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Accumulation Rates and Patterns of Polynuclear Aromatic Hydrocarbons Emitted from Indoor Biomass Fuel Combustion on Soot Deposits

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Abstract

Cancer is a major health concern in Kenya, even amongst the non-smoking group, yet potential causes of the many cancer cases in the region are unknown. Polynuclear Aromatic Hydrocarbons (PAHs) are known carcinogens. Emission and possible accumulation of PAHs from indoor biomass burning in soot deposits has been reported. However, it is not known if the rate and patterns of accumulation of the PAHs vary with the type of biomass used as fuel. This study investigated the emissions and accumulation patterns of PAHs from indoor biomass burning in soot deposits. The study was laid out in a completely randomised block design with fuel biomass types as the main factor and age of the house as the other factor. Soot samples were collected from under the roofs of the houses, extracted, cleaned and analyzed by gas chromatography. The PAHs were identified basing on retention times of authentic PAHs standards and verified by gas chromatographic mass spectral analysis. The concentrations were determined from peak area responses and corrected for recovery. The results of this study showed that the levels of PAHs increased significantly ($P \leq 0.05$) with the household age, indicating accumulation of PAHs resulting from indoor burning of biomass fuel in soot deposits. This study further reports significant interaction ($P \leq 0.05$) in the patterns of accumulation of naphthalene, phenanthrene, fluoranthene, pyrene, and Benzo (a) anthracene resulting from various fuel biomass types. These significant interactions indicate these PAHs accumulate faster when some biomass types are used as fuel than others. The results of this study indicate that use of biomass fuel from some sources pose greater health risks to the population the others.

INTRODUCTION

In Kenya, cancer has been ranked third as a cause of death after infectious diseases and cardiovascular diseases; cancer is estimated to account for about 7% of total national mortality every year [1]. Further, the risk of getting cancer before the age of 75 years in Kenya is estimated at 14% while the risk of dying of cancer is estimated at 12% [1]. However potential causes of these cancer cases among the rural population, in Kenya remain unknown. PAHs are known carcinogens. Recent studies have reported that the population in this region could be exposed to PAHs from indoor biomass fuel burning [2], through drinking of contaminated water [3] and consumption of contaminated fish [4] from Kisumu city Bay in Winam Gulf. But the cancer prevalence levels among populations residing far away from the gulf remain alarmingly high. As a result further investigations into the possible causes of these cancer cases are necessary.

The traditional rural houses in Kenya, and in many other parts of rural Africa, are either round or almost square with low walls, about six feet above the ground surface, fairly high grass thatched roofs and tiny wooden windows and door. As result of this house design it is generally dark indoors even during day time. In addition, the houses have very poor indoor air flow. This is compounded by the fact that residents do not always use seasoned dry wood as source of fuel. A study [5] reported that the differences in emission factors of PAHs, EF (PAHs), from combustion of biomass pellets in comparison with raw fuel burning, were not significant ($p > 0.05$). However, the study estimated that 71% reductions in the total emissions of PAHs could be achieved by replacing the raw biomass fuels combusted in traditional cooking stoves with pellets burned in modern pellet burners [5]. These results indicate that the burning conditions are a major factor in the levels of PAHs emitted from biomass burning.

Biomass burning in these houses is done for several hours each day in open three-stone fire places, most of the times when people are indoors resulting in higher human exposure to smoke pollutants (Figure 1), including PAHs, than from outdoor sources

[6]. The PAHs released to the atmosphere may be removed by wet and dry deposition onto soil, water, and vegetation, where they probably undergo volatilization, photolysis, oxidation or biodegradation [7]. Conversely, the PAHs emitted from indoor biomass fuel combustion in poorly ventilated houses have been reported to accumulate in soot [2]. However, the study [2] did not investigate if the rate and patterns of accumulation of the various PAHs in soot under the roofs was homogeneous across the biomass types (Figure 1).

The objective of this study was to determine if the rate and patterns of accumulation of the various PAHs, resulting from indoor biomass burning, on the soot deposits under roofs of the poorly ventilated households, varied with the predominant biomass type used as fuel.

MATERIALS AND METHODS

Study design and sampling

This study was a continuation of a previous study [2] which reported possible accumulation of PAHs, resulting from indoor biomass fuel burning in poorly ventilated houses, in soot. Thus the study area and the sampling sites in the present study were the same as those reported in the preceding study [2]. Due to variations in human settlements and agricultural activities in Western Kenya, the main sources of the biomass also vary distinctly across the region. The current study was laid out a two factorial completely randomised block design. The main factor was the predominant biomass type used in the sub-region, while the age of the house was the sub-factor. The experiments were set in a 4x3 arrangement with 4 replications. Only houses with grass thatched roofs within the sampling regions were included in this research. Also only houses exclusively using wood or dung as fuel in their entire lifespan for cooking and space warming were used in the study.

The houses with grass thatched roofs were classified into four according to the predominant biomass type used as fuel in the sub-region: Those that predominantly use wood fuel from the indigenous trees species; those that predominantly use wood fuel from exotic soft wood tree species; Those that predominantly use dry shrubs and crop residues; finally those that use dry cow dung as fuel. Houses in each sub-region were further categorized according to the approximate ages of the houses: Less than 5 years, 5-10 years and more than 10 years. This classification therefore formed the sampling units.

Figure 1 Photograph of the traditional cooking fire place inside rural houses in Western Kenya.

Soot samples were collected from under the roofs of four randomly selected houses in each sampling unit into a clean aluminium foil, by hand in gloves, wrapped in black polythene bags, and labelled appropriately. The samples were then refrigerated at temperatures below -4°C until extraction was done. During sampling, protective gloves, goggles and mouth and nose masks were worn.

Experiments

Extraction of PAHs from soot samples and purification: Extraction of PAHs from the soot samples was done in soxhlet apparatus in folded pre-extracted filter papers [8] loaded with 30g dry weight of soot samples, using analytical grade dichloromethane. Each extract was then cleaned on a silica gel packed column using n-hexane as the eluent [9]. Each soot sample was extracted and purified in triplicates and labelled appropriately. The samples were stored in glass vials wrapped in aluminium foil and kept in a deep freezer at temperatures below -4°C at all stages until GC analysis [10].

Calibration and method efficiency: Calibration standards were formulated from the authentic PAHs standards mix stock solution, from Dr. Ehrenstorfer, Augsburg, Germany, in HPLC grade n-hexane and 1µl of the internal standard spiked into 1ml of each of the calibration standards. The calibration curves for each of the 16 PAHs analysed were linear over the concentration range with $R^2 > 0.99$. The standard samples were then stored in glass vials with teflon-lined screw caps, wrapped in aluminium foil and kept in a deep freezer (at <10°C) for periodic calibration.

The relative response factors of the analytes were determined according to the US EPA method 8100/8015 [11]. The peak area responses of the identified analytes were tabulated against their concentration and that of the internal standard, and the relative response factors (RRF) for each of the PAHs calculated using the equation: $RRF = A_S * C_{IS} / A_{IS} * C_S$; Where, A_S = Peak Area for the target PAH measured; A_{IS} = Peak Area for the internal standard; C_{IS} = Concentration of the internal standard; C_S = Concentration of the target PAH

The method recovery study was done using 2, 4-dinitrophenlyhydrazine (2,4-DNPH) as the surrogate standard [8]. The percentage recovery of 2, 4-DNPH was calculated using equation: Percentage Recovery = {[Amount (µg/g) in the spiked sample - Amount (µg/g) in the unspiked sample] / Amount (µg/g) spiked }* 100. The mean percentage recovery rate of 78.20% to 82.33% was obtained and used to correct all the PAHs concentrations calculated for recovery.

Analysis of the samples: The GC-FID analysis of the samples was done according to the methods used by Lalah and Kaigwara [8]. Only 1µL of each sample was injected into the GC for analysis. The mass-spectral analysis of the samples was done according to the US EPA method 8270C [12]. The samples were analyzed using Agilent Technologies 7890A GC-MS system and separation

achieved using a HP-5MS, (5% methyl silox), (30 m × 250 µm × 0.25 µm) column. The injector was set in the splitless mode with a total flow rate of 10.2 mL/min, septum purge flow rate of 3 mL/min and a pressure of 8.8271 psi using N_2 as the carrier gas. The oven equilibration time was 1min. The oven temperature was maintained at 35°C for 5 min, and then increased to 280°C at the rate of 10°C/min and maintained there for 10.5 min. Finally the temperature was increased to 285°C at the rate of 50°C/min and maintained there for 9.9 min. The heater temperature was set at 250°C. Only 1µL of sample was injected for analysis.

Characterisation and confirmation of the PAHs: Characterisation of the PAHs was based on the retention times of the peaks in the GC-FID chromatograms obtained [8]. The PAHs were identified by comparing peak retention times on the chromatograms of authentic standards with the retention times indicated on the gravimetric certificate supplied with authentic standards [8]. The PAHs in the extracts were then identified by comparing the peak retention times in the chromatograms of the extracts, with those in the chromatograms of the authentic standards. The samples were also analysed by GC-MS and the retention times of the analytes in the samples in GC-MS analysis matched with the retention times of the PAHs in the authentic standards mix for further identification.

The spectra of the identified analytes were generated and confirmation of identity of the analytes was done according to US-EPA method 8270C [12]. This involved calculation, by the data system analysis, of a similarity index, match factor or purity between the unknown spectrum and library (reference) spectra using NIST/EPA/NIH MASS SPECTRAL LIBRARY (NIST 05) and NIST MASS SPECTRAL SEARCH PROGRAM Version 2.0d.

Quantification of PAHs: Those samples whose analyze concentrations were above the linear range were diluted and the dilution factor (D) noted [8]. Quantification of the PAHs concentration was then done using the internal standard method, according to the US EPA method 8100/8015 [11]. The analyte concentrations were calculated using the equation: Concentration (µg/g) = $A_S * W_{IS} * D * F / A_{IS} * RRF * W_S$; Where, A_S = Peak Area for the analyte in the sample; A_{IS} = Peak Area for the internal standard in the sample; W_{IS} = Amount (µg) of internal standard (dodecane) added to the sample; D = Dilution factor if dilution was made on the sample prior to analysis. If no dilution was made, D = 1, dimensionless; W_S = Weight of soot extracted, in g, dry weight; F = Factor if the samples are split in half for analyses. All the samples had a split factor (F) of 25 since only 2mL of the 50mL extracted were taken for clean-up. RRF = relative response factor for the analyte (section 2.2.2). All the concentrations were corrected for recovery (section 2.2.2)

Statistical analysis of data: Separation of means and analysis of variance (ANOVA) of the data was done using the MSTAT-C programme for a two factor randomized complete block design. Statistical analysis was based on a 4x3 layout. The concentrations of naphthalene, phenanthrene and Dibenzo (a,h) anthracene in some soot samples were below the minimum detection limit (MDL). In such cases a 3x3 arrangement was used in statistical analysis. Analyte concentration below the MDL was assumed to have a concentration of zero, while PAHs whose concentration was above the detection limit in less than 20% of the samples were excluded from statistics. These include benzo(k)fluoranthene, benzo(b)fluoranthene and indeno(1,2,3-c,d)anthracene.

The data was then subjected to the ANOVA F-test ($P \leq 0.05$) [13,14] to test the hypothesis. Pair-wise comparisons of the means were done using the LSD test [14] to determine if the variation in the mean concentration of each PAH in the various biomass types and in different house age groups was significant. The interactions in the patterns of accumulation of the PAHs from various wood types with time were also assessed.

Data transformation: Analysis of variance of the data in the original scale gave relatively large variation coefficients. The data was then subjected to the logarithmic transformation, $X^1 = \ln (X+1)$: where, X is the concentration of PAH in µg/g of soot and ln is the natural logarithm [14,15]. This was to achieve homogeneity in variance of the experimental errors and to ensure that the errors are normally distributed [13-15].

The data in the logarithmic scale was then subjected to ANOVA, with MSTAT-C programme, for a two factor randomized complete block design to separate the means and further subjected to the F-test ($P \leq 0.05$) [13, 14) and the LSD-test ($P \leq 0.05$) [2] as the data in the original scale. The results from the comparison of means in the transformed data were then used to make inferences about the data in the original scale [2,14].

RESULTS AND DISCUSSION

Identity of PAHs on the soot deposits

Only the sixteen US EPA priorities carcinogenic PAHs were investigated. Naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo (a) anthracene, chrysene, benzo (a)pyrene, Dibenzo (a,h) anthracene, benzo (b) fluoranthene, benzo (k) fluoranthene and indeno (1,2,3-c,d) anthracene were identified in soot samples using retention times from soot samples by GC-FID analysis and confirmed by GC-MS spectra by marching the GC-MS spectra of each of the analyte in the sample extracts with the spectra in the GC-MS internal reference library. These findings were in agreement with those of an early study [16] which suggested the possibility of surface adsorption of lower molecular weight PAHs on to particulate matter.

Variations in concentrations of PAHs with biomass types and age of houses

Benzo (b) fluoranthene, benzo (k) fluoranthene and indeno (1,2,3-c,d)anthracene were not included in the analysis of variance since they were only quantifiable in less than 20% of all the samples analysed. The variations in the concentrations of twelve PAHs in soot from houses, of various ages, that use various biomass types were therefore analysed.

Factorial analysis of variance of the data gave relatively high coefficients of variation (CV %); an indication of heterogeneous variance of the experimental errors. This high variability within experimental units could have resulted from the grouping of the houses in large age clusters: 0-5 years, 5-10 years and more than 10 years. For instance, in the cluster 5-10 years, houses which are 5 years old may have been sampled with those which are

9-10 years old as replicates. Similarly, in the cluster more than 10 years old, houses which are 11years old may have been sampled with those which are more than 18 years old as replicates. The high variability might have also been caused by variation in composition of the different types of biomass, used as fuel, which affects the oxidation state of the biomass [17], and probably the rate of combustion of each of the various biomass types, as well as the identity, composition and levels of the PAHs emitted. As a result some biomass types emitted much higher levels of PAHs than others over the same period of time.

In this study, the various PAHs concentration range within replicates showed a linear relationship to the mean concentrations of the PAHs in the replicates, that is, the range increased proportionally with the mean. This was an indication that the experimental errors had heterogeneous variance that is functionally related to the mean [2]. One of the assumptions of parametric statistics is that the data being compared have constant/equal variance, that is, experimental errors in the data have common or homogenous variance [14,15]. Hence two means cannot be compared when the variances are significantly different. The second assumption is that the experimental errors are normally distributed [14,15]. Hence, transformation of the data was necessary to achieve homogeneity in the variance of the experimental errors and to normalize their distribution.

When the data was subjected to the natural logarithmic transformation and subjected to ANOVA, the resulting data showed much lower coefficient of variation percentages (Table 1); an indication that the variance of experimental errors in the transformed data was homogenous and the errors normally distributed. Table 1 shows the variation of the logarithm transformed data due to biomass type and house age.

Variation of PAHs concentration with age of house

The findings o this study showed that the levels of PAHs in the soot deposits increased with increase in the age of the houses. The mean concentrations range (in µg/g of soot) of the PAHs in soot samples from the traditional rural houses were; 0.985 – 14.775µg/g naphthalene, 5.342 – 19.843 µg/g acenaphthylene, 17.969 – 87.882 µg/g acenaphthene, 3.580 – 36.224 µg/g fluorene, 3.477 – 10.807 µg/g phenanthrene, 8.505 – 66.517 µg/g anthracene, 6.950 – 23.035 µg/g fluoranthene, 15.313 – 69.517 µg/g pyrene, 5.761 – 56.560 µg/g benzo(a) anthracene, 13.382 – 38.625 µg/g chrysene, 11.475 – 75.725 µg/g benzo (a) pyrene and 1.709 – 4.928 µg/g Dibenzo (a,h) anthracene. The trend in concentrations of benzo (b) fluoranthene, benzo (k) fluoranthene and indeno (1,2,3-cd) pyrene could not be established because they were above the minimum detection limit in less than 20% of the samples. These findings show that soot deposits under the roofs of poorly ventilated houses is a major repository for PAHs, including the carcinogenic ones, emitted during residential burning of biomass fuel.

The levels of naphthalene, acenaphthylene, acenaphthene, fluorene, anthracene, fluoranthene, pyrene, phenanthrene, benzo(a)anthracene and benzo (a) pyrene in houses more than 10years old were significantly higher ($P \leq 0.05$) than those in houses which were 0 – 5 years old (Table 1), while the levels of naphthalene, fluorene, anthracene, benzo (a) anthracene, pyrene and benzo (a) pyrene in houses of ages between 5 – 10 years were significantly higher ($P \leq 0.05$) than those in houses of ages between 0 – 5 years (Table 1). Though the levels of chrysene and Dibenzo (a,h) anthracene increased with the age of the houses, the differences between their mean concentrations in the houses of the various age groups were not significant at $P \leq 0.05$ (Table 1). In general, the mean concentrations of various PAHs on the soot deposits under the roof of the grass thatched rural houses were found to increase ($P \leq 0.05$) with the age of the houses; An indication that the PAHs emitted from indoor fuel biomass burning associate with, and accumulate on the soot deposits under the roofs.

The results of this study indicate accumulation of PAHs indoors, including the lower molecular weight ones (MW ≤ 202), usually formed in gaseous phase [18], in the particulate phase. This implies that the soot deposits underneath the roofs of the traditional rural houses act as an indoor reservoir for PAHs, by

Table 1: Variations in levels (Ln (X+1) µg/g of soot) of PAHs with age of households.

PAH	0-5 Years	5-10 Years	> 10 Years	CV %	LSD (P ≤ 0.05)	Interaction
Naphthalene	0.524	1.562	2.390	38.35	1.005	0.990
Acenaphthylene	1.386	2.273	2.722	32.21	1.042	NS
Acenaphthene	2.071	3.138	3.447	26.71	1.173	NS
Fluorene	1.053	2.423	2.907	15.52	0.503	NS
Phenanthrene	1.457	1.604	2.324	31.06	0.829	1.202
Anthracene	1.648	2.957	3.376	26.10	1.056	NS
Fluoranthene	1.593	2.011	2.749	23.58	0.759	0.864
Pyrene	2.287	2.990	3.729	11.99	0.548	0.623
Benzo(a)anthracene	1.480	2.544	3.221	20.92	0.769	0.874
Chrysene	1.901	2.476	3.369	37.93	1.490	NS
Benzo(a)pyrene	1.841	2.707	3.405	17.61	0.710	NS
Dibenzo(a,h)anthracene	0.747	0.765	1.455	59.82	NS	NS

Abbreviations: Ln: Natural Logarithm; LSD: Least Significant Difference; CV%: Coefficient of Variance Percentage; NS: Not Significant

accumulating both particulate phase and gaseous phase PAHs formed as a result of continuous burning of wood and dung by the rural population as fuel, for cooking and space warming, over the years. Accumulation of PAHs has also been reported to exhibit a tendency to accumulate in sediments where they may be present at levels thousands of times higher than those in the overlying water [19]. Similarly, accumulation of PAHs in snow-packs during winter, especially in the urban environment, as a result of wet deposition process has also been reported [20]. Recently, a study reported accumulation of PAHs from outdoor sources in urban areas, predominantly phenanthrene, fluorene, fluoranthene, and pyrene, on window surfaces in Guangzhou and Hong Kong cities of China [21].

Biomass fuel, wood and dung, burning indoors is done daily in open fire places releasing the combustion products, including PAHs, inside the poorly ventilated houses. As the smoke, which includes PAHs, slowly finds its way through the grass thatched roofs, the PAHs particles physically adsorb on to the soot deposits [16]. Fate process for PAHs such as photolysis and biodegradation either do not occur at all or are severely impeded by the dark and dry indoor conditions of these houses. This implies that the rate of PAHs deposition on the soot deposits under the roofs of the traditional rural houses is faster than their rate of removal through any of the fate process, leading to accumulation.

The vapour pressure of the lower molecular weight PAHs range from naphthalene, 10.4 Pa, fluoranthene, 1.2 x 10^{-3} Pa to chrysene, 8.4 x 10^{-5} Pa (Table 1). The health problem results from the probable vaporization of these adsorbed PAHs, which include lower molecular weight PAHs (MW < 202.3) usually formed in vapour phase [18], due to the high indoor temperatures, as a result of wood and dung burning open fires places. This, in addition to the daily emission of PAHs directly from the burning biomass during cooking, may lead to higher continuous human exposure to higher vapour phase PAHs concentration, including the highly carcinogenic ones, indoors than outdoors or in those houses using cooking stoves with ventilation by flues, hoods or chimneys and improved combustion efficiency, even at times when no cooking is taking place. The health risk problem is compounded by the observation that most of the cooking houses also serve as the living houses yet air movement indoors is very low due to poor ventilation.

The effect of replacing open pit stoves by improved stoves equipped with a chimney has been reported to significantly reduce exposure to PAHs emitted during indoor burning of biomass fuels [22]; after the installation of the new stoves, the median reduction of 10 hydroxylate PAH metabolites (OH-PAHs) in urine samples from women tasked within the households was 19%-52% [22]. The results of the current study point to a very high probability of continuous human exposure to much higher levels of both vapour phase PAHs, and particulate phase PAHs, through inhalation of falling fine soot particles, in these rural houses, even during times when no cooking or space warming is taking place, than outdoors. While this study can not conclusively establish a relationship between these relatively high indoor levels of carcinogenic PAHs, emitted during burning of biomass as fuel, and the many cases of cancer patients diagnosed in the region, the possibility of a link between the two cannot be simply ignored.

Variation in the rates and patterns of accumulation of PAHs on soot deposits with predominant biomass type used

The results of this study show that continuous burning of each of the biomass types considered in the study, as fuel in open fire places inside the traditional rural grass thatched houses, leads to accumulation of PAHs on the soot deposits under the grass-thatched roofs. Significant interaction in accumulation patterns of the various PAHs, on the soot deposits, resulting from burning various biomass types; wood from perennial indigenous trees and fast-growing exotic trees, shrubs and crop residues and dry cow dung, was set at $P \leq 0.05$. The interaction in the patterns of accumulation of naphthalene, phenanthrene, fluoranthene, pyrene, and benzo (a) anthracene, from predominantly burning the various biomass types, was significant ($P \leq 0.05$) (Table 1). This means that these PAHs accumulate on the soot deposits faster when some biomass types are predominantly used than others. This indicates that the pattern of accumulation of each of these PAHs vary with variation in biomass type predominantly used for cooking and space warming.

Previous studies [22,16] on the mechanisms of individual PAHs, including those emitted from biomass burning, association with particulate matter gave an inconsistent trend. This pointed to multiple mechanisms of PAH-particle associations, including adsorption and absorption. The results of the study [23] indicated that the surface areas of particles seemed highly sensitive to the PAH mass, which affects both adsorption and absorption processes. During PAHs distribution, higher and lower molecular weight PAHs preferentially segregate to fine particles and coarse particles respectively [23,24]. This variation in PAH-particle association mechanisms with particle size and PAH mass probably causes variation in the accumulation patterns of some of the PAHs emitted from burning various biomass types on soot deposits under the roofs of the traditional rural houses.

The interaction in the patterns of accumulation of acenaphthylene, acenaphthene, fluorene, anthracene, chrysene, benzo (a) pyrene and Dibenzo (a,h) anthracene were not significant at $P \leq 0.05$ (Table 1). These results indicate that the accumulation patterns of these PAHs from biomass burning in open fire places in the traditional rural houses is homogeneous across all the biomass types considered in the study.

Biomass burning inside the rural houses is done in poorly ventilated conditions. Thermal breakdown and alteration of the cellulose polymer and steam-stripping distillation are among the particle formation mechanisms of biomass combustion [25]. The fuel type and combustion conditions therefore influence the particulate matter mass distributions [26]. Higher temperatures likely limit particle size partitioning of organics, including soot particles, lessen agglomeration, and shift the mass distributions to smaller diameters. High ventilation can also help to encourage and sustain an intense flaming condition, which in turn produces a large concentration of smaller diameter particles [23]. Similarity in the indoor biomass burning conditions probably has an effect on the distribution in the size of the particulate matter, emitted during biomass burning, which has a homogenous effect, across all the biomass types, on the pattern of accumulation of some of the PAHs on the soot deposits under the roofs.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study showed the PAHs emitted from indoor biomass fuel combustion accumulated on soot deposits under the roofs of the houses.

This study further revealed significant interaction in the patterns of accumulation of naphthalene, phenanthrene, fluoranthene, pyrene, and benzo (a) anthracene in the soot deposits. This means that these PAHs accumulated faster when some biomass fuels are used than others, in the order; dung ≥ perennial indigenous trees ≥ exotic trees ≥ shrubs and crop residues. These results indicate that the health risks posed these PAHs emitted from indoor biomass combustion are greater when some biomass types are used than others. However, the accumulation patterns of acenaphthylene, fluorene, acenaphthene, anthracene, benzo (a) pyrene, Dibenzo (a,h) anthracene and chrysene, did depend on the biomass type used.

The fight against cancer must shift from curative to preventive care. It is therefore necessary for further studies to be carried out to characterize specific tree species used as sources of biomass fuel according to the rate of emission of PAHs when burnt under these conditions. This will help the population in choosing sources of biomass fuels that emit lower levels of PAHs.

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