Determination Of Benzo[A]Pyrene Levels In Cashew Nut Shells And Kernels Processed Using Different Traditional Methods And Fuel Sources From Kilifi County, Kenya

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Abstract: The aim of this study was to determine BaP levels generated in cashew nut shell and kernel samples processed from two methods (roasting and sun-drying), roasted separately using different fuel sources namely: pine, mango and coconut husks and shells, when roasted for different durations using the same fuel source and the effect of the shell. In the roasted shell samples using different fuel sources, pine generated the highest BaP concentration (12.918±5.270µg/kg), followed by mango wood (5.842±2.307µg/kg) while coconut shell and husk mixture generated the least BaP (2.298±1.664µg/kg) in the cashew nut shell samples. The BaP concentrations were below the detection limit in all the 90 roasted cashew nut kernels samples. BaP levels were also below the detection limit in the 30 shell and 30 kernel samples (from 3 batches) processed through sun-drying method. BaP was not detected in all 36 roasted cashew nut kernel samples collected from the roadside vendors from the 3 towns. This could be attributed to the shell leading to 100% BaP reduction by preventing pyrolysis of the kernel and deposition of BaP by the smoke from the fuel source. The BaP non-detection in the kernel samples meant they were below the EU Maximum residual limit of 5µg/kg hence safe for human consumption.

Keywords: Benzo[A]pyrene, Cashew nuts, Coconut, Mango, Pine.

1. Introduction

Benzo[A]pyrene (BaP) is a member of 16 polycyclic aromatic hydrocarbons (PAHs) that are classified as carcinogenic by the United States Environmental Protection Agency (USEPA). BaP has the highest carcinogenic potency and is the most studied species of the 16 PAHs. BaP has been upgraded from a group 2B (possibly carcinogenic to humans) to group 1 (carcinogenic to humans) by the International Association for Research on Cancer (IARC) [5]. The European Union (EU) has passed a legislation (EC) No. 2008/2005 setting a Maximum Recommended Limit (MRL) for PAHs of 5µg/kg in foodstuffs. Majority of the population are exposed to carcinogens through dietary exposure [3]. Certain food processing techniques like smoking, barbecuing, roasting, grilling, drying, baking, and frying generates BaP on the food [4]. In Kenya, 90% of cashew nuts are produced in Coastal region with 3 counties Lamu, Kwale and Kilifi the major producers. The cashew nut tree produces an edible kernel that is enclosed in a hard outer shell hence a processing method is needed for kernel extraction. There are two common traditional cashew nut processing methods namely roasting and sun-drying methods. Both the two processing methods generate BaP in food. BaP in roasted foodstuffs can be generated through three mechanisms. The first mechanism is pyrolysis of the foodstuff's organic compounds of fats, carbohydrates and proteins at a temperature above 200^0C. The second mechanism is the dripping of lipids from the food into the fuel which generate BaP that are carried by the smoke and deposited on the food surface. The third mechanism involves incomplete combustion of the fuel source that generates BaP which are deposited on the food surface by smoke [5]. Sun drying of foodstuffs is also known to produce traces of PAHs due to atmospheric deposition from PAHs-infested air or through photochemical reactions on the dried food surface [14]. There are three combustion stages in a wood fuel source (devolatilization, flaming and smoldering). The 3 combustion stages are reported to generate varying BaP levels in foodstuffs [8], [20].

Both the two traditional processing methods are reported to generate varying BaP levels in food. Therefore, there is a need to compare BaP levels in cashew nut samples processed by the two methods to determine a processing method that will generate the least BaP levels to consumers. Previous studies show that different fuel sources generate varying BaP levels in roasted foodstuffs. There is a need to determine which of the 3 fuel sources will generate the least BaP levels in roasted cashew nuts samples. The three combustion stages (devolatilization, flaming and smoldering) of wood are reported to generate varying BaP concentrations. People would begin roasting cashew nuts without knowing the ideal combustion stage to begin the roasting process. There is a need to compare the three combustion stages of a wood fuel with respect to BaP levels generated in cashew nuts samples so as to determine the stage that will produce the least BaP levels. Cashew nuts contain the edible kernel that is enclosed inside a hard inedible shell. Studies have reported that a presence of a barrier between a foodstuff and a fuel source during roasting or ambient air during sun-drying leads to reduced BaP levels generated in the foodstuff [6],[14]. It is therefore important to determine the BaP levels of both the cashew nut shell and kernel so as to ascertain the barrier effect of the inedible shell to BaP generation in the edible kernel during the roasting and sun-drying process. The results of this study will help to provide information to the vendors, consumers and relative agencies on presence and quantities of BaP in cashew nuts sold in Kilifi County. This project sought to provide information on the better method, safer fuel source and combustion stage that will lead to minimal dietary exposure of PAHs to cashew nuts consumers. The results can be used for processing other foodstuffs (roasted meat and vegetables) so as to minimize BaP levels to consumers.

2. Materials and Methods

A. Sampling

Twelve cashew nut vendors were selected randomly in Kilifi County markets (4 vendors in Kilifi town, 4 vendors in Malindi town and 4 vendors in Mariakani town). From each vendor, three 100g sachets of roasted cashew nuts were bought and sent to Kenyatta University labs. The sampling procedure involved sample collection once a week for 3 weeks to obtain 3 roasted cashew nut samples from each vendor. A total of 36 roasted cashew nut kernel samples were collected. 20kg of unprocessed cashew nuts each were bought from 3 farmers in Kilifi (Mavueni), Malindi (Gede) and Mariakani (Kokotoni) towns to obtain a total of 120 samples (500g sample) of unprocessed cashew nuts. From the 120 cashew nut samples obtained, 30 were processed using the sun-drying method and the rest samples were sub-divided into 30 samples that were each processed through open-roasting using pine, mango wood and coconut husks and shells mixture as the fuel sources. From the above 30 sun-dried cashew nut samples, 60 samples comprised of 30 shells and 30 kernels samples were collected. Therefore, 180 samples (90 shells and 90 kernels) were obtained from the 90 samples processed through open-roasting method using the 3 fuel sources. Therefore, a total of 270 samples (30 roasted cashew nut kernels from vendors, 120 cashew nut shells and 120 cashew nut kernels samples) were analyzed in this study. Measurements of the samples was done in triplicate using HPLC-UV.

B. Roasting processing procedure

A ratio of 1:1 coconut husks and shells mixture by amount, softwood (Pine) and hardwood (mango wood) were used separately as the fuel sources. Pine was purchased from a local firewood shop whereas mangowood and coconut shells and husks were collected from a farm in Malindi town. They were all dried in the sun for two weeks. Appendix 1, 2, 3 and 4 shows images of coconut shells, husks and mango wood fuel sources respectively. The 500g sample of cashew nuts were roasted separately using the roasting processing method as described by Azam-Ali and Judge (2001) using the coconut husk and shells mixture, pine and Mango as the fuel sources. The nuts were placed in a steel pan in contact with the fire until the cashew nut shell liquid ignites and then after 1 minute, dowsed in the sand. Three kilograms of each fuel source roasted a batch made up of ten 500g samples of cashew nuts consecutively without fuel addition and each roasted batch time was measured using a digital stopwatch. Ten galvanized steel pans were made measuring 30cm by 60cm by 8cm so as to be able to roast cashew nuts samples consecutively without using the same pan. Holes were pierced in bottom of the ten galvanized steel pans to enable flames from the fuel source to be in contact with the cashew nuts for the ignition of the CSNL. A constant distance to the fire was maintained for every batch by using only one traditional firewood place made of 3 similar size bricks of measurements 30cm long by 7.5cm wide by 15cm high. The roasted nuts were opened by wooden batten to obtain the kernels and the shells which were then separately homogenized, and 100g of the homogenized samples were separately packaged in clean containers. Each fuel source was used to roast a ten-500g samples batch that generated 10 kernels and 10 shells samples. A total of 180 samples (90 cashew nut kernels and 90 cashew nut shells) were obtained from open roasting processing method using the three fuel sources.

C. Sun drying processing procedure

Ten 500g sample batches of cashew nuts collected thrice from the 3 farms in Kilifi (Mavueni), Malindi (Gede) and Mariakani (Kokotoni) were processed using the sun-drying method as described by Azam-Ali and Judge (2001). The cashew nuts batches were dried in the sun for five days to make the shell brittle. The shell was removed using a knife to obtain the kernel samples which were further dried in the sun for an additional three days to achieve low moisture content making them more palatable. A 100g sample of both the kernel and shell were extracted from the cashew nut samples and were packaged in clean containers. From each of the three ten-500g sample batches, 10 kernel and 10 shells samples of 100g were obtained. A total of 60 cashew nut samples (30 shells and 30 kernels) were obtained from the traditional sun-drying processing method.

D. Chemical and Reagents

HPLC grade. dichloromethane (DCM) (99.5%), n-hexane (99.5%), ethanol (99.5%), cyclohexane (99.7%), anhydrous sodium sulphate (99.0%), silica gel 230-400 mesh particle size, n-pentane (99.5%), high purity nitrogen (99.9%) and acetonitrile (99.5%) were obtained from Merck (Darmstadt, Germany). Benzo[A]pyrene standard (≥96% (HPLC grade)) was obtained from Sigma (St. Louis, USA) through Pyrex East Africa (Nairobi).

E. Standard preparation

A 99.9% pure Benzo[A]pyrene sample standard was sourced from Sigma Ltd through their agent Pyrex East Africa, Nairobi, Kenya. BaP stock solution was prepared by accurately weighing 1 mg of the BaP standard and dissolved in 1000ml acetonitrile. External reference standard solution was prepared by diluting the BaP stock solution at different concentrations (50, 40, 30, 20 and 10µg/kg). The standard solutions were protected from light exposure by storing it in amber colour volumetric flasks and stored at 4^{0}C.

F. Benzo[A]pyrene extraction and analysis

This extraction procedure was based on the research by Kumari *et al*. (2012). Each 100g cashew nut sample was homogenized by shaking for one minute in a beaker, and 15g of the homogenized portion of the kernel sample was ground in a pestle and mortar while the shell samples were ground in a commercial blender (Von CHB952R HP3) into a powdered form. The crushed powdery cashew nut sample was then added into 150 ml de-ionized water and shaken for 8 hours in a horizontal shaker at 250rpm. The diluted sample was transferred into a 250ml separating funnel and extracted thrice with 25ml n-hexane. 2ml ethanol was added to the n-hexane combined extracts for de-emulsification. The extract was dried under a gentle stream of nitrogen gas and re-dissolved in 2ml cyclohexane. Purification of the sample's extract was done using column chromatography to remove interferences from other compounds. The chromatographic column was prepared with 6g of activated silica gel (activated by heating the silica gel overnight at 150^0C) sandwiched between two 0.5g anhydrous sodium sulphate. 10ml n-pentane was used to wash the column and before the exposure of the anhydrous sodium sulphate layer to air; the 2ml cyclohexane extract was transferred to the column. The sample vial was washed with additional 2ml cyclohexane and transferred onto the column. 10ml n-pentane was used for elution of the aliphatic portion of the sample, and the portion was then discarded. The aromatic fraction was eluted with 15 mL mixture of DCM: n-pentane (2:3, v/v). The whole eluent was collected, evaporated to dryness under a gentle gas stream of nitrogen, and the final volume was made up with 0.5mL acetonitrile, filtered through 0.45µm sized filter. An aliquot of 50µL was injected and analyzed by HPLC system. A 2014 shimadzu HPLC UV-VIS composed of a SIL-20A HT autosampler coupled with a CTO-10AS VP column oven and a 3 channeled DGU-20 A3R degassing unit. The detector was a SPD 20A UV-Visible detector with a deuterium lamp having a wavelength range of 190-700nm and an operating temperature range of 4^oC to 35^oC. A column thermostat (Waters) was used to maintain the column temperature at 27^oC during the analysis. Separation of PAHs was carried out with a mobile phase composed of 100% acetonitrile in isocratic mode at a flow rate of 1 ml/min with a run time of 10 min.

G. Benzo[A]pyrene quantification

BaP in the samples was confirmed by the retention times and quantification of the samples peak area ratios versus calibration of BaP standard solutions of different concentrations. Miller and Miller (1993) guidelines was used to calculate detection limits for Benzo[A]pyrene then the resulting values were converted to ppb of BaP of the sample through the division of the results obtained by the mass of the sample analyzed.

3. RESULTS AND DISCUSSION

1. Roasting times for cashew nuts batches from different towns using the 3 fuel sources.

Table 4.1 shows the recorded roasting time for each of the ten 500g samples in a batch collected from Mavueni (Kilifi), Gede (Malindi), Kokotoni (Mariakani), respectively, (A, B, C, D, E, F, G, H, I, J) that were processed through roasting method using pine, mango and coconut shells and husks.

	PINE			MANGO			COCONUT SHELLS AND HUSKS		
	KILIFI	**MALINDI**	**MARIAKANI**	**KILIFI**	**MALINDI**	**MARIAKANI**	**KILIFI**	**MALINDI**	**MARIAKANI**
A	16.0500	11.7333	13.3833	12.3833	11.3000	12.6833	13.6667	17.0500	15.3500
B	6.2333	5.6333	6.6167	5.6833	4.9333	5.6000	5.5500	7.4667	7.2333
C	5.7167	5.8167	5.6000	5.5500	5.1500	5.4167	5.3000	7.2333	5.7667
D	5.1333	5.1167	4.9167	5.1000	5.2667	5.1500	5.6667	6.8000	4.1667
E	5.5333	5.5000	4.7000	4.9833	4.8333	5.0167	5.0500	6.4500	3.9333
F	5.2833	5.1833	4.4000	5.2667	4.7166	5.2667	4.6333	6.4833	3.8167
G	5.8167	5.7167	4.9500	5.4667	4.4333	4.8833	4.2833	6.1333	4.3833
H	5.9333	5.3833	5.4833	5.3833	4.3833	5.6500	4.7000	6.8833	5.0167
I	5.8500	5.5667	6.2833	5.7833	5.1667	5.9667	5.0167	7.3167	5.6333
J	6.2167	6.0667	7.1500	7.5833	5.8166	7.2167	5.6333	8.1000	7.2667
Total	68.6667	61.8333	59.1667	64.1667	56.0000	62.2167	59.5000	80.0000	65.8333
Mean	5.8667 ± 3.3500[a]	6.1833 ± 1.9667[a]	5.9167 ± 2.7500[a]	6.4167 ± 2.2167[b]	5.6000 ± 2.0500[b]	6.2833 ± 2.3500[b]	5.9500 ± 2.7500[c]	8.0000 ± 3.2333[c]	6.5833 ± 3.4333[c]

Table 1 Roasting times (seconds) for cashew nuts samples using the three fuel sources

From Table 1, sample A had the highest roasting times for all the three batches roasted by all the three fuel sources. This is because the sample A underwent roasting during devolatilization phase (initial heating and wood drying) and also the flaming stage (roasted in the first two combustion stages) that led to its longest roasting time. In contrast, the later sample batches were roasted during one of the remaining combustion cycle duration (flaming and smoldering). From Table 1, the roasting time for the three batches showed a decreasing trend then increased with the last samples in a batch. This could be attributed to the fact that the last samples were roasted during the smoldering stage compared to the earlier samples roasted during the flaming stage. The characteristic temperature released during smoldering (930^{0}C) is lower than those in flaming stage (1500^{0}C) and also the heat of combustion produced during wood combustion is about 15-20 MJ/kg, about two-thirds of which is released during flaming stage and the rest during smoldering (Bartlett *et al*., 2018; Kim *et al*., 2013). This meant that samples roasted during flaming stage had shorter roasting times due to higher temperatures and heat of combustion than samples roasted during smoldering stage.

H. Benzo[A]pyrene levels in cashew nut shells and kernels samples roasted using the 3 fuel sources

The mean BaP concentrations for the 180 samples (90 shells and 90 kernels) collected from 3 farms from the 3 towns (Mavueni, Gede and Kokotoni from Kilifi, Malindi and Mariakani towns, respectively) that were processed through roasting method using the 3 fuel sources are presented in Table 4.2.

	Kilifi town		Malindi town		Mariakani town		Mean	
	Shells	Kernels	Shells	Kernels	Shells	Kernels	Shells	Kernels
Pine	9.635±0.807^{b}	N.D.	20.203±1.285^{c}	N.D.	8.916±0.570^{a}	N.D.	12.918±5.270	N.D.
Mango	4.339±0.648^{a}	N.D.	8.710±0.819^{b}	N.D.	4.478±1.570^{a}	N.D.	5.842±2.307	N.D.
Coconut shells and husks	0.884±0.564^{a}	N.D.	4.465±0.639^{b}	N.D.	1.224±0.825^{a}	N.D.	2.298±1.664	N.D.

Table 2: The mean BaP concentrations for the 180 samples (90 shells and 90 kernels) collected from 3 farms from the 3 towns (Mavueni, Gede and Kokotoni from Kilifi, Malindi and Mariakani towns, respectively) that were processed through roasting method using the 3

Shells samples open-roasted using pine had the highest mean BaP concentration of 12.918±5.270µg/kg with Malindi batch had the highest average BaP level of 20.203±1.285µg/kg, followed by Kilifi batch with a mean BaP concentration of 9.635±0.807µg/kg, while Mariakani batch had the lowest mean BaP level of 8.916±0.570µg/kg. Shells samples roasted using mango wood (30 samples comprised of three 5kg batches subdivided into ten 500g samples from Kilifi, Malindi and Mariakani) had an average BaP concentration of 5.842±2.307µg/kg with Malindi batch had the highest average BaP level of 8.916±0.570µg/kg, followed by Mariakani batch with a mean BaP concentration of 4.478±1.570µg/kg, while Kilifi batch had the lowest mean BaP level of 4.339±0.648µg/kg. Shells samples roasted with coconut shells and husks (30 samples comprised of three 5kg batches subdivided into ten 500g samples from Kilifi, Malindi and Mariakani) had an average BaP concentration of 2.298±1.664µg/kg with Malindi batch had the highest average BaP level of 4.465±0.639µg/kg, followed by Mariakani batch with a mean BaP concentration of 1.224±0.825µg/kg while Kilifi batch had the lowest mean BaP level of 0.884±0.564µg/kg. Malindi shells samples had the highest BaP concentrations processed through open-roasting by all the three fuel sources compared to Kilifi and Mariakani shells sample. This could be attributed to higher fat content in cashew nuts batches from Malindi town. Higher fat content in foodstuffs lead to higher BaP generated through roasting process (Akpambang *et al*., 2013; Okoronkwo, 2014). There was significant difference between the mean BaP concentrations in the three batches from Kilifi, Malindi and Mariakani towns, respectively open-roasted using pine, mango wood, and coconut shells and husks, respectively.

Shells samples roasted with pine had the highest mean BaP level of 12.918±5.270µg/kg followed by mango wood-roasted shell samples with an average BaP concentration of 5.842±2.307µg/kg while shell samples roasted with coconut shells and husks mixture with a mean BaP level of 2.298±1.664µg/kg had the lowest concentration. The difference in the mean BaP concentrations could be attributed to differences in hexosans and pentosans content in the three fuel sources. The coconut husk and shell are composed of 27.7% pentosans content out of 30% total hemicellulose content (Mostapha and Husseinsyah, 2011). Mango (hardwood) is composed of 19-26% pentosans out of 20-38% total hemicelluloses content. Pine (softwood) on the other hand, contains 7-14% pentosans out of 33% total hemicelluloses content (Gonzales and Alcala, 2013). Hexosans do not undergo complete degradation to α-cellulose, which increases the concentration of PAHs and BaP in their smoke. Pentosans, on the other hand, undergo complete pyrolysis to produce carboxylic acids, furan and furan derivatives (Maga, 1988). This may explain the trend of pine having higher BaP generation in shells samples followed by mango wood and coconut shell and husk mixture.

BaP concentrations were below the limit of detection in all the 90 cashew nut kernels that were processed through roasting method using pine, mangowood and coconut shells and husks fuel sources from the 3 towns. This might be attributed by the presence of the cashew nut shell acting as a barrier between the fuel source and the kernel hence prevented BaP contamination of the kernel during roasting process. BaP was not formed in the cashew nut kernel samples since the shell prevented direct pyrolysis of the kernel's organic compounds to be converted into BaP and other PAHs and also prevented smoke from the fuel sources depositing on the kernel. This finding has been corroborated by a study by Farhadian *et al*. (2010) who reported that Aluminium foil wraps resulted in 100% reduction of BaP concentration in charcoal-grilled chicken and beef samples while banana leaf wraps led to 85% reduction in charcoal-grilled beef samples and 39.34% BaP levels reduction in charcoal-grilled chicken samples.

I. BaP levels in sun-dried cashew nut shells and kernels

The mean BaP concentrations for the 60 samples (30 shells and 30 kernels) collected from 3 farms in Mavueni (Kilifi town), Gede (Malindi town) and Kokotoni (Mariakani town), respectively, that were processed through sun-drying method and open-roasting method using pine, mango and coconut shells and husks mixture are presented in Table 4.3.

	Shells			Kernels		
	Kilifi	Malindi	Mariakani	Kilifi	Malindi	Mariakani
A	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
B	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
C	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
D	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
E	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
F	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
G	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
H	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
I	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
J	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

Table 3 BaP levels in sun-dried cashew nut shells and husks from the 3 towns

Benzo[A]pyrene was not detected in all 30 cashew nut shells samples and 30 kernels samples from Kilifi, Malindi and Mariakani towns. This may be due to absence of BaP or presence below the limit of detection. Kilifi County has low industrial activities, minimal road coverage in farm areas leading to minimal vehicular emissions of PAHs, no mountains for volcanic eruptions hence its low levels of BaP in the ambient air leading to the non-detection of BaP in samples during the sun drying process. The non-detection of BaP levels in the sun-dried cashew nut samples were also corroborated by Muntean *et al*. (2013) who reported BaP was not detected in sun-dried plant origin foods (wheat, wheat flour, coffee, dried plums and dates). Surma *et al*. (2018) also reported non-detection of BaP in 5 sun-dried fruits (dates, apricots, raisins, plums and cranberry) from Polish retail markets. Muhigija and Njale (2018) also reported non-detection of BaP in sun-dried *Synodontis victoriae*, *Hapo chromis*s and *Lates niloticus* from Ntama, Ibanda and Kirumba, respectively in Mwanza, Tanzania. Onyango *et al*. (2012) reported non-detection of BaP in goat and raw pork samples in 2 out of 3 popular meat joints within Kisumu City, Kenya. BaP has however been detected in sun-dried foodstuffs in other studies. Okenyi *et al*. (2016) reported mean BaP concentration of 1.40±0.20µg/kg in sun-dried fish from Otuocha River from Anambra State, Nigeria. Ingenbleek *et al*. (2019) reported that BaP was quantified in 6 cassava dry samples with a lower bound of 0.1 ppb and an upper bound of 0.19 ppb. BaP was also detected in 1 yam dry composite with a lower bound of 0.3 ppb and upper bound of 0.4 ppb. Misnawi (2012) reported BaP concentrations ranging from 0.11 to 0.71 ppb with a mean concentration of 0.38 ppb in Indonesia.

J. BaP concentration in cashew nut kernels from vendors in Kilifi County

BaP was not detected in all 36 roasted cashew nut kernel samples collected from the roadside vendors from the 3 towns. This could be attributed to the shell leading to 100% BaP reduction by preventing pyrolysis of the kernel and deposition of BaP by the smoke from the fuel source. The BaP non-detection in the kernel samples meant they were below the EU Maximum residual limit of 5µg/kg hence safe for human consumption.

4. Conclusion

The initial sample in the ten 500g samples batch (sample A) had the highest roasting time. The roasting time decreased along the batch before increasing towards the later samples which were roasted in smoldering stage. This was attributed to higher temperatures of the flaming stage compared to smoldering stage. Samples roasted during the smoldering stage had the least BaP levels compared to samples roasted during the flaming and devolatilization stage hence it is safer to let the fuel source to begin the roasting process during the smoldering stages of a fuel source.In the roasted shell samples using different fuel sources, pine generated the highest BaP concentration (12.918±5.270µg/kg), followed by mango wood (5.842±2.307µg/kg) while coconut shell and husk mixture generated the least BaP (2.298±1.664µg/kg) in the cashew nut shell samples. This finding shows that coconut shell and husk mixture is the safest fuel source for roasting food compared to mango while pine is the least safe of the three fuel sources used in the study. The BaP concentrations were below the detection limit in all the 90 roasted cashew nut kernels samples (30 samples each roasted using the three fuel sources (pine, mango wood and coconut shells and husk mixture). This shows that the cashew nut shell led to 100% BaP reduction in cashew nut kernels. BaP levels were also below the detection limit in the 30 shell and 30 kernel samples (from 3 batches) processed through sun-drying method. This indicated very low ambient BaP levels in the air of Kilifi County that could contaminate the samples through atmospheric deposition. BaP was not detected in all 36 roasted cashew nut kernel samples collected from the roadside vendors from the 3 towns. This could be attributed to the shell leading to 100% BaP reduction by preventing pyrolysis of the kernel and deposition of BaP by the smoke from the fuel source. The BaP non-detection in the kernel samples meant they were below the EU Maximum residual limit of 5µg/kg hence safe for human consumption.

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