perylene followed by benz[a]anthracene and indeno[1,2,3-cd]pyrene. Table 2 shows the concentration of the total identified PAHs (TIP) found in the biomass smoke studied. The TIP concentration exhibit in all smoke aerosol samples ranged from 0.41 to 42.2 $\mu\text{g}/\text{m}^3$. The PAHs compounds quantified were classified according to their numbers of aromatic rings as follows: 2-ring (e.g., naphthalene); 3-ring (e.g., phenanthrene); 4-ring (e.g., pyrene); 5-ring (e.g., benzo[a]pyrene), and 6-ring (e.g., benzo[g,h,i]perylene). In all smoke aerosol samples, concentration of larger PAHs compounds (more lipophilic PAHs; 3 ring PAHs and above) were generally higher than the smaller and more volatile PAHs. The percentage of 2-ring, 3-ring, 4-ring, 5-ring and 6-ring PAHs accounted for ca. 0.17% to 4.81%, 8.07% to 46.7%, 16.0% to 54.9%, 3.87% to 61.7% and 0.95% to 15.4% of the total PAHs detected in all smoke samples, respectively.

Comparison between smoke samples revealed that Bachang litter fall smoke emitted significantly higher percentage of 3-rings and 4-rings PAHs, whilst Jambu Air litter fall and dry burnt grass smoke emitted higher percentage of 3-, 4- and 5-ring PAHs, whereas Fresh burnt grass smoke and Jackfruit litter fall smoke had higher 3-, 4-, 5-, 6-ring PAHs and Mango litter fall smoke on the other hand emitted significantly higher percentage 4-ring and 5 ring PAHs. Results also indicate that all smoke aerosols samples generate greater portion of intermediate to higher molecular weight PAHs, including genotoxic PAHs (B[a]A, Chr, B[b]F, B[k]F, D[ah]A and Ind) and co-carcinogens PAHs (Fla, Py, B[e]P and B[ghi]P). The low concentration and percentage of 2-ring PAHs in all smoke samples is probably due to their higher tendency to evaporate. According to Finlayson-Pitts and Pitts [11], in ambient air, at 25 °C, depending on their vapor pressure, naphthalene that have a high vapor pressure exist in the gas phase thus easily evaporated compared to other aromatic components. In addition, these low molecular weight PAHs which were lighter tend to remain in the gaseous phase than the particulate phase of the smoke aerosols. This was consistent with the results reported by Zou *et al.* [12] which detected the lower molecular weight PAHs (molecular weight ≤ 200) in the gaseous phase of firewood smoke aerosols. Since only smoke aerosol particulates were trapped to the fibre filter paper, it is not surprising that higher concentration of 3-rings and above PAHs was observed in this study. Another aspect that could possibly contributed to the high concentration of these medium to high molecular weight PAHs is the combustion temperature. A study by Grimmer [13] and Jauhiainen *et al.* [14] has shown how temperatures effect the formation of PAHs compounds where increasing the temperature resulted in the increase of PAHs compounds. At high temperature combustion ($T^\circ\text{C} > 700^\circ\text{C}$), where the pyrolysis reaction occurred in the insufficient of oxygen enhances the formation of PAHs compounds. This process could be used to explain the differences in PAHs concentration found in the dry burnt grass and fresh burnt grass where dry burnt grass gave 4.75 $\mu\text{g}/\text{m}^3$ of TIP with domination of 4- and 5-ring PAHs and fresh burnt grass gave 0.41 $\mu\text{g}/\text{m}^3$ of TIP with domination of 3-, 4-, 5-, and 6-ring PAHs, respectively. Fresh Grass sample has higher percentage of moisture content compared the dry Grass, thus affected the combustion efficiency and reduces the combustion temperature of the former sample.

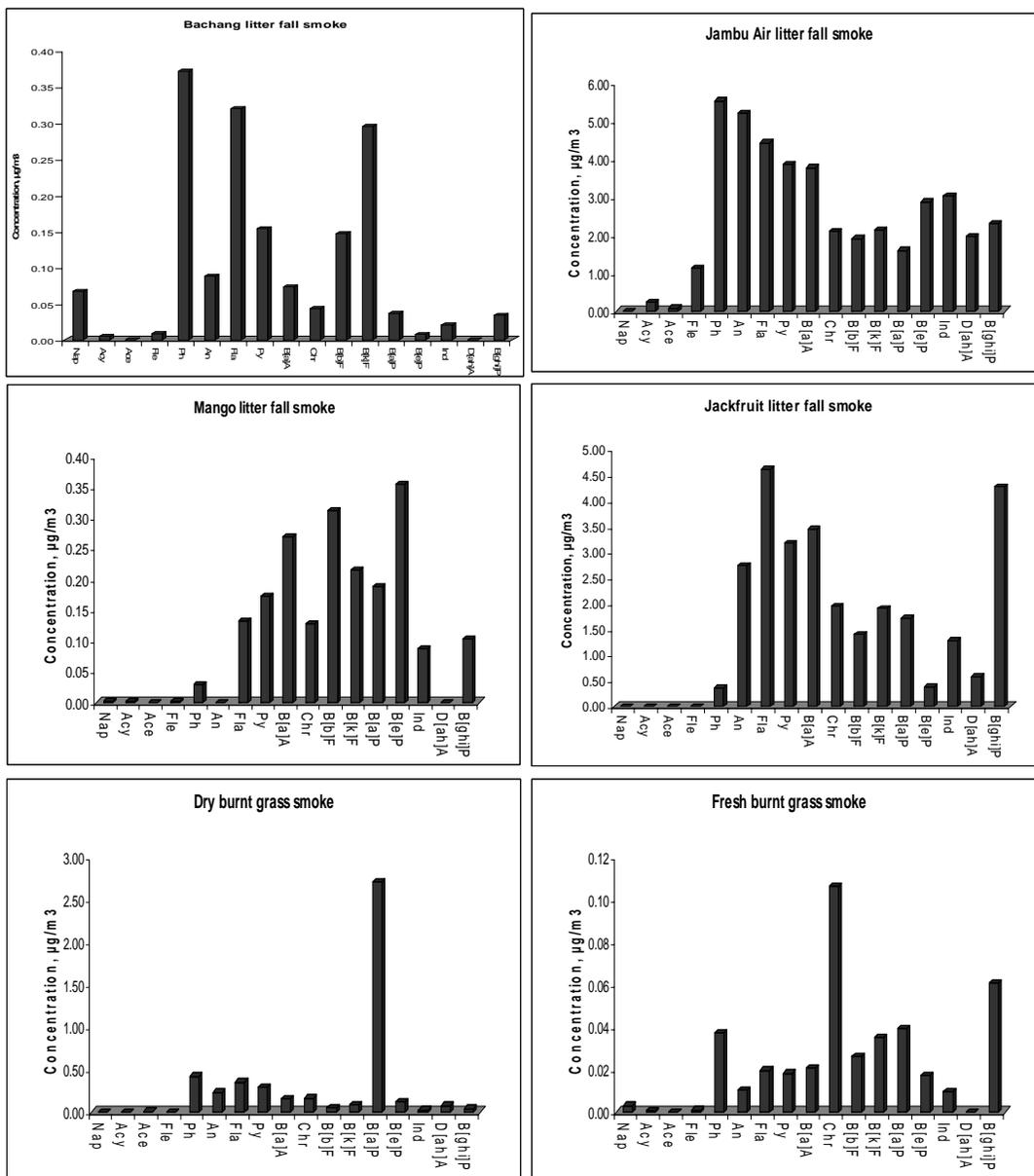


Figure 1: Concentration of individual PAHs in garden waste smoke aerosol samples

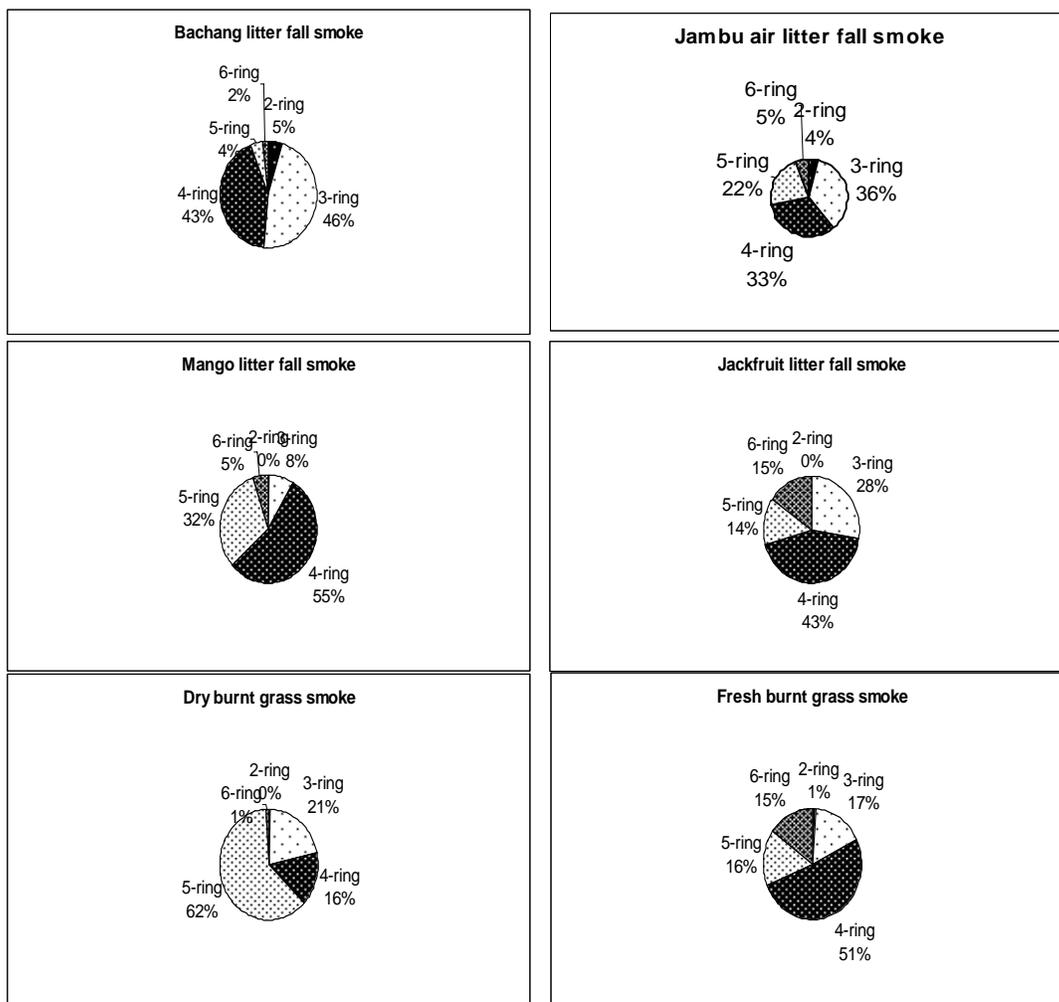


Figure 2: Ring number distribution of PAHs in samples studied

Table 2: Concentration of total identified PAHs (TIP) obtained in smoke samples.

| | Bachang (<i>Mangifera foetida</i>) litter fall smoke | Jambu Air (<i>Eugenia aquea</i>) litter fall smoke | Mango (<i>Mangifera indica</i>) litter fall smoke | Jackfruit (<i>Artocarpus heterophyllus</i>) litter fall smoke | Dry burnt grass (<i>Panicum repen</i>) smoke ^a | Fresh burnt grass (<i>Panicum repen</i>) smoke ^b |
|--|---|---|--|--|--|--|
| Total identified PAHs (TIP, $\mu\text{g}/\text{m}^3$) | 1.67 | 42.2 | 2.00 | 27.8 | 4.75 | 0.41 |

^a with $33.0 \pm 0.84\%$ of moisture content, ^b with $52.9 \pm 1.23\%$ of moisture content

PAHs ratios

PAH ratios have been used to determine PAH sources, classify samples by location and estimate the importance of combustion- and petroleum-derived PAH [15,16]. The diagnostic ratios for PAHs were listed in Table 3. According to Yunker *et al.* [15,16], the ratio value of $An/(An+Ph) > 0.10$ and $B[a]A/(B[a]A+Chr) > 0.50$ indicate the dominance source of combustion in general, whilst ratio of $Fla/(Fla+Py) > 0.50$ is indicating of grass/coal/wood combustion and $B[a]A/(B[a]A+Chr) < 0.50$ indicate low temperature diagenesis process [17]. Ratio values calculated from results obtained in this study shows that ratios of $An/(An+Ph)$ in all smoke aerosol samples ranged from 0.19 to 0.89 (mean = 0.42), whilst $Fla/Fla+Py$ ratios determined range from 0.44 to 0.68 (mean = 0.55) and $B[a]A/(B[a]A+Chr)$ were in the range of 0.16 to 0.68 (mean = 0.54), respectively. Results obtained from this study, in general provide supporting evidence to the usefulness of using these ratios for evaluating possible source of the PAHs in the environment.

Table 3: PAHs ratios for smoke samples.

| Smoke sample | Ratio | | |
|------------------|--------------|----------------|---------------------|
| | $An/(An+Ph)$ | $Fla/(Fla+Py)$ | $B[a]A/(B[a]A+Chr)$ |
| Bachang leaves | 0.19 | 0.68 | 0.63 |
| Jambu air leaves | 0.49 | 0.53 | 0.64 |
| Mango leaves | 0.00 | 0.44 | 0.68 |
| Jackfruit leaves | 0.89 | 0.59 | 0.64 |
| Dry grass | 0.35 | 0.55 | 0.50 |
| Wet grass | 0.22 | 0.52 | 0.16 |

^a - anthracene peak was not detected

Environmental health risk assessment

No threshold for a dose-response relationship appears to exist for PAHs [19] and furthermore, identification of the most dangerous environmental PAHs and their mode of action in producing specific health effects remain uncertain and difficult to quantify the exposure risk precisely. In addition, there is still no reference data or limit suggested for PAHs risk assessment from biomass burning sources. Hence, there is no absolute safe levels that has been established for these compounds. Currently, the assessment of health risk due to inhalatory exposure of PAHs is mostly based on atmospheric concentrations of PAHs using epidemiological results. The development of toxic equivalency factors (TEFs) for PAHs could help to assess more precisely the carcinogenic properties of PAHs components [12]. A complete list of TEFs for PAHs mixture that have been proposed by Nisbet and Lagoy [11] seems to better reflect the actual state of knowledge on the relative potency of individual PAHs in which BaP has been given a TEF of 1.0. TEFs compare the relative toxicity of individual PAHs to BaP and the determined concentration of individual PAHs are then converted to BaP equivalents (BaP_{eq}) concentration based on TEFs.

The BaP_{eq} concentration calculated for all PAHs compounds found in this study were shown in Table 4. Total BaP_{eq} concentration calculated for smoke aerosol samples studied were in the range of $5.60 \times 10^4 \text{ pg/m}^3$ to $4.98 \times 10^6 \text{ pg/m}^3$ with Jambu air litter fall smoke showed the highest concentration and fresh burnt grass smoke showed the lowest total BaP_{eq} . For all samples studied, the carcinogenicity of the PAHs mixture was dominated by BaP which justified the use of BaP as a surrogate compound for PAH mixtures except for Jambu Air litter fall smoke which were dominated by dibenzo[ah]anthracene. The BaP concentration calculated contributed 32.2% to 70.5% of total carcinogenic activity of the PAHs mixture. The result of BaP domination obtained in this study is in agreement with the conclusion of Petry *et al.* [11] and Castellano *et al.* [20] who reported that, in their respective study, the contribution of the carcinogenic potency of BaP alone was found to range between 26% to 67% of the carcinogenic activity of the different PAHs mixture. The NCEA [21] recommended value for the general population average inhalation rate of $15.2 \text{ m}^3/\text{day}$ for men and $11.3 \text{ m}^3/\text{day}$ for women. Inhalation amounts of PAHs per unit time for the smoke aerosol samples studied were then calculated by multiplying the total concentrations of PAHs by individual's respiration rate recommended by NCEA. The PAHs inhalation amount per unit time were shown in Table 5 and results showed the inhalation amount were ranged from $4.3 \times 10^{-3} \text{ } \mu\text{g}/\text{min}$ to $4.45 \times 10^{-1} \text{ } \mu\text{g}/\text{min}$ for men and $3.22 \times 10^{-3} \text{ } \mu\text{g}/\text{min}$ to $3.31 \times 10^{-1} \text{ } \mu\text{g}/\text{min}$ for

women with fresh burnt grass smoke exhibited the lowest and Jambu air litter fall smoke exhibited the highest PAHs inhalation for the both gender, respectively.

Table 4: BaP_{eq} concentration for PAHs compound present in the selected garden smoke aerosol samples using Nisbet and Lagoy (1992) TEFs.

| PAHs | TEFs | Bachang | Jambu air | Mango | Jackfruit | Dry burnt | Fresh burnt |
|---------|-------|---|---|---|---|---|---|
| | | litter fall smoke | litter fall smoke | litter fall smoke | litter fall smoke | grass smoke | grass smoke |
| | | BaP _{eq} (pg/m ³) |
| Nap | 0.001 | 67 | n.d. | 3 | n.d. | n.d. | 3 |
| Acy | 0.001 | 5 | 254 | 2 | n.d. | n.d. | 1 |
| Ace | 0.001 | n.d. | 86 | n.d. | n.d. | 8 | n.d. |
| Fle | 0.001 | 9 | 1142 | 2 | n.d. | n.d. | 1 |
| Ph | 0.001 | 371 | 5529 | 29 | 357 | 425 | 37 |
| An | 0.010 | 880 | 51992 | 0 | 27385 | 2313 | 105 |
| Fla | 0.001 | 320 | 4429 | 133 | 4621 | 352 | 20 |
| Py | 0.001 | 154 | 3868 | 173 | 3183 | 294 | 18 |
| B[a]A | 0.100 | 7330 | 377220 | 27040 | 345290 | 16120 | 2090 |
| Chr | 0.010 | 431 | 20975 | 1280 | 19538 | 1637 | 1062 |
| B[b]F | 0.100 | 14700 | 191930 | 31340 | 139770 | 4860 | 2620 |
| B[k]F | 0.100 | 29510 | 213490 | 21510 | 190620 | 9110 | 3530 |
| B[a]P | 1.000 | 36600 | 1606700 | 189200 | 1722500 | 2706700 | 39500 |
| B[e]P | - | - | - | - | - | - | - |
| Ind | 0.100 | 2070 | 302770 | 8800 | 128060 | 2910 | 950 |
| D[ah]A | 1.000 | n.d. | 1971800 | n.d. | 576400 | 77600 | n.d. |
| B[ghi]P | 0.100 | 3380 | 230740 | 10350 | 427920 | 4520 | 6080 |
| Total | | 95826 | 4982927 | 289861 | 3585643 | 2826849 | 56017 |

n.d.: not detected

-: no TEFs has been suggested

Table 5: PAHs inhalation amount per unit time calculated for all smoke samples

| PAHs inhalation, (µg/min) | Bachang litter fall smoke | Jambu air litter fall smoke | Mango litter fall smoke | Jackfruit litter fall smoke | Dry burnt Grass smoke | Fresh burnt Grass smoke |
|---------------------------------|---------------------------------|-----------------------------------|-------------------------------|-----------------------------------|-----------------------------|----------------------------------|
| Men | 1.76 E-02 | 4.45 E-01 | 2.11 E-02 | 5.87 E-01 | 5.01 E-02 | 4.33 E-03 |
| Women | 1.31 E-02 | 3.31 E-01 | 1.57 E-02 | 2.18 E-01 | 3.73 E-02 | 3.22 E-03 |

Conclusion

The total identified PAHs (TIP) obtained in the smoke aerosols from the selected garden waste ranged from 0.41 µg/m³ - 42.2 µg/m³. Among the five garden wastes, Jambu Air litter fall smoke exhibit the highest TIP, whilst Fresh burnt grass smoke generates the lowest TIP. On the whole, it is observed that all smoke aerosols exhibit PAHs with intermediate to higher molecular weight that is those compounds with more than three rings. The diagnostic ratios of PAHs calculated in this study are consistent with earlier reports [15,16] and lend further support to the usage of PAHs ratio as an indicator of PAHs sources and their origins. All smoke samples

exhibit the presence of B[a]P, which is a signature PAH compound associated with incomplete combustion of biomass materials. The total BaP_{eq} calculated for all smoke aerosols samples ranged from 5.60 E+04 pg/m³ to 4.98 E+06 pg/m³ with BaP contributing 32.2% to 70.5% of total carcinogenic activity of the PAHs mixture. Furthermore, the inhalation of PAHs per unit time calculated were ranged from 4.33 E-03 µg/min to 4.45 E-01 µg/min for men and 3.22 E-03 µg/min to 3.31 E-01 µg/min for women. Conclusively, the practice of garden wastes burning exposed great risks effect of PAHs compound from the smoke aerosols emitted from this practice.

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