Review Article

Polycyclic Aromatic Hydrocarbons in Brazilian Food: A Critical Review of Levels, Human Health Risk Assessment, and Potential Gaps in the Recent Literature

Gabriel Henrique Savietto[1], André Augusto Vilela Lima[1,2], Ana Beatriz Cintra da Silva[1,3], Isarita Martins Sakakibara[4], Bruno Rocha[5], Un-Jung Kim[6], Rajendiran Karthikraj[7], Jose L. Domingo[8], Fernando Barbosa[9], Marilia Cristina Oliveira Souza[1]

1. Department of Biomolecular Sciences, Universidade de São Paulo, Brazil; 2. Universidade Federal de Alfenas, Alfenas, Brazil; 3. Universidade de Ribeirão Preto, Brazil; 4. Department of Clinical and Toxicological Analysis, Universidade Federal de Alfenas, Alfenas, Brazil; 5. Institute of Chemistry, Federal University of Alfenas, Alfenas, Brazil; 6. Department of Earth and Environmental Sciences, The University of Texas at Arlington, United States; 7. Department of Kinesiology, The University of Texas at Arlington, United States; 8. Laboratory of Toxicology and Environmental Health, School of Medicine, Universitat Rovira i Virgili, Spain; 9. Department of Clinical Analyses, Toxicology and Food Sciences, Universidade de São Paulo, Brazil

Polycyclic aromatic hydrocarbons (PAHs) are pollutants with well-known carcinogenic, mutagenic, and teratogenic properties. Their presence in food is a critical concern, particularly in developing countries such as Brazil, where regulatory frameworks may be inadequate to mitigate contamination risks effectively. This article systematically reviews the recent literature on PAH contamination in Brazilian food, assesses the associated health risks, and identifies critical gaps in research and regulatory practices. A literature search was conducted using predefined inclusion criteria across databases: Scopus, ScienceDirect, PubMed, and Web of Science. Health risk characterization was performed using risk assessment methodologies, including Estimated Daily Intake, Hazard Quotient (HQ), and Cancer Risk (CR) calculations, with consumption data derived from the Brazilian Family Budget Research. Out of 36 eligible studies, significant regional disparities in research efforts were noted, with 55.6% of studies concentrated in Southeast Brazil. Analysis revealed that several food categories exceeded European Union regulatory limits for benzo[a] pyrene and PAH4 (benzo[a] pyrene, chrysene, benzo[b] fluoranthene, and benzo[a] anthracene). CR alarming values in tea (3.73×10^{-2}), cheese (1.24×10^{-2}), and vegetable oils (4.05×10^{-3}), all of which exceeded the acceptable threshold. These findings underscore the need for stringent regulatory measures. Currently, Brazilian standards are limited mainly to olive oils. The analysis identified critical gaps in PAH monitoring, with research funding disparities contributing to uneven geographical coverage, thereby hindering comprehensive national risk assessments. This article highlights an urgent need for enhanced regulatory oversight, standardized monitoring protocols, and increased investment in research to address PAH contamination across Brazil's food supply.

Corresponding author: Marília Cristina Oliveira Souza, mcosouza@usp.br

Highlights

- Thirty-six studies were included in this review.
- Brazilian legislation on PAH levels in food is inadequate for effectively regulating exposure.
- The highest concentration of PAHs was found in fishery products.
- The reviewed food products showed a CR higher than the international threshold.

1. Introduction

PAHs are a significant class of legacy pollutants from natural processes and anthropogenic activities. Their formation primarily occurs through the incomplete combustion of organic matter, fossil fuels, wood, and tobacco, as well as various industrial processes, such as coal tar production and aluminum smelting[1]. Structurally, these organic compounds are characterized by two or more fused benzene rings, categorized based on their molecular mass into low and high-molecular-weight compounds. This classification influences their environmental distribution patterns. These compounds have been extensively documented for their adverse biological effects, including carcinogenic, mutagenic, and teratogenic properties[1][2][3][4].

The United States Environmental Protection Agency (US.EPA) has established a list of 16 priority PAHs (Table 1) for environmental monitoring and regulation. Within this group, benzo[a] pyrene (BaP) holds unique significance as the only compound classified in Group 1A (carcinogenic to humans) by the International Agency for Research on Cancer (IARC), serving as a critical marker for PAH toxicity across environmental matrices. The remaining PAHs are classified as either Group 2A (probably carcinogenic to humans) or Group 2B (possibly carcinogenic to humans). The assessment of human health impacts is complicated by occupational exposure patterns, which often involve exposure to complex mixtures of multiple PAHs and other carcinogenic compounds. This complexity makes it difficult to isolate and attribute specific carcinogenic effects to individual PAH compounds[5][6][7][8].

Contamination of the food supply chain is one of the main routes of human exposure to PAHs, with up to 70% of total PAH exposure in non-smoking individuals attributable to food consumption. The complexity of this exposure pathway is highlighted by data from the American Academy of Pediatrics, indicating that over 10,000 chemicals are present in modern food supplies[9][10][11]. The concentrations of PAHs in food products vary significantly, influenced by multiple factors, including commercial food processing using heat, cooking methodology, preservation techniques, storage conditions, and individual dietary patterns[12][13][1][14][15].

High-temperature cooking methods, including grilling, frying, roasting, and smoking processes, generate additional PAHs through the incomplete combustion of organic materials, particularly fats and proteins, which are subsequently absorbed into the food matrix. Commercial food processing, like roasting of coffee and guaraná, and in the baking of *coalho* cheese, are examples of this process[13][14][16]. Furthermore, environmental matrices represent additional contamination sources for food. The lipophilic characteristics of these pollutants facilitate their bioaccumulation, raising concerns regarding animal-derived food products due to biomagnification through the food chain[17][18][19][16].

On the other hand, PAH contamination in food products can be further exacerbated by migration from packaging materials during the storage or transportation phases, increasing their concentration in food products[20]. This multi-pathway contamination profile underscores the importance of implementing comprehensive monitoring protocols and developing targeted mitigation strategies to reduce human exposure to these compounds[5][20][21].

International regulatory oversight of PAHs in food products is primarily governed by Codex Alimentarius, a collaborative initiative between the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO). This framework establishes Maximum Limits (MLs) for BaP across specific food categories, including fish, meats, and smoked goods[22]. The European Union (EU) has also implemented additional comprehensive regulations through Regulation (EU) 2023/915, which establishes MLs for both individual benzo[a] pyrene and a defined combination of four PAH compounds (PAH4): benzo[a] pyrene, benz[a] anthracene, benzo[b] fluoranthene, and chrysene. These regulations specifically address PAH contamination in processed food products, including smoked, roasted, grilled, and dried foods, as well as oils and fats[21] (EU, 2023).

The Brazilian regulatory framework for PAH control shows notable limitations in scope and implementation. The Brazilian National Health Surveillance Agency (ANVISA), through Resolution RDC No. 722/2022, has established regulatory parameters for various food contaminants. However, PAH monitoring remains restricted, with limits established solely for benzo[a] pyrene in olive pomace and olive pit oils—products with minimal market presence in Brazil. While ANVISA's recognition of 16 priority PAHs indicates emerging awareness, this has not translated into comprehensive monitoring protocols. Despite partial alignment with international standards (Codex Alimentarius Commission and European Food Safety Authority - EFSA), current oversight mechanisms remain insufficient for effective PAH contamination control in the food supply chain[5][23].

The present article systematically reviews PAH contamination in Brazilian food products through a comprehensive analysis of peer-reviewed literature published between 2014 and 2024, specifically focusing on regional distribution patterns and contamination levels. The research methodology integrates quantitative assessment of PAH concentrations, analysis of consumption patterns, and evidence-based evaluation of carcinogenic risk factors compared to established international regulatory standards. This review is structured to achieve three primary objectives: (1) to identify critical gaps in existing PAH monitoring frameworks and research protocols, (2) to prioritize areas for future research through a systematic evaluation of current evidence, and (3) to develop data-driven recommendations for regulatory agencies aimed at mitigating PAH exposure within the Brazilian food supply chain.

2. Methodology

The search strategy for this systematic literature review utilized four major scientific databases: Scopus (https://www.scopus.com), ScienceDirect (https://www.sciencedirect.com), PubMed (https://pubmed.ncbi.nlm.nih.gov), and Web of Science (https://www.webofscience.com). The search protocol encompassed publications from 2014 to 2024 to ensure comprehensive coverage of recent research developments. Search strategies included the use of the following keywords in the Boolean operator "OR" such as - "PAH", "Polycyclic Aromatic Hydrocarbons", "Polyaromatic hydrocarbons", "High molecular weight PAHs (HMW-PAHs)", "Low molecular weight PAHs (LMW-PAHs)" and the specific PAH name (i.e., Naphthalene, Fluorene, Phenanthrene, Anthracene, Benzo[a] pyrene). These keywords were combined using the Boolean operator "AND" with "food samples," "low-water food," "high-water food," "animal-origin food," "processed food," and the specific food name + Brazil, Brazilian regions, or specific Brazilian states.

The article selection followed strict methodological criteria to ensure data quality and analytical consistency: i) a description of the food samples used in the study and their geographical location within the Brazilian territory; ii) an adequate analytical method and quality control for the analysis, including the description of analytical merit figures. The systematic evaluation excluded conference proceedings, review articles, articles with methodological flaws, and publications in non-English languages to maintain methodological uniformity and facilitate comparative analysis. A flowchart, demonstrated in Figure 1, was created to summarize the search strategy.

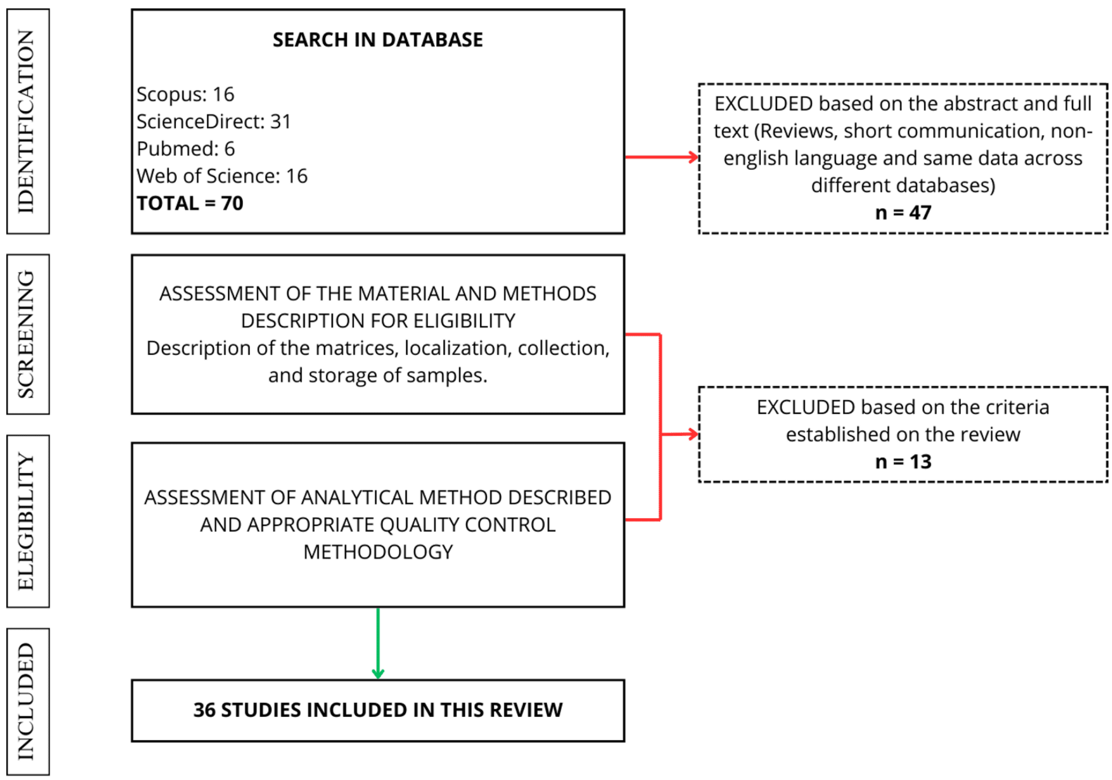

Figure 1. Flowchart of search strategy

3. Human health risk characterization

Non-carcinogenic (HQ) and carcinogenic (CR) risks were estimated to assess potential human health impacts. The risk calculations incorporated standardized consumption data from the Brazilian Family Budget Research (Pesquisa de Orçamentos Familiares - POF) conducted by the Brazilian Institute of Geography and Statistics[24]. The assessment protocol utilized was to reference an adult body weight of 70 kg and assumed chemical stability during the food preparation and consumption. The following equations were used for risk quantification[25]. Assuming no chemical alteration during cooking and consumption:

doi.org/10.32388/9UA4UF.2

$$EDI = \frac{(C.IR)}{BW}$$
$$HQ = \frac{EDI}{RfD}$$
$$HI = \sum HQ$$

$$CR = EDI.oSF$$

Where:

- EDI: Estimated Daily Intake
- C: Average PAH concentration in food (mg/kg)
- IR: Ingestion Rate
- BW: Body Weight (70 kg)
- HQ: Hazard Quotient
- RfD: Reference oral dose (mg/kg/day)
- HI: Hazard Index
- CR: Cancer risk
- oSF: Oral Slope factor (mg/kg·day).

The risk assessment methodology used the highest and the available median PAH concentrations from each food category to define upper-limit and normal exposure scenarios, ensuring conservative estimates for evaluating human health risks. The health risk was also evaluated in normal situations, considering the median values of the sum of all PAHs in the calculations. For the summation of PAH concentrations in food samples, three distinct values were calculated: (1) the total concentration of all detected compounds, (2) the cumulative concentration of compounds with a defined Reference Dose (RfD), and (3) the cumulative concentration of compounds with an Oral Slope Factor (oSF). This approach provides a robust framework for assessing the potential health impacts of dietary PAH exposure. It is essential to note that calculating health risk based on the total concentration of all detected PAHs may introduce limitations, as the carcinogenicity of compounds varies, and some compounds have been identified as non-carcinogenic to humans (IARC groups 3 and 4).

Risk assessment thresholds were established according to the United States Environmental Protection Agency[26] guidelines, which define HI values exceeding 1.0 as indicative of potential chronic systemic effects. For carcinogenic risk, CR values above 1×10^{-5} indicate elevated cancer risk from continuous exposure. The Centers for Disease Control and Prevention provides additional risk interpretation guidance[27], with CR values between 1×10^{-4} and 1×10^{-6} suggesting increased susceptibility within tolerable ranges.

4. Results

Initial database screening identified 70 publications, which were reduced to 47 after excluding duplicate data across different databases, with 36 studies meeting the established inclusion criteria for comprehensive analysis. Table 2 presents all available articles from the five Brazilian regions: North, Northeast, Midwest, South, and Southeast. Quantitative analysis revealed a significant regional disparity in research output, with 20 publications in the Southeast region (55.6% of eligible studies), as depicted in Figure 2. This disproportionate regional distribution reflects established patterns in research funding allocation and institutional capacity, factors analyzed in detail in subsequent sections.

doi.org/10.32388/9UA4UF.2

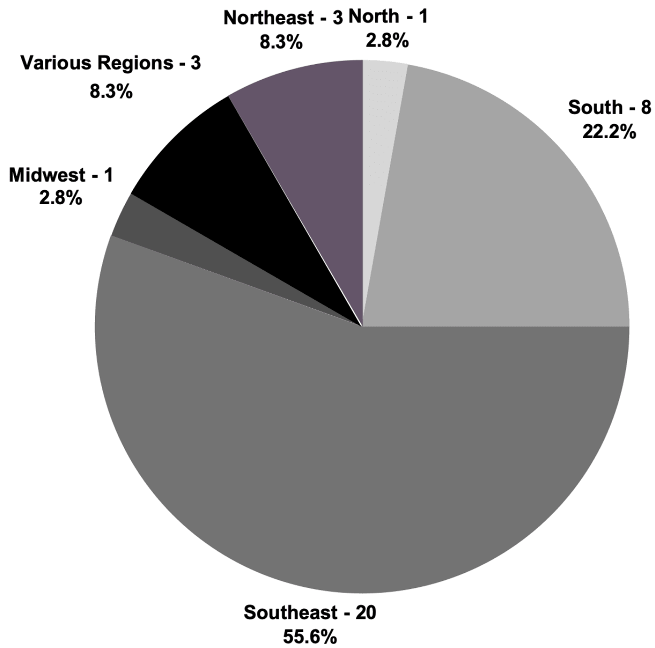

Figure 2. Distribution of PAH studies on food samples across different Brazilian regions.

Analysis of PAH concentrations across food categories, compared against Regulation (EU) 2023/915 standards, revealed significant exceedances in multiple food matrices, particularly cocoa beans, chocolate, oils, tea, and fishery products. Quantitative assessment of toasted cocoa beans found BaP concentrations exceeding regulatory thresholds (5.0 µg kg^{-1}) in two independent studies. Belo et al.[28] reported a maximum BaP concentration of 9.06 µg kg^{-1}, while Abballe et al.[29] found levels as high as 22.2 µg kg^{-1}. Notably, the estimated median concentrations in the latter study also exceeded the threshold, reaching 11.1 µg kg^{-1}. In turn, Guizellini et al.[30] reported high PAH concentrations in chocolate samples, with both individual BaP levels and cumulative PAH4 (Benzo[a] pyrene, Chrysene, Benzo[b] fluoranthene, and Benzo[a] anthracene) concentrations surpassing established regulatory limits.

Analysis of vegetable oils revealed significant PAH contamination relative to regulatory limits. Brazilian legislation, as specified by ANVISA, stipulates a maximum BaP concentration of 2.0 µg kg^{-1} for olive pomace and olive pit oils. Tfouni et al.[31] reported BaP concentrations reaching 25.51 µg kg^{-1}, exceeding the regulatory threshold by approximately twelve-fold. European Union standards similarly establish a 2.0 µg kg^{-1} limit for BaP and 10 µg kg^{-1} for cumulative PAH4 concentrations. While some samples exhibited BaP concentrations surpassing the PAH4 cumulative limit, comprehensive interpretation was constrained by incomplete BaP data[32], highlighting a methodological limitation in contamination assessment.

The assessment of seafood and fishery products revealed substantial PAH contamination according to European Union regulatory thresholds (2.0 µg kg^{-1} BaP for smoked fishery products and 5.0 µg kg^{-1} for bivalve mollusks). Santiago et al.[33], Ramos et al.[34], and Souza et al. (2023) reported cumulative concentrations of 16 IARC-regulated PAHs, with maximum levels reaching 988.76 µg kg^{-1} in certain samples. Moreover, Massone et al.[35] reported even higher contamination levels, with cumulative concentrations for the sum of 37 PAHs reaching 4074.0 µg kg^{-1} in fishery products. While these measurements reflect broader PAH profiles than EU-regulated PAH4 compounds, the reported concentrations significantly exceed acceptable thresholds. This highlights potential public health risks, underscoring the urgent need for improved monitoring protocols and expanded research efforts in this field.

PAH concentrations in food categories are currently exempt from regulatory oversight, creating a potential for exposure risk. For example, Rocha et al.[36] reported striking concentrations of PAHs in coalho cheese, with BaP concentrations reaching 149.4 µg kg^{-1} and 139.5 µg kg^{-1} of DahA, the latter being classified as probably carcinogenic to humans by the IARC. Similarly, Silva et al.[37] highlighted concerning levels of the total PAH4 group in salami, with a maximum concentration of 33.84 µg kg^{-1}. These quantitative findings demonstrate substantial contamination in unregulated food matrices, likely due to the food processing method, which involves high temperatures.

Current PAH regulations, including EU standards for high-risk food matrices, provide essential monitoring parameters but exhibit significant limitations in fully assessing exposure. A critical analysis identifies two key challenges: limited coverage of diverse food categories and the absence of standardized analytical protocols. In the Brazilian context, these limitations are evident, as most food products analyzed in the past decade fall outside EU regulatory classifications, hindering accurate exposure assessments for local dietary patterns. Methodological inconsistencies in the selection of PAH compounds further compromise data quality, particularly when studies exclude benzo[a] pyrene. These systematic gaps in standardization reduce both inter-study comparability and the reliability of risk assessments, underscoring the need for harmonized analytical protocols and a focus on priority polycyclic aromatic hydrocarbon compounds to improve the quality and relevance of future research.

The research examines various analytical approaches for detecting polycyclic aromatic hydrocarbons across Brazilian studies. Researchers commonly employed solid-liquid extraction or modified QuEChERS methodology for initial sample preparation, followed by purification via solid-phase extraction (SPE) or chromatographic columns using silica gel. The extraction process typically utilizes low-polarity solvents such as hexane or dichloromethane. For instrumental analysis, researchers primarily employed either gas chromatography with mass spectrometry (GC-MS) or high-performance liquid chromatography with fluorescence detection (HPLC-FLD), both recognized for their detection capabilities with these compounds. Recent technological advancements have introduced more refined techniques, including GC-MS/MS, HPLC-MS/MS, and supercritical fluid chromatography (SFC), offering enhanced selectivity and sensitivity[38][39][40][41][42]. The European Union suggests detection limits below 0.3 µg kg^{-1} and quantification limits under 0.9 µg kg^{-1} for the four primary PAHs in foodstuffs, with acceptable recovery percentages ranging from 50-120% to ensure measurement reliability.

The lack of unified methodological approaches across Brazilian research facilities has resulted in significant variation in analytical performance, particularly regarding the spectrum of PAHs quantified (ranging from just the four EU-priority compounds to comprehensive panels of 16 EPA-designated or 37 different PAHs in certain investigations). This methodological diversity complicates comparative analysis and comprehensive risk evaluation. Future investigations should emphasize protocol standardization, validation across multiple laboratories, and comprehensive reporting of quality assurance parameters, including recovery rates, repeatability, and matrix interference effects. A significant challenge remains the absence of consistent, validated analytical procedures for PAH determination in Brazilian food matrices. Several studies fail to document recovery percentages, detection and quantification limits, or verification of reference materials, potentially affecting the comparability and accuracy of reported PAH measurements. Alignment with international benchmarks established by the EU and ISO would enhance data reliability and strengthen regulatory frameworks.

4.1. Research Infrastructure Inequities and Monitoring Limitations

The geographical distribution of PAH research in Brazil reveals a significant regional concentration, with the South and Southeast regions exhibiting the predominant research output, correlating with the density of urban centers and academic institutions[43]. This regional disparity reflects institutional infrastructure patterns, as these areas host the most prominent universities and research facilities. Analysis of food product contamination requires consideration of both production geography and consumption patterns. While agricultural activities span the country's diverse regions, generating varied food matrices for analysis, research capacity remains geographically concentrated. This dichotomy is exemplified by studies of regional foods like jambu (a Brazilian leafy) in the North, where local agricultural practices and dietary patterns intersect with research capabilities. The observed research distribution primarily stems from historical patterns in funding allocation and institutional resource distribution[44].

Brazil's research infrastructure operates through a complex network of funding sources, with public academic institutions serving as primary research centers. Three major public organizations dominate the research funding landscape: the National Council for Scientific and Technological Development (CNPq - Conselho Nacional de Desenvolvimento Tecnológico e Científico), the Federal Agency for Support and Evaluation of Graduate Education (CAPES - Centro de Aperfeiçoamento de Nível Superior), and the São Paulo Research Foundation (FAPESP - Fundação de Amparo à Pesquisa do Estado de São Paulo). Quantitative analysis of research output from 2011-2018 demonstrates their significance, with publication counts of 122,967, 70,048, and 56,667, respectively[45]. This publication distribution underscores the critical role of public funding in Brazilian scientific research. Research project execution requires substantial resource allocation beyond investigator expertise, encompassing infrastructure, personnel, and material costs, highlighting the fundamental importance of institutional funding support[46][47].

This discrepancy can greatly impact the data obtained from each study. Determination of organic compounds is a challenging task, as the available methods vary in terms of analytical performance, sensitivity to different PAH, technical demands, and such[48]. The different scenarios in Brazil regarding funding and research profiles make each laboratory almost unique in its capabilities and equipment. Each analytical method differs in sensitivity, accuracy and reliability, and when detecting pollutants as PAHs, the presence of numerous isomers within the 16 regulated compounds can further complicate detection and separation[48][49] Additionally, the lack of standardized methodologies has resulted in limited interlaboratory studies, which further complicates the geographical consistency of research data[50][43].

According to InCites and Clarivate Analytics, research funding and productivity demonstrate clear geographical patterns across Brazilian states, with São Paulo, Rio de Janeiro, Minas Gerais, Rio Grande do Sul, and Paraná showing the highest research output. These states, located in the Southern and Southeastern regions, account for the majority of PAH studies in this review. The Southeast region's research dominance is reflected in its urban infrastructure, comprising over one-third of Brazil's urban areas[51]. This concentrated research output stems from established funding mechanisms, institutional resources, and established research networks in these regions[52][53][54][55].

Brazilian public funding agencies face significant operational constraints due to recent budget reductions. These financial limitations have impacted research continuity, reflecting a broader challenge among emerging nations where research potential exists, but resource limitations constrain scientific advancement[56][57][58]. Due to substantial infrastructure requirements, the impact is particularly pronounced in analytical chemistry and toxicological research[59][60]. Critical instrumentation, such as chromatography-mass spectrometry systems, requires significant capital investment, limiting institutional research capacity. For emerging economies, equipment importation introduces additional cost barriers. Operational considerations, including consumables, maintenance requirements, and specialized personnel training, further compound these financial challenges, creating significant obstacles for high-impact research implementation[60][59].

An assessment of scientific funding reductions in Brazil reveals cumulative losses of US$14 billion between 2014 and 2021. This significant decline in research support was documented during a formal review by the Economic Development, Industry, and Commerce Committee of the Chamber of Deputies, specifically addressing national science and technology funding status[61]. CAPES, operating under the Ministry of Education and Culture (MEC - Ministério da Educação e Cultura), experienced substantial budget reductions between 2015-2017, with funding decreasing by approximately US$ 166 million[62]. This significant reduction impacted scholarship allocation and researcher recruitment, creating additional barriers to scientific advancement under increasingly resource-constrained conditions[63].

The relationship between chemical analysis and governmental regulations encompasses multiple critical intersections, influencing both research methodology and practical applications[64][65][66][67] (Papadakis et al., 2017). The standards and guidelines made by governmental agencies to ensure the accuracy, reliability, and safety of their results, which are strongly inculcated in quality control, assurance, traceability, and documentation, depend on data found in meaningful research. Environmental safety regulations address critical operational parameters in hazardous chemical management through standardized handling protocols, secure storage requirements, and regulated disposal procedures. Integrating these quality assurance systems with systematic pollutant monitoring methods enables consistent evaluation of environmental contaminants while maintaining methodological rigor and data reliability.[66][67][68] (Papadakis et al. 2017).

4.2. Food regulation in Brazil and PAH studies

Brazilian food legislation is based on national laws and international agreements. These practices are overseen by the Brazilian Health Regulatory Agency (ANVISA)[69]. Despite Brazil's participation in the CODEX Alimentarius Commission's international standardization efforts, implementation barriers persist. The universal application of standardized food safety, quality assurance, and trade protocols often fails to accommodate nation-specific regulatory requirements and implementation capabilities[70][71]. Regions with limited regulatory enforcement capacity or inadequate exposure monitoring systems face elevated risks from chronic PAH exposure, highlighting the critical gap between standardized requirements and practical implementation capabilities[72][73].

Food safety hazards include various toxicological impacts correlated with specific agricultural practices and processing methodologies. Thus, PAH contamination exhibits an association with high-temperature food preparation protocols, including grilling, smoking, toasting, roasting, and frying processes, which facilitate compound formation through thermal degradation pathways[74][75]. The potential health risks of long-term PAH exposure should be more widely recognized, as prolonged contact can increase the risk of developing cancer, as well as problems with the bladder, liver, and skin[76].

Current monitoring systems demonstrate two critical limitations: insufficient data on regional consumption patterns and inadequate characterization of PAH contamination levels across diverse food matrices. Even though international legislation was built to be a universal metric for limits of different pollutants in food, its consumption levels reflect and consequently benefit developed countries more than emerging ones. The sixteen priority PAHs guidelines were based on studies from regulatory agencies, such as the US.EPA and the European Union (EU). However, comprehensive analysis of this variability remains constrained by limited systematic investigation across different geographical and agricultural contexts[77][78] (Zhang et al., 2021).

The Brazilian Institute of Geography and Statistics (IBGE - Instituto Brasileiro de Geografia e Estatística) released data on the national consumption patterns through the 2017-2018 (Family Budget Survey). Generally, coffee was the most consumed food by the population (78.1%), followed by rice (76.1%) and beans (60%). The Brazilian consumption patterns strongly correlate with household economic parameters, exhibiting significant heterogeneity across geographical regions. Data released by the Department of National Household Sample Survey (PNAD - Pesquisa Nacional por Amostra de Domicílios) reveals that at least 27.6% of Brazilian households are affected by food insecurity, with the North and Northeast regions being the most affected. These findings underscore systematic regional variation in dietary practices and food security status across Brazil's diverse geographical regions[24] (PNAD, 2023).

Over the past decade, only a few food groups have been studied for PAH levels, with most of the research concentrated in Brazil's South and Southeast regions. This systematic research pattern reflects dual constraints: regional consumption characteristics and methodological limitations in contamination assessment protocols. A critical examination of processing methodology impacts on PAH contamination levels demonstrates the need for standardized analytical approaches across geographical regions, particularly given the variable food processing methods employed throughout Brazil's diverse territories[79] (Zhang et al., 2021).

The dietary intake of PAHs represents a significant route of human exposure[14][80][81]. However, the distribution of the PAH studies across different food classes is uneven, creating gaps in understanding the real risk posed by these contaminants. This limitation becomes particularly relevant considering primary Brazilian dietary components (rice, beans, coffee), which remain underrepresented in current analytical investigations[24].

In general, processed foods possess higher levels of PAHs, particularly in matrices subjected to thermal processing, smoke exposure, and incomplete combustion conditions (e.g., smoked foods, barbecued foods, fried foods, and processed meats)[82][83]. Despite several studies on these food groups over the past decade, many have focused on beverages. In this review, the analyzed studies used market samples. However, it may lead to an underestimated risk of this exposure. Grilling, particularly over charcoal, is common for preparing meats. This method exposes food directly to combustion byproducts, leading to higher PAH formation due to fat dripping onto hot surfaces and incomplete combustion of organic material. Similarly, roasting—frequently used for coffee, nuts, and some meats—can contribute to PAH accumulation, depending on temperature and duration. Frying, another prevalent cooking method, may also enhance PAH levels, especially when oils are reused or exposed to high temperatures for extended periods[83][75].

While relevant, these studies do not offer sufficient legislation and risk assessment data. In the present review, we found that products of animal origin showed the highest levels of PAHs, indicating a need for more studies on that issue, mainly applied to processed food. Massone et al.[35] reported concentrations of 4074.0 μg kg^{-1} for the sum of 37 PAHs in sardine samples, while Souza et al. (2023) found levels as high as 988.76 μg kg^{-1} in some mussels for the sum of 16 PAHs. These elevated concentrations reflect bioaccumulation mechanisms through aquatic food chains, particularly in fish species (Shi et al., 2024).

Although these mechanisms of PAH contamination do not significantly impact fruits and vegetables, studies on these food groups are crucial to fully understanding their risks. Overall, the available data are insufficient to make substantial progress in PAH-related legislation. Given the importance of these cooking practices in Brazilian cuisine, more comprehensive and targeted studies are necessary to assess human health risks and accurately inform policy decisions. Additionally, raising consumer awareness and promoting safer cooking methods could help mitigate exposure to these contaminants.

5. Human health risk characterization

Among the 16 regulated PAHs, the most notable is BaP, one of the most extensively studied PAHs recognized for their potent carcinogenic properties. It is classified as Group 1, carcinogenic to humans, by the IARC[84][85][86]. Other compounds possess variable carcinogenic potential: dibenz[a, h] anthracene (DahA), classified as probably carcinogenic to humans in Group 2A[85], benzo[b] fluoranthene (BbF), benzo[k] fluoranthene (BkF), indeno[1,2,3-cd] pyrene (Ind), and chrysene (Chr) are classified as possibly carcinogenic to humans (Group 2B)[85][87][88][89]. There is a limitation in health risk characterization when calculations are based on the total concentration of all detected PAHs, as their carcinogenic potential varies, and some are classified as non-carcinogenic to humans (IARC Groups 3 and 4).

Despite their environmental prevalence, current research provides limited characterization of the toxicological effects of low-molecular-weight PAHs. However, they may still pose risks. For example, naphthalene has been a concern in environmental and occupational exposures due to its harmful and carcinogenic effects[90][91]. More recent research suggests that studies of LMW-PAHs act as co-carcinogens, particularly in human lung epithelial cell lines[92]. It indicates that even PAHs with LMW, which might have been considered less harmful in the past, can contribute to cancer development, especially when combined with other carcinogenic agents. It highlights the need for further research and the development of effective strategies to reduce exposure to PAHs.

This review aimed to assess the risk of exposure to PAHs through the most commonly consumed food groups among the Brazilian population, using data from the IBGE study as a reference. For the main goal of this review, some papers on cocoa beans and other foods will be excluded, for which there are no available data regarding their consumption in the country. Based on the risk and danger of naphthalene and benzo[a] pyrene and the summation of all PAHs, the Hazard Quotient (or Index) and Cancer Risk were assessed using available data. The Tables included in the *supplementary information* present the risk assessment based on the median values of naphthalene, benzo[a] pyrene, and the total of all PAHs in each study. For studies that did not provide median or mean values, an estimated value was calculated using the available minimum and maximum concentration ranges from the articles listed in Table 2.

In Tables 3, 4, 5, S1, S2, and S3, the bold values indicate a significant risk, where the Hazard Index (HI) exceeds 1, signifying a health risk (HI > 1), and the cancer risk (CR) exceeds 1 x 10^{-5} (CR > 1 x 10^{-5}). Underlined numbers indicate CR values between 1 x 10^{-5} and 1 x 10^{-6}, which could mean a risk. NE means that the values were not estimated.

 doi.org/10.32388/9UA4UF.2

Unfortunately, current research shows significant gaps in naphthalene contamination profiles across food matrices, with quantitative data limited to rice grains and cachaça (a Brazilian liquor) samples. Although this lack of data is problematic, rice has shown a cancer risk higher than the acceptable limit at the highest concentration detected (8.02 x 10^{-3}) and at the estimated median concentration as well (4.01 x 10^{-3}), while cachaça had a value indicating potential risk in both calculations shown in Tables 3 and S1 (5.04 x 10^{-6} and 2.51 x 10^{-6} respectfully). All samples had an HQ below the limits. Naphthalene levels in food should be generally low unless the food has been exposed to fire or smoke[90][93]. Naphthalene concentrations in various non-fish food items range from detection limits to higher levels in smoked or charred foods[94][40][95].

Based on slope factor analysis, naphthalene has a lower carcinogenic potency than benzo[a] pyrene, but chronic environmental exposure warrants systematic investigation due to potential cumulative health impacts. Recent studies have shown that relatively LMW-PAHs, such as naphthalene, could also be detected in raw materials, especially in tuber and starchy vegetable samples. Its processing increased the relative amounts of both high- and low-molecular-weight PAHs in the samples, even in baked or electric-roasted items[14][96]. These systematic findings underscore critical research priorities: comprehensive profiling of naphthalene contamination patterns, quantitative assessment of processing impacts, analysis of cumulative exposure effects, and investigation of high molecular weight PAH formation mechanisms.

Cancer risk assessment for BaP revealed elevated risk profiles using for the calculation of the highest value of BaP found in each study across four distinct food matrices: tea (3.73 x 10^{-2}), cheese (1.24 x 10^{-2}), chocolate (2.23 x 10^{-4}), and vegetable oil (4.05 x 10^{-3}). This is plausible due to the drying processes of grains and leaves involved in producing tea, chocolate, and oil, which can potentially generate more PAHs[97][98][99][100]. The cheese samples analyzed in the study were cooked using charcoal, which could lead to the aggregation of more PAHs in the food. These samples, along with chocolate, soybean grains, and cachaça, also exhibited high risk in the hazard quotient assessment, indicating a slight but potential danger.

Overestimating risks in food consumption can be problematic in risk assessment, potentially leading to false allegations and the creation of alarming profiles that do not reflect reality. Increasing evidence suggests that risk calculations should be based on bioaccessible concentrations rather than the total concentrations[101][102]. Although the present study uses conservative estimates of carcinogenic risk based on total PAH concentrations, it is essential to acknowledge that the scarcity of data on human exposure to pollutants, considering bioaccessibility and bioavailability, can lead to overestimation of actual exposure levels. Recent dietary risk assessment frameworks have increasingly incorporated these parameters, along with the Margin of Exposure (MoE) approach, which provides a more realistic interpretation of health risks by comparing estimated exposure with toxicological reference points. Therefore, while worst-case scenarios are useful for establishing protective benchmarks, incorporating bioaccessibility data and MoE estimations would contribute to a more balanced and accurate risk communication strategy[103][104][105]. Despite these limitations, even the median values reported and estimated in the studies included in this review may still indicate a level of risk. As shown in Table S2, the cancer risk associated with the same food groups remains high, with tea (1.95 x 10^{-2}), cheese (1.20 x 10^{-2}), chocolate (1.23 x 10^{-4}), and vegetable oil (2.05 x 10^{-3}).

Humans are daily exposed to multiple environmental pollutants, contributing to cumulative cancer risk profiles. Current research reveals significant methodological gaps in understanding the synergistic interactions between PAHs and other environmental contaminants, as well as between different PAH compounds (Mauderly et al., 2009)[106][107]. The estimated upper limit and median values for CR and HI, considering the risk summation of all the PAH concentrations available for each food group, are shown in Table 5 and S3. Currently, there are several PAHs classified for their slope factors, including naphthalene, benzo[a] pyrene, benzo[b] fluoranthene, benzo[k] fluoranthene, chrysene, dibenz[a, h] anthracene, and indeno[1,2,3-cd]. However, only a few of them were detailed in the collected data. A comprehensive analysis of PAH contamination data across 16 food groups using the upper limit concentration found (Table 4) reveals systematic exceedance of acceptable cancer risk thresholds through cumulative PAH exposure. Data regarding the summation of PAHs present a cancer risk above the acceptable limits. The cancer risk calculations using the median values of PAHs with slope factors in the study (Table S3) also indicated a high risk across all food matrices.

In general, to the best of our knowledge, Brazil shows limited data in the literature on the risk assessment of human exposure to PAHs, considering the risk estimate by food and/or water ingestion, air inhalation, and total body burden of the pollutant. In addition, there are numerous exposure sources and pathways to these ubiquitous chemicals, and considering only one source may underestimate the risk of human exposure. Different food groups may be susceptible to contamination with PAHs. Guizellini et al.[30] demonstrate a low potential health risk of PAH exposure by chocolate ingestion. Andrade et al.[41] evaluated the levels and the risk of PAHs in sediment from Northeast Brazil, since these pollutants in sediments and water bodies have shown significant risks to human health. The findings showed that BaP exceeded 90%, followed by DahA, contributing 8% of the average risk. It demonstrates that the levels of these priority PAHs represent a threshold for carcinogenic and mutagenic properties in humans. Franco et al.[108] calculated the CR using the PAH levels in street dust (SD) from Rio de Janeiro, Brazil. The results indicated the CR values were similar considering ingestion and dermal contact to SD, and the inhalation was a negligible exposure pathway.

Souza et al.[4] performed the risk characterization of vulnerable groups exposed to PAHs, including Brazilian infants, children, and pregnant women, and considered the body burden of their metabolites. The HQ and CR values depend on the PAH levels in the human body; therefore, the greater the body load of PAHs, the greater the risk. The results showed the hazard index (HI – the sum of all hazard quotients calculated by the group) higher than 1 for pregnant women and children, with a greater influence of BaP on the results. Besides, the CR values were higher than 1×10^{-4} for BaP and negligible for naphthalene (lower than 10^{-6}). Cesila et al.[109] also reported the risk assessment of Brazilian pregnant women, indicating a HI of 1.4 and a CR above 10^{-4} for BaP, which may pose a potential risk to this vulnerable group. Galindo et al.[42] evaluated the PAH levels in Brazilian breastmilk and the risk to infants through a margin of exposure calculation. In this study, due to the high concentration of PAHs and high human milk consumption, infants may have higher exposure margins to these chemical compounds than adults.

Although this represents an extreme scenario, based on the maximum concentration of each PAH reported in various studies, these findings warn of potential health risks and highlight the urgent need for stricter regulatory measures and further research. Systematic assessment of PAH exposure demonstrates significant cumulative risk potential through combined dietary and environmental pathways, with documented potential for lifetime health impacts[110]. Despite this, regulatory standards for PAHs in food have significant limitations in addressing complex, real-world exposure scenarios: variable standards across jurisdictions, insufficient coverage of exposure pathways, limited integration of cumulative risk assessment, and inadequate monitoring protocols. Moreover, quantitative risk analysis indicates the necessity for systematic intervention strategies and critical implementation requirements: enhanced monitoring systems for food matrices, comprehensive public education initiatives, strengthened regulatory oversight mechanisms, and integrated exposure assessment protocols. It underscores the critical importance of implementing systematic risk mitigation strategies through coordinated regulatory and public health initiatives.

6. Future trends and perspectives

In recent years, Brazil has experienced substantial population growth, which has driven the expansion of the chemical and food industries. Current population exposure to various pollution pathways, particularly through dietary routes, is raising significant public health concerns that necessitate coordinated intervention strategies from both the government and society. To mitigate these issues, future actions could include promoting and investing in research on foodborne PAHs in Brazil and other emerging countries. A systematic research approach would enable the development of region-specific regulatory frameworks tailored to local agricultural practices, dietary habits, and exposure scenarios. This research should focus on multiple exposure pathways, such as comprehensive exposure assessments incorporating atmospheric quality parameters in urban areas, systematic evaluations of compound interactions and synergistic effects, quantitative analyses of occupational exposure patterns, and investigations into correlations between environmental contamination levels and endogenous biomarkers.

Building and enhancing research infrastructure for PAHs monitoring is essential for regional development. Such investments would generate crucial data to inform regulatory decision-making, foster international collaborations among developing nations, and establish robust frameworks for evidence-based policy formulation. A systematic approach to research and monitoring would strengthen analytical capabilities and ensure standardized protocols for pollutant monitoring across diverse geographical regions.

PAH	Abbreviation	Molar mass (g/mol)	Number of benzenic rings	LMW/HMW	Carcinogenic risk*
Naphthalene	Nap	128.17	2	LMW	2B
Acenaphthylene	Acy	152.18	2	LMW	3
Acenaphtene	Ace	154.21	2	LMW	3
Fluorene	Flu	166.22	2	LMW	3
Anthracene	Ant	178.23	3	LMW	2B
Phenanthrene	Phe	178.23	3	LMW	3
Fluoranthene	Flt	202.26	3	LMW	3
Pyrene	Pyr	202.25	4	HMW	3
Chrysene	Cry	228.28	4	HMW	2B
Benzo[a] anthracene	BaA	228.28	4	HMW	2B
Benzo[a] pyrene	BaP	252.31	5	HMW	1
Benzo[b] fluoranthene	BbK	252.31	4	HMW	2B
Benzo[k] fluoranthene	BbF	252.31	4	HMW	2B
Benzo[g, h, i] perylene	BghiP	276.33	6	HMW	3
Indeno(1,2,3-cd) pyrene	IndP	276.33	5	HMW	2B
Dibenzo[a, h] anthracene	DahA	278.35	5	HMW	2A

Table 1. Polycyclic aromatic hydrocarbons (PAH) properties and carcinogenic risk classification

* *Carcinogenic risk classification by IARC – International Agency for Research on Cancer*

Region	PAH	Sample	n°	Median	LOD	LOQ	Minimun-Maximun	Reference
Various Brazilian regions	BaP	Cocoa Beans (μg kg^{-1})	8	-	0.14	0.50	<LOD* - 9.06	Belo et al.[28]
	BaA				0.20	0.75	<LOD - 11.05	
	Chr				0.31	0.75	<LOD - 20.90	
	BbF				0.14	0.75	<LOD - 8.95	
	BkF				0.29	0.75	<LOD - 9.06	
	IcdP				0.01	0.75	<LOD - 7.18	
	DahA				0.30	0.75	<LOD - 4.06	
	BghiP				0.28	0.75	<LOD	
Southeast	BaA	Vegetable oil blends (μg kg^{-1})	36	-	0.16	0.30	0.43 - 8.82	Tfouni et al.[31]
	Chr				0.07	0.30	1.22 - 7.09	
	BjF				0.52	3.00	<LOD - 5.85	
	BbF				0.16	0.30	0.51 - 11.77	
	BkF				0.03	0.30	<LOD - 5.53	
	BaP				0.07	0.30	0.29 - 25.51	
	DalP				0.03	0.30	<LOD - 0.32	
	DahA				0.04	0.30	<LOD - 3.36	
	IcdP				0.19	3.00	<LOD - 15.65	
	DaeP				0.10	0.30	<LOD - 1.71	
	DaiP				0.06	0.30	<LOD - 0.67	
	DahP				0.02	0.30	<LOD	
South	BaA	Soybens (*Glycine max* L.)	39	-	-	0.1	<LOQ** - 58.75	Garcia et al.[111]
	Chr	(μg kg^{-1})			-	0.1	<LOQ - 103.89	
	BbF				-	0.1	<LOQ - 18.52	
	BkF				-	0.1	<LOQ - 3.71	
	BaP				-	0.1	<LOQ - 3.49	
	DaiP				-	0.1	<LOQ - 8.06	
Northeast	Nap	Guarana seeds (*Paullinia*	38	89.5	17.9	59.7	20.2 - 434	Junior et al.[112]
	Acy	*cupana*) (μg kg^{-1})		39.88	15.7	52.4	<LOD - 468	

Table 2. Levels of reported polycyclic aromatic hydrocarbons in different food samples from all Brazilian regions in the last ten years.

	Ace			75.5	8.33	27.7	31.3 - 334	
	Flu			113.9	15.3	51.1	34.5 - 384	
	Phe			62.1	18.3	61.1	<LOD - 621	
	Ant			15.24	2.68	8.92	<LOD - 130	
	Flt			20	12.2	40.5	6.18 - 78.3	
	Pyr			25.34	19.2	63.9	<LOD - 329	
	BaA			2.27	10.2	34.1	<LOD - 22.7	
	Chr			13.8	20.4	68.2	10.7 - 78.9	
Northeast	BaA	Cocoa beans (μg kg^{-1})	77	-	0.08	0.30	<LOQ** - 30.6	[29]
	Chr				0.19	0.30	<LOQ - 47	
	BbF				0.11	0.30	<LOQ - 17.7	
	BkF				0.08	0.30	<LOQ - 12.1	
	BaP				0.11	0.30	<LOQ - 22.2	
	DaeP				0.07	0.30	<LOQ - 4.3	
Southeast	BaA	Tea (μg kg^{-1})	10	27	0.3	0.5	3.8 - 44	Tfouni et al. (2017)
	Chr			54	0.3	0.5	8.7 - 84	
	BbF			21	0.3	0.5	4.1 - 35	
	BaP			14	0.2	0.5	2.3 - 54	
Southeast	Σ4PAHs (BaA, Chr, BbF, BaP)	Salami (μg kg^{-1})	22	-	0.15 - 0.30***	0.50 - 1.00	<LOQ - 33.84	[37]
Southeast	Nap	Cachaça (μg L^{-1})	5	-	0.061	0.206	<LOD - 1.733	Souza et al. (2022)
	Ace				0.081	0.272	<LOD - 4.089	
	Flu				0.186	0.622	.<LOD - 12.638	
	Phe				0.108	0.362	<LOD - 0.692	
	Ant				0.162	0.540	<LOD	
	Flt				0.072	0.242	<LOD - 4,096	
	Pyr				0.082	0.266	<LOD - 1,823	
	BaA				0.134	0.448	<LOD - 1,059	
	Acy				0.086	0.288	<LOD - 0.799	
	BaP				0.170	0.568	<LOD - 0.447	

South	Nap	Rice grains (μg kg^{-1})	16	-	0.29	0.86	<LOD - 35.6	Bertinette et al. (2017)
	Acy				0.32	0.97	<LOD - 14.3	
	Flu				0.20	0.52	<LOD - 15.3	
	Phe				0.14	0.37	<LOD - 44.4	
	Ant				0.16	0.41	<LOD - 19.2	
	Flt				0.11	0.28	<LOD - 11.3	
	Pyr				0.11	0.27	<LOD - 9.2	
	BaA				0.17	0.46	<LOD - 1.5	
	Chr				0.18	0.48	<LOD - 4.9	
Southeast	Nap	Cachaça (μg L^{-1})	5	-	0.06	0.21	0.32 - 2.95	Barbosa et al. (2017)
	Ace				0.08	0.27	0.51 - 2.87	
	Flu				0.19	0.62	1.73 - 3.61	
	Phe				0.11	0.36	<LOD - 0.63	
	Ant				0.16	0.54	<LOD	
	Flt				0.07	0.24	0.24 - 3.14	
	Pyr				0.08	0.27	<LOD - 4.57	
	BaA				0.13	0.45	<LOD - 5.26	
	Acy				0.09	0.29	0.70 - 5.26	
	BaP				0.17	0.57	<LOD - 6.93	
South	Flu	Corn grains (μg kg^{-1})	22	-	-	4.00	<LOD - 10.93	[113]
	Phe				-	1.20	<LOD - 51.28	
	Ant				-	2.30	<LOD - 16.09	
	Flt				-	1.80	2.65 - 17.99	
	Pyr				-	1.40	3.28 - 17.96	
	BaA				-	1.30	<LOD - 7.25	
	Chr				-	1.00	<LOD - 7.02	
	Σ7PAHs (Flu, Phe, Ant, Flt, Pyr, BaA, Chr)				-	1.00 - 4.00	5.93 - 127.32	

South	Σ16PAHs (Nap, Ace, Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF,	Rice (μg kg^{-1})	6	-	-	1.0 - 5.0	1.0 - 7.0	[114]
	BaP, IcdP, DahA, BghiP)								
South	Σ8PAHs (Flu, Phe, Ant, BaA, BbF, BkF, IcdP, DahA)	Honey (μg kg^{-1})	13	-	- 0.3 - 3.0	1.0 - 10.0	1.4 - 23.3	Marcolin et al. (2022)
South	Σ16PAHs (Nap, Ace, Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF, BaP, IcdP, DahA, BghiP)	Brown mussels (μg kg^{-1})	15	-	0.07 - 0.29	0.82	37.8 - 169	Santiago et al. (2016)
Southeast	Σ14PAHs (Ace, Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF, BaP, IcdP, DahA)	Baby food (μg kg^{-1})	50	-	0.05	0.1	<LOD	[115]
Southeast	Σ16PAHs (Nap, Ace, Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF,	Mussels (Perna perna) and Oysters (Crassostrea rhizophorae) (μg kg^{-1})	27 Oysters 27	- -	-	-	88.38 - 138.62 96.94 - 988.76	Souza et al. (2023)
	BaP, IcdP, DahA, BghiP)		Mussels						
South	Σ16PAHs (Nap, Ace,	Mussels (Perna perna) (μg kg^{-1})	90	-	0,00001 - 0,00004	0,00114	38.96 - 243,59	[34]
	Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF, BaP, IcdP, DahA, BghiP)								
Southeast	BaP	Chocolate (μg kg^{-1})	38	-	0.11	0.50	1.09 - 10.42	[30]
	Σ4PAHs (Chr, BaP, BaA, BbF)				0.11 - 0.57	0.50 - 1.00	8.38 - 41.58		

Southeast	Σ16PAHs (Nap, Ace, Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF,	Cachaça stored in tanks (μg L^{-1})	30	51.57	0.05 - 0.10	0.20 - 0.30	-	[116]
	BaP, IcdP, DahA, BghiP)	Cachaça stored in glass jugs (μg L^{-1})		6.07			-	
Midwest	Σ13PAHs (BaA, BbF, BjF, BkF, BaP, Chr, DahA, DaeP, DahP, DaiP, DalP, IcdP, 5MChr)	Soybean grains (μg kg^{-1})	22	3.14	-	-	1.76 - 5.06	[117]
Southeast	BaP	Coalho cheese (μg kg^{-1})	30	-	0.003	0.008	140.7 - 149.4	[36]
	DahA				0.002	0.007	135.0 - 139.5	
Southeast	Σ17PAHs (BkF, Phe, Chr, IcdP, BaA, Ant, Flu, BaP, Flt, Pry, BghiP, DahA, DalP, BbjF, Ace, Acy, Nap)	Whitemouth Croaker (μg kg^{-1})	-	-	0,00004 - 0,0081	-	1.32 - 5.41	[118]
Southeast	Nap	Beer (μg L^{-1})	26	-	0.025	0.085	<LOD - 21.85	[119]
	Acy				0.0.18	0.062	<LOD - 1.93	
	Ace				0.014	0.046	<LOD - 1.58	
	Flu				0.012	0.042	<LOD - 4.96	
	Phe				0.003	0.013	<LOD - 19.06	
	Ant				0.003	0.011	<LOD - 6.95	
	Flt				0.003	0.010	<LOD - 1.30	
	Pyr				0.040	0.012	<LOD - 1.48	
	BaA				0.006	0.020	<LOD - 3.04	
	Chr				0.013	0.043	<LOD - 6.84	
	BbF				0.02	0.070	<LOD - 16.05	

	BkF				0.013	0.044	<LOD - 13.62	
Southeast	Σ10PAHs (Flt, Pyr, BaA, Chr, BbF, BkF, BaP, IcdP, DahA, BghiP)	Roasted coffe (μg kg^{-1})	24	-	0.03 - 0.18	0.11 - 0.59	1.0 - 11.29	[120]
Southeast	16PAHs (Nap, Ace, Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF, BaP, IcdP, DahA, BghiP)	Cachaça (μg L^{-1})	29	-	0.01 - 0.08	0.02 - 0.22	1.96 - 52.0	[121]
Southeast	Σ13PAHs (BaA, Chr, 5MChr, BjF, BbF, BkF, BaP, DalP, DahA, IcdP,	Canola oil (μg kg^{-1}) Sunflower oil (μg kg^{-1})	70	-	0.07 - 1.95	0.3 - 3.0	<LOD - 31.7 0.65 - 17.88	[32]
	DaeP, DaiP, DahP)	Corn oil (μg kg^{-1})					2.61 - 38.23	
Southeast	Σ16PAHs (Nap, Ace,	Coffee brew (μg L^{-1})	27	-	0.003 - 0.067	0.025 - 0.224	1.086 - 2.169	[122]
	Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF, BaP, IcdP, DahA, BghiP)							
Southeast	BaA, BaP, BbF, BkF, BaP	Coffee (C, arabica) (μg kg^{-1})	2		0.006 - 0.01	-	0.015 - 0.105	[123]
		Coffee (C. canephora) (μg kg^{-1})					0.011 - 0.111	
Northeast	Σ37PAHs	Seafood (finfish and shellfish) (μg kg^{-1})	194	-	-	-	8.71 - 418	[124]
North	Σ11PAHa (BaA, Chr, BbF, BkF, BaP, IcdP, DahA, DaiP, DalP, DaeP, DahP)	Jambu (μg kg^{-1})	6	-	0.2 - 0.4	0.6 - 1.5	1.49 - 2.76	[44]

Southeast	Σ16PAHs (Nap, Ace, Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF, BaP, IcdP, DahA, BghiP)	Soft drinks (µg L^{-1})	34	-	0.1	0.20	0.20 - 1.82	Caldeirão et al. (2021)
Brazilian coast	BaA	Seafood (Fish, Lobster, Mussel,	110	-	1.25	5.00	<LOQ - 64.2	[39]
	Chr	Oyster, Octopus) (µg kg^{-1})			1.25	5.00	<LOQ - 85.4	
	BbF				1.25	5.00	<LOQ - 105	
	BkF				1.25	5.00	<LOQ - 5.14	
	BaP				0.90	1.25	<LOQ - 4.10	
	DahA				1.00	2.50	<LOQ - 4.45	
	BghiP				1.00	5.00	<LOQ - 7.15	
	IcdP				1.00	5.00	<LOQ - 5.35	
	Σ4PAHs (BaA, Chr, BbF, BaP)				0.90 - 1.25	1.25 - 5.00	<LOQ - 139	
South and Southeast	Σ37PAHs	Sardine muscle (µg kg^{-1})	50	-	0.02 - 0.07	0.50	<LOQ - 4074	[35]
Various brazilian regions	Σ16PAHs (Nap, Ace, Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF, BaP, IcdP, DahA, BghiP)	Toasted Guaraná seeds (µg kg^{-1})	6	-	0.05 - 0.101	0.01 - 0.2	<LOD - 0.78	[125]
Southeast	Σ16PAHs (Nap, Ace, Acy, Chr, Flu, Phe, Ant, Flt, Pyr, BaA, BbF, BkF, BaP, IcdP, DahA, BghiP)	Cachaça (µg L^{-1})	5	-	0.25	1.00	2.0 - 4.0	[126]

** Limit of Detection; ** Limit of Quantification; ***Range of LOD or LOQ regarding the sum of a PAH group*

Food sample	IR (g/day)	C (mg/kg)	EDI (mg/kg.bw.day)	EDI (ug/kg.bw.day)	HQ	CR	Reference
Vegetable oil	11.1	NA*	NE	NE	NE	NE	-
Soybean	1	NA	NE	NE	NE	NE	-
Tea	48.4	NA	NE	NE	NE	NE	-
Processed meats	0.3	NA	NE	NE	NE	NE	-
Cachaça	1.7	0.00173	4.20E-05	4.20E-08	2.10E-06	5.04E-06	Souza et al. (2022)
Rice grains	131.4	0.0356	6.68E-02	6.68E-05	3.34E-03	**8.02E-03**	Bertinette et al. (2017)
Corn	16.6	NA	NE	NE	NE	NE	-
Honey	2.1	NA	NE	NE	NE	NE	-
Seafood	0.7	NA	NE	NE	NE	NE	-
Fish	13.1	NA	NE	NE	NE	NE	-
Chocolate	1.5	NA	NE	NE	NE	NE	-
Cheese	5.8	NA	NE	NE	NE	NE	-
Beer	34.7	NA	NE	NE	NE	NE	-
Jambu	3.4	NA	NE	NE	NE	NE	-
Soda	67.1	NA	NE	NE	NE	NE	-
Coffee	163.2	NA	NE	NE	NE	NE	-

Table 3. Risk assessment, Hazard Quotient (or Index), and Cancer Risk of naphthalene, using available data in the review.

**NA: not available; **NE: not estimated.*

Food sample	IR (g/day)	C (mg/kg)	EDI (mg/kg.bw.day)	EDI (ug/kg.bw.day)	HQ	CR	Reference
Vegetable oil	11.1	2.55E-02	4.05E-03	4.05E-06	**1.35E+01**	**4,05E-03**	[31]
Soybean	1	3.49E-03	4.99E-05	4.99E-08	1.66E-01	**4,99E-05**	[111]
Tea	48.4	5.40E-02	3.73E-02	3.73E-05	**1.24E+02**	**3,73E-02**	[127]
Processed meats	0.3	NA*	NE**	NE	NE	NE	-
Cachaça	1.7	4.47E-04	1.09E-05	1.09E-08	3.62E-02	**1,09E-05**	Barbosa et al. (2017)
Rice grains	131.4	NA	NE	NE	NE	NE	-
Corn	16.6	NA	NE	NE	NE	NE	-
Honey	2.1	NA	NE	NE	NE	NE	-
Seafood	0.7	NA	NE	NE	NE	NE	-
Fish	13.1	NA	NE	NE	NE	NE	-
Chocolate	1.5	1.04E-02	2.23E-04	2.23E-07	7.44E-01	**2,23E-04**	[30]
Cheese	5.8	1.49E-01	1.24E-02	1.24E-05	**4.13E+01**	**1,24E-02**	[36]
Beer	34.7	NA	NE	NE	NE	NE	
Jambu	3.4	NA	NE	NE	NE	NE	
Soda	67.1	NA	NE	NE	NE	NE 0	
Coffee	163.2	NA	NE	NE	NE	NE	

Table 4. Risk assessment, Hazard Quotient (or Index), and Cancer Risk of benzo[a] pyrene, using available data in the review.

**NA: not available; **NE: not estimated.*

doi.org/10.32388/9UA4UF.2

Food sample	IR (g/day)	C summation (mg/kg)	C of PAHs with RfD (mg/kg)	C of PAHs with CR (mg/kg)	EDI summation (ug/kg.bw.dia)	EDI of PAHs with RfD (ug/kg.bw.day)	EDI of compounds with CR (ug/kg.bw.day)	HI Σ	CR	Reference
Vegetable oil	11.1	0.8628	0.02551	0.06574	1.37E-01	4.05E-03	1.04E-02	**1,35E+01**	**3,76E-02**	[31]
Soybean	1	0.19642	0.00349	0.18836	2.81E-03	4.99E-05	2.69E-03	1,66E-01	**3,26E-03**	[111]
Tea	48.4	0.217	0.058	0.217	1.50E-01	4.01E-02	1.50E-01	1,66E-01	**1,80E-01**	[127]
Processed meats	0.3	0.03384	0.03384	0.03384	1.45E-04	1.45E-04	1.45E-04	4,83E-01	**1,74E-04**	[37]
Cachaça	1.7	0.027376	0.024379	0.003239	6.65E-04	5.92E-04	7.87E-05	1,21E-03	**9,60E-05**	Souza et al. (2022)
Rice grains	131.4	0.1557	0.0906	0.042	2.92E-01	1.70E-01	7.88E-02	3,39E-02	**1,74E-02**	Bertinette et al. (2017)
Corn	16.6	0.12732	0.06297	0.0252	3.02E-02	1.49E-02	5.98E-03	3,64E-02	**6,04E-04**	[113]
Honey	2.1	0.0233	0.0233	0.0233	6.99E-04	6.99E-04	6.99E-04	2,06E-03	**9,16E-04**	Marcolin et al. (2022)
Seafood	0.7	0.98876	0.98876	0.98876	9.89E-03	9.89E-03	9.89E-03	2,02E-02	**2,29E-02**	[4]
Fish	13.1	4.074	4.074	4.074	7.62E-01	7.62E-01	7.62E-01	**1,56E+00**	**2,92E+00**	[35].
Chocolate	1.5	0.04158	0.01042	0.04158	8.91E-04	2.23E-04	8.91E-04	7,44E-01	**1,07E-03**	[30].
Cheese	5.8	0.2889	0.1494	0.1494	2.39E-02	1.24E-02	1.24E-02	**4,13E+01**	**2,48E-02**	Rocha et al. (2010).
Beer	34.7	0.07488	0.03776	0.0614	3.71E-02	1.87E-02	3.04E-02	3,82E-02	**6,42E-03**	[119].
Jambu	3.4	0.00276	0.00276	0.00276	1.34E-04	1.34E-04	1.34E-04	3.56E-030	**3,10E-04**	[44].
Soda	67.1	0.00182	0.00182	0.00182	1.74E-03	1.74E-03	1.74E-03	3,56E-03	**4,03E-03**	Caldeirão et al. (2021)
Coffee	163.2	0.01129	0.01129	0.01129	2.63E-02	2.63E-02	2.63E-02	3,76E-01	**6,08E-02**	[120]

Table 5. Risk assessment, Hazard Quotient (or Index), and Cancer Risk of the sum of PAHs, using available data in the review.

**NA: not available; **NE: not estimated.*

Supplementary Material

Food sample	IR (g/day)	C (mg/kg)	EDI (mg/kg.bw.day)	EDI (ug/kg.bw.day)	HQ	CR	Reference
Vegetable oil	11.1	NA*	NE**	NE	NE	NE	-
Soybean	1	NA	NE	NE	NE	NE	-
Tea	48.4	NA	NE	NE	NE	NE	-
Processed meats	0.3	NA	NE	NE	NE	NE	-
Cachaça	1.7	0.00086	2.09E-05	2.09E-08	1.04E-06	2.51E-06	
Rice grains	131.4	0.0178	3.34E-02	3.34E-05	1.67E-03	**4.01E-03**	Bertinette et al. (2017)
Corn	16.6	NA	NE	NE	NE	NE	-
Honey	2.1	NA	NE	NE	NE	NE	-
Seafood	0.7	NA	NE	NE	NE	NE	-
Fish	13.1	NA	NE	NE	NE	NE	-
Chocolate	1.5	NA	NE	NE	NE	NE	-
Cheese	5.8	NA	NE	NE	NE	NE	-
Beer	34.7	NA	NE	NE	NE	NE	-
Jambu	3.4	NA	NE	NE	NE	NE	-
Soda	67.1	NA	NE	NE	NE	NE	-
Coffee	163.2	NA	NE	NE	NE	NE	-

Table S1. Risk assessment, Hazard Quotient (or Index), and Cancer Risk of naphthalene, using the available and estimated median data in this review.

**NA: not available; **NE: not estimated.*

doi.org/10.32388/9UA4UF.2

Food sample	**IR (g/day)**	**C (mg/kg)**	**EDI (mg/kg.bw.day)**	**EDI (ug/kg.bw.day)**	**HQ**	**CR**	**Reference**
Vegetable oil	11.1	1.29E-02	2.05E-03	2.05E-06	**6.82E+00**	**2.05E-03**	
Soybean	1	1.74E-03	2.49E-08	2.49E-08	8.29E-02	**2.49E-05**	
Tea	48.4	2.28E-02	1.95E-02	1.95E-05	**6.49E+01**	**1.95E-02**	
Processed meats	0.3	NA*	NE**	NE	NE	NE	-
Cachaça	1.7	4.47E-04	1.09E-05	1.09E-08	3.26E-02	**1.09E-05**	Barbosa et al. (2017)
Rice grains	131.4	NA	NE	NE	NE	NE	-
Corn	16.6	NA	NE	NE	NE	NE	-
Honey	2.1	NA	NE	NE	NE	NE	-
Seafood	0.7	NA	NE	NE	NE	NE	-
Fish	13.1	NA	NE	NE	NE	NE	-
Chocolate	1.5	5.75E-03	1.23E-04	1.23E-07	4.11E-01	**1.23E-04**	
Cheese	5.8	1.45E-01	1.20E-02	1.20E-05	**4.01E+01**	**1.20E-02**	
Beer	34.7	NA	NE	NE	NE	NE	
Jambu	3.4	NA	NE	NE	NE	NE	
Soda	67.1	NA	NE	NE	NE	NE	
Coffee	163.2	NA	NE	NE	NE	NE	

Table S2. Risk assessment, Hazard Quotient (or Index), and Cancer Risk of benzo[a]pyrene, using the available and estimated median data in this review.

**NA: not available; **NE: not estimated.*

doi.org/10.32388/9UA4UF.2

Food sample	IR (g/day)	C summation (mg/kg)	C of PAHs with RfD (mg/kg)	C of PAHs with CR (mg/kg)	EDI summation (ug/kg.bw.dia)	EDI of PAHs with RfD (ug/kg.bw.day)	EDI of compounds with CR (ug/kg.bw.day)	HI
Vegetable oil	11.1	0.04433	0.0129	0.04216	7.03E-03	2.05E-03	6.69E-03	**6.82E**
Soybean	1	0.09809	0.00174	0.09406	1.40E-03	2.49E-05	1.34E-03	8.29E-
Tea	48.4	0.10135	0.02815	0.10135	7.01E-02	1.95E-02	7.01E-02	8.29E-
Processed meats	0.3	0.016912	0.01692	0.01692	7.25E-05	7.25E-05	7.25E-05	2.42E-
Cachaça	1.7	0.01363	0.01238	0.0016	3.31E-04	3.01E-04	3.89E-05	6.13E-
Rice grains	131.4	0.07785	0.0453	0.021	1.46E-01	8.50E-02	3.94E-02	1.70E-
Corn	16.6	0.06662	0.03444	0.00713	1.58E-02	8.17E-03	1.69E-03	1.99E-
Honey	2.1	0.01305	0.01305	0.01305	3.92E-04	3.92E-04	3.92E-04	1.15E-
Seafood	0.7	0.54285	0.54285	0.54285	5.43E-03	5.43E-03	5.43E-03	1.11E-
Fish	13.1	2.037	2.037	2.037	3.81E-01	3.81E-01	3.81E-01	**7.78E-**
Chocolate	1.5	0.02498	0.0575	0.02498	5.35E-04	1.23E-03	5.35E-04	4.11E+
Cheese	5.8	0.2823	0.14505	0.14505	2.34E-02	1.20E-02	1.20E-02	**4,01E**
Beer	34.7	0.04931	0.01905	0.03069	2.44E-02	9.94E-02	1.52E-02	1.93E-
Jambu	3.4	0.00212	0.00212	0.00212	1.03E-04	1.03E-04	1.03E-04	3.43E-
Soda	67.1	0.00101	0.00101	0.00101	9.68E-04	9.68E-04	9.68E-04	1.97E-
Coffee	163.2	0.00614	0.00614	0.00614	1.43E-02	1.43E-02	1.43E-02	2.04E-

Table S3. Risk assessment, Hazard Quotient (or Index), and Cancer Risk of the sum of PAHs, using the available and estimated median data in this review.

**NA: not available; **NE: not estimated.*

Statements and Declarations

Credit author statement

- Gabriel Henrique Savietto: Conceptualization; Formal analysis; Investigation; Methodology; Resources; Writing – original draft.
- André Augusto Vilela Lima: Conceptualization; Investigation; Writing – original draft.
- Ana Beatriz Cintra da Silva: Conceptualization; Investigation; Writing – original draft.
- Isarita Martins Sakakibara: Conceptualization; Writing – review & editing.
- Un-Jung Kim: Conceptualization; Writing – review & editing.
- Rajendiran Karthikraj: Conceptualization; Writing – review & editing.
- José L Domingo: Conceptualization; Writing – review & editing.
- Fernando Barbosa: Conceptualization; Writing – review & editing.
- Marília Cristina Oliveira Souza: Conceptualization; Funding acquisition; Supervision; Project administration; Writing – review & editing.

Funding

This research was supported by the Sao Paulo Research Foundation (FAPESP - process numbers 2022/06443-0, 2023/11634-2, 2024/03034-8, and 2024/03041-4).

Ethics approval and consent to participate

Not applicable.

Conflicts of 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.

Data availability

Data will be made available on request.

Acknowledgments

We would like to thank FAPESP for the financial support and for granting research fellowships (process numbers 2022/06443-0, 2023/11634-2, 2024/03034-8, and 2024/03041-4).

References

1. [a, b, c] *Scovronick N, Dora C, Fletcher E, Haines A, Shindell D (2015). "Reduce short-lived climate pollutants for multiple benefits." The Lancet. 38:628–31. doi:10.1016/S0140-6736(15)61043-1.*
2. ^ *Barbosa F Jr, Rocha BA, Souza MCO, Bocato MZ, Azevedo LF, Adeyemi JA, Santana A, Campiglia AD (2023). "Polycyclic aromatic hydrocarbons (PAHs): Updated aspects of their determination, kinetics in the human body, and toxicity." Journal of Toxicology and Environmental Health B. 26:28-65. doi:10.1080/10937404.2022.2164390.*
3. ^ *Siudek P (2022). "Atmospheric deposition of polycyclic aromatic hydrocarbons (PAHSs) in the coastal urban environment of Poland: Sources and transport patterns." International Journal of Environmental Research and Public Health. 19:14183. doi:10.3390/ijerph192114183.*
4. [a, b, c] *Souza MCO, Rocha BA, Cruz JC, Palir N, Campíglia AD, Domingo JL, Barbosa F (2023). "Risk characterization of human exposure to polycyclic aromatic hydrocarbons in vulnerable groups." Science of the Total Environment. 892:164219. doi:10.1016/j.scitotenv.2023.164219.*
5. [a, b, c] *European Food Safety Authority (EFSA) (2008). "Polycyclic Aromatic Hydrocarbons in Food [1] - Scientific Opinion of the Panel on Contaminants in the Food Chain 2008." EFSA Journal. 6:724. doi:10.2903/j.efsa.2008.724.*
6. ^ *Food Standards Agency (2024). "Polycyclic Aromatic Hydrocarbons." Food Standards Agency. www.food.gov.uk/business-guidance/polycyclic-aromatic-hydrocarbons#:~:text=Polycyclic%20aromatic%20hydrocarbons%20(PAHs)%20are.*
7. ^ *Dutta K, Shityakov S, Zhu W, Khalifa I (2022). "High-risk meat and fish cooking methods of polycyclic aromatic hydrocarbons formation and its avoidance strategies." Food Control. 142:109253. doi:10.1016/j.foodcont.2022.109253.*
8. ^ *International Agency for Research on Cancer (IARC) (2024). "IARC Monographs on the Identification of Carcinogenic Hazards to Humans." IARC. https://www.iarc.who.int/.*
9. ^ *Skupinska K, Misiewicz I, Kasprzycka-Guttman T (2004). "Polycyclic aromatic hydrocarbons: physicochemical properties, environmental appearance and impact on living organisms." Acta Poloniae Pharmaceutica - Drug Research. 61:233-40. PMID 15481250.*
10. ^ *Xia Z, Duan X, Qiu W, Liu D, Wang B, Tao S, Jiang Q, Lu B, Song Y, Hu X (2010). "Health risk assessment on dietary exposure to polycyclic aromatic hydrocarbons (PAHs) in Taiyuan, China." Science of the Total Environment. 22:5331-7. doi:10.1016/j.scitotenv.2010.08.008.*
11. ^ *Trasande L, Shaffer RM, Sathyanarayana S (2018). "Food additives and child health." Pediatrics. 142:1410. doi:10.1542/peds.2018-1408.*
12. ^ *Lioy PJ, Greenberg A (1990). "Factors associated with human exposures to polycyclic aromatic-hydrocarbons." Toxicology and Industrial Health. 6(2):209–223. doi:10.1177/074823379000600020.*
13. [a, b] *Domingo JL (2011). "Influence of cooking processes on the concentrations of toxic metals and various organic environmental pollutants in food: a review of the published literature." Critical Reviews Food Science Nutrition. 51:29-37. doi:10.1080/10408390903044511.*
14. [a, b, c, d] *Bansal V, Kim KH (2015). "Review of PAH contamination in food products and their health hazards." Environment International. 84:26-38. doi:10.1016/j.envint.2015.06.016.*

15. ^Zhang H, Zhang X, Wang Y, Bai P, Hayakawa K, Zhang L, Tang N (2022). "Characteristics and influencing factors of polycyclic aromatic hydrocarbons emitted from open burning and stove burning of biomass: A brief review." International Journal of Environmental Research and Public Health. 19:3944. doi:10.3390/ijerph19073944.
16. a, bLu J, Zhang Y, Zhou H, Cai K, Xu B (2024). "A review of hazards in meat products: Multiple pathways, hazards and mitigation of polycyclic aromatic hydrocarbons." Food Chemistry. 445:138718. doi:10.1016/j.foodchem.2024.138718.
17. ^Sánchez-Arévalo CM, Olmo-García L, Fernández-Sánchez JF, Carrasco-Pancorbo A (2020). "Polycyclic aromatic hydrocarbons in edible oils: An overview on sample preparation, determination strategies, and relative abundance of prevalent compounds." Comprehensive Reviews in Food Science and Food Safety. 19:3528-3573. doi:10.1111/1541-4337.12637.
18. ^Faboya OL, Sojinu SO, Oguntuase BJ, Sonibare OO (2020). "Impact of forest fires on polycyclic aromatic hydrocarbon concentrations and stable carbon isotope compositions in burnt soils from tropical forest, Nigeria." Scientific African. 8:e00331. doi:10.1016/j.sciaf.2020.e00331.
19. ^Hu G, Cai K, Li Y, Hui T, Wang Z, Chen C, Xu B, Zhang D (2021). "Significant inhibition of garlic essential oil on benzo[a] pyrene formation in charcoal-grilled pork sausages relates to sulfide compounds." Food Research International. 141:110127. doi:10.1016/j.foodres.2021.110127.
20. a, bSampaio GR, Guizellini GM, Silva SA, Almeida AP, Pinaffi-Langley ACC, Rogero MM, Camargo AC, Torres EAFS (2021). "Polycyclic aromatic hydrocarbons in foods: Biological effects, legislation, occurrence, analytical methods, and strategies to reduce their formation." International Journal of Molecular Science. 22:6010. doi:10.3390/ijms22116010.
21. a, bFood Standards Agency (FSA) (2024). "Polycyclic aromatic hydrocarbons." Food Standards Agency (FSA). https://www.food.gov.uk/business-guidance/polycyclic-aromatic-hydrocarbons.
22. ^CODEX STAN (1995). "CODEX general standard for contaminants and toxins in food and feed." CODEX STAN. https://www.fao.org/fileadmin/user_upload/livestockgov/documents/1_CXS_193e.pdf.
23. ^National Health Surveillance Agency (ANVISA) (2022). "Resolution RDC N° 766, January 2022." ANVISA. https://anvisalegis.datalegis.net/action/ActionDatalegis.php?acao=categorias&cod_modulo=310&menuOpen=true.
24. a, b, cInstituto Brasileiro de Geografia e Estatística (IBGE) (2020). "Family Budget Survey (POF), Analysis of personal food consumption in Brazil, 2017–2018." IBGE. https://biblioteca.ibge.gov.br/visualizacao/livros/liv101742.pdf.
25. ^Souza MCO, Rocha BA, Souza JMO, Souza JCJ, Barbosa F (2021). "Levels of polybrominated diphenyl ethers in Brazilian food of animal origin and estimation of human dietary exposure." Food and Chemical Toxicology. 150:112040. doi:10.1016/j.fct.2021.112040.
26. ^United States Environmental Protection Agency (USEPA) (2022). "Regional Screening Levels (RSLs) - Generic Tables." United States Environmental Protection Agency (USEPA). https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables.
27. ^Centers for Disease Control and Prevention (CDC) (2022). "Cancer Risk Factors." CDC. https://www.cdc.gov/cancer/riskfactors/index.html.
28. a, bBelo RFC, Figueiredo JP, Nunes CM, Pissinatti R, Souza SVC, Junqueira RG (2017). "Accelerated solvent extraction method for the quantification of polycyclic aromatic hydrocarbons in cocoa beans by gas chromatography-mass spectrometry." Journal of Chromatography B. 1053:87-100. doi:10.1016/j.jchromb.2017.03.017.
29. a, bAbballe C, Gomes FML, Lopes BD, Oliveira APF, Berto MI, Efraim P, Tfouni SAV (2021). "Cocoa beans and derived products: Effect of processing on polycyclic aromatic hydrocarbons levels." LWT - Food Science and Technology. 135:110019. doi:10.1016/j.lwt.2020.110019.
30. a, b, c, d, eGuizellini GM, Sampaio GR, Silva SA, Soares-Freitas RAM, Almeida AP, Torres EAFS (2023). "Concentration and potential health risk of polycyclic aromatic hydrocarbons for consumers of chocolate in Brazil." Food Chemistry. 405:134853. doi:10.1016/j.foodchem.2022.134853.
31. a, b, c, dTfouni SAV, Padovani GR, Reis RM, Furlani RPZ, Camargo MCR (2014). "Incidence of polycyclic aromatic hydrocarbons in vegetable oil blends." Food Control. 46:539-543. doi:10.1016/j.foodcont.2014.06.028.
32. a, bMolle DRD, Abballe C, Gomes FML, Furlani RPZ, Tfouni SAV (2017). "Polycyclic aromatic hydrocarbons in canola, sunflower and corn oils and estimated daily intake." Food Control. 81:96-100. doi:10.1016/j.foodcont.2017.05.045.
33. ^Santiago IU, Molisani MM, Nudi AH, Scofield AL, Wagener ALR, Filho AML (2017). "Hydrocarbons and trace metals in mussels in the Macaé coast: Preliminary assessment for a coastal zone under influence of offshore oil field exploration in southeastern Brazil." Marine Pollution Bulletin. 103:349-353. doi:10.1016/j.marpolbul.2015.12.034.
34. a, bRamos ABA, Farias CO, Hamacher C, Araújo M (2017). "Assessment of PAHs occurrence and distribution in brown mussels (Perna perna Linnaeus 1758) subject to different levels of contamination in Brazil." Regional Studies in Marine Science. 14:145-151. doi:10.1016/j.rsma.2017.05.005.
35. a, b, c, dMassone CG, Santos AA, Ferreira PG, Carreira RS (2021). "A baseline evaluation of PAH body burden in sardines from the southern Brazilian shelf." Marine Pollution Bulletin. 163:111949. doi:10.1016/j.marpolbul.2020.111949.
36. a, b, cRocha HB, Silva ACR, Balthazar CF, Guimarães JT, Freitas MQ, Esmerino EA, Pimentel TC, Raices RL, Cruz AG, Quiterio SL (2020). "Charcoal-barbecued Coalho cheese: An investigation on the formation and ingestion of polycyclic aromatic hydrocarbons." LWT – Food Science and Technology. 124:109186. doi:10.1016/j.lwt.2020.1

09186.

37. a, b, c Silva SA, De Rossi GZ, Ossugi MM, Almeida AP, Guizellini GM, Sampaio GR, Torres EAFS (2022). "Quantification of Polycyclic Aromatic Hydrocarbons in Commonly Consumed Salami in Brazil." Food Analytical Methods. 16:293-303. doi:10.1007/s12161-022-02414-z.
38. ^ Barbosa RB, Santiago WD, Alvarenga GF, Oliveira RES, Ferreira VRF, Nelson DL, Cardoso MG (2022). "Physical-Chemical Profile and Quantification of Phenolic Compounds and Polycyclic Aromatic Hydrocarbons in Cachaça Samples Aged in Oak, (Quercus sp.) Barrels with Different Heat Treatments." Food and Bioprocess Technology. 15:1977-1987. doi:10.1007/s11947-022-02853-w.
39. a, b de Melo APZ, Hoff RB, Molognoni L, Kleemann CR, Oliveira T, Oliveira LVA, Daguer H, Barreto PLM (2022). "Determination of polycyclic aromatic hydrocarbons in seafood by PLE-LC-APCI-MS/MS and preliminary risk assessment of the northeast Brazil oil spill." Food Analytical Methods. 15:1826-1842. doi:10.1007/s12161-022-02252-z.
40. a, b Agus BAP, Rajentran K, Selamat J, Lestari SD, Umar NB, Hussain N (2023). "Determination of 16 EPA PAHs in food using gas and liquid chromatography." Journal of Food Composition and Analysis. 116:105038. doi:10.1016/j.jfca.2022.105038.
41. a, b Andrade ADC, Fernandes GM, Martins DA, Cavalcante RM, Chaves MRB, de Souza AA, da S Filho JP, Nascimento RF, de Lima SG (2024). "Concentrations, sources and risks of polycyclic aromatic hydrocarbons in sediments from the Parnaiba Delta basin, Northeast Brazil." Chemosphere. 349:140889. doi:10.1016/j.chemosphere.2023.140889.
42. a, b Garlindo MV, Hantao LW, Sampaio NMFM, Pessoto MA, Oliveira WS, Godoy HT (2025). "Analysis of polycyclic aromatic hydrocarbons in Brazilian human milk: A simple and effective approach." Food Control. 167:110796. doi:10.1016/j.foodcont.2024.110796.
43. a, b Brazil (2022). "Higher Education Census 2022 Statistical Notes." Directorate of Educational Statistics — DEED. https://abmes.org.br/arquivos/documentos/siteABMES.
44. a, b, c Neves DA, Oliveira WS, Petrarca MH, Rodrigues MI, Godoy HT (2021). "A multivariate approach to overcome chlorophyll interferences in the determination of polycyclic aromatic hydrocarbons in jambu (Acmella olerarea (L.) R.K. Jansen)." Journal of Food Composition and Analysis. 104:104189. doi:10.1016/j.jfca.2021.104189.
45. ^ Lopes MACQ, Brasil D, Oliveira GMM (2021). "Research and Publication in Brazil: Where we are and Where we Head to." International Journal of Cardiovascular Sciences. 34(2):231-235. doi:10.36660/ijcs.20200004.
46. ^ Neema S, Chandrashekar L (2021). "Research funding: Why, when, and how?" Indian Dermatology Online Journal. 34(1):134-138. doi:10.4103%2Fidoj.IDOJ_684_20.
47. ^ Stavale R, Pupovac V, Ferreira GI, Guilherm DB (2022). "Research integrity guidelines in the academic environment: The context of Brazilian institutions with retracted publications in health and life sciences." Frontiers in Research Metrics and Analytics. 7:991836. doi:10.3389/frma.2022.991836.
48. a, b Beyer J, Jonsson G, Porte C, Krahn MM, Ariese F (2010). "Analytical methods for determining metabolites of polycyclic aromatic hydrocarbon (PAH) pollutants in fish bile: A review." Environmental Toxicology and Pharmacology. 30:224-244. doi:10.1016/j.etap.2010.08.004.
49. ^ Wise SA, Sander LC, Schantz MM (2014). "Analytical methods for determination of polycyclic aromatic hydrocarbonets (PAHs) — A historical perspective on the 16 U.S.EPA priority pollutant PAHs." Polycyclic Aromatic Compounds. 35:187-247. doi:10.1080/10406638.2014.970291.
50. ^ Konieczka P, Wolska L, Namiesnik J (2010). "Quality problems in determination of organic compounds in environmental samples, such as PAHs and PCBs." TrAC Trend in Analytical Chemistry. 29(7):706-717. doi:10.1016/j.trac.2010.03.012.
51. ^ Instituto Brasileiro de Geografia e Estatística (IBGE) (2019). "Southeast concentrates more than one third of urbanized areas in Brazil." IBGE. https://biblioteca.ibge.gov.br/visualizacao/periodicos/2415/epag_2021_dez.pdf.
52. ^ Almeida RDC, Tabak BM, Moreira TBS (2023). "Demographic aspects and regional income convergence in Brazil: a panel data approach." CEPAL Review. (139). https://repositorio.cepal.org.
53. ^ Brazil (2018). "Funding Agencies and Research in Brazil: A report for CAPES by Clarivate Analytics." Incites. https://www.gov.br.
54. ^ Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP (2018). "Research in São Paulo." FAPESP. https://fapesp.br.
55. ^ Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq (2018). "Management Report 2018." CNPq. https://www.gov.br.
56. ^ Vose PB, Cervellini A (1983). "Problems of Scientific Research in Developing Countries." IAEA bulletin. 25:37-40.
57. ^ Amarante V, Burger R, Chelwa G, Cockburn J, Kassouf A, Mckay A, Zurbrigg J (2021). "Underrepresentation of developing country researchers in development research." Applied Economics Letters. 29(17):1659-1664. doi:10.1080/13504851.2021.1965528.
58. ^ Nguyen A, Tran M (2024). The over-reliance in foreign science news in developing countries: Causes, consequences and solutions. Routledge. 1st ed. 1:1-16.
59. a, b Shrivastava S, Deshpande P, Daharwal SJ (2018). "Key aspects of analytical method development and validation." Journal of Ravishanka University. 31:31-39. doi:10.52228/JRUB.2018-31-1-6.
60. a, b Sharma S, Goyal S, Chauhan K (2018). "A Review on Analytical Method Development and Validation." International Journal of Applied Pharmaceutics. 10:8-15. doi:10.22159/ijap.2018v10i6.28279.

61. ^Brazil (2021). "Annual Report 2021." Commission for Economic Development, Industry, Commerce and Services (CDEICS). https://www.gov.br.

62. ^Brazil (2017). "Annual Report 2017." Commission for Economic Development, Industry, Commerce and Services (CDEICS). https://www.gov.br.

63. ^Araújo-Pereira M, Andrade BB (2024). "The heroic journey of young Brazilian Scientists: Challenges and opportunities." The Lancet Regional Health. 33:100735. doi:10.1016/j.lana.2024.100735.

64. ^Hutt PB (1985). "The Importance of Analytical Chemistry to Food and Drug Regulation." Vanderbilt Law Review. 38:479. doi:10.1093/jaoac/68.2.

65. ^Burns DT (2000). "Analytical Chemistry and the Law: Progress for Half a Millennium." Fresenius' Journal of Analytical Chemistry. 368:544–547. doi:10.1007/s002160000500.

66. a, bWang Y, Guan A, Wickramasekara S, Phillips KS (2018). "Analytical chemistry in the regulatory science of medical devices." Annual Review of Analytical Chemistry. 11:307–327. doi:10.1146/annurev-anchem-061417-125556.

67. a, bDoneski L, Dong MW (2023). "Pharmaceutical Regulations: An Overview for Analytical Chemist." LCGC International - North America. 41:211–215. doi:10.1146/annurev-anchem-061417-125556.

68. ^Madilo FK, Kunadu APH, Debrah KT (2024). "Challenges with Food Safety Adoption: A Review." Journal of Food Safety. 44(1):e13099. doi:10.1111/jfs.13099.

69. ^National Health Surveillance Agency (ANVISA) (2020). "Regulation of Food Products." ANVISA. https://www.gov.br/anvisa/pt-br/english/regulation-of-products/food.

70. ^Trienekens J, Zuurbier P (2008). "Quality and Safety Standards in the Food Industry, Developments and Challenges." International Journal of Production Economics. 113:107–122. doi:10.1016/j.ijpe.2007.02.050.

71. ^Henson S, Humphrey J (2010). "Understanding the complexities of private standards in global agri-food chains as they impact developing countries." Journal of Development Studies. 46(9):1628–1646. doi:10.1080/00220381003706494.

72. ^Boffetta P, Jourenkova N, Gustavsson P (1997). "Cancer risk from occupational and environmental exposure to polycyclic aromatic hydrocarbons." Cancer Causes and Control. 8:444–472. doi:10.1023/A:1018465507029.

73. ^Kim KH, Jahan SA, Kabir E (2013). "A review of Diseases Associated with Household Air Pollution Due to Use of Biomass Fuels." Journal of Hazardous Materials. 192(2):425–431. doi:10.1016/j.jhazmat.2011.05.087.

74. ^Zelinkova Z, Wenzl T (2015). "The occurrence of 16 EPA PAHs in food - A review." Polycyclic Aromatic Compounds. 35:248–284. doi:10.1080/10406638.2014.918550.

75. a, bEFSA Panel on Contaminants in the Food Chain (CONTAM) (2020). "Update on the risk assessment of mineral oil hydrocarbons in food." EFSA Journal. 18:e06287. https://food.ec.europa.eu/horizontal-topics/general-food-law_en.

76. ^Zhao X, Gao J, Zhai J, Yu X, Xiao Y (2023). "Recent evidence on polycyclic aromatic hydrocarbon exposure." Healthcare. 11:1958. doi:10.3390/healthcare11131958.

77. ^Chen SC, Liao CM (2006). "Health risk assessment on human exposed to environmental polycyclic aromatic hydrocarbons pollution sources." Science of The Total Environment. 366:112–123. doi:10.1016/j.scitotenv.2005.08.047.

78. ^Shen H, Tao S, Wang R, Wang B, Shen G, Li W, Su S, Huang Y, Wang X, Liu W, Li B, Sun K (2011). "Global time trends in PAH emissions from motor vehicles." Atmospheric Environment. 45:2067–2073. doi:10.1016/j.atmosenv.2011.01.054.

79. ^Siddique R, Zahoor AF, Ahmad H, Zahid FM, Karrar E (2021). "Impact of different cooking methods on polycyclic aromatic hydrocarbons in rabbit meat." Food Science and Nutrition. 9:3219–3227. doi:10.1002/fsn3.2284.

80. ^Domingo JL, Nadal M (2015). "Human dietary exposure to polycyclic aromatic hydrocarbons: A review of the scientific literature." Food and Chemical Toxicology. 86:144–153. doi:10.1016/j.fct.2015.10.002.

81. ^Sewor C, Eliason S, Jaakkola JJK, Amegah AK (2024). "Dietary polycyclic aromatic hydrocarbon (PAH) consumption and risk adverse birth outcomes: A systematic review and meta-analysis." Environmental Health Perspectives. 132:16002. doi:10.1289/EHP12922.

82. ^Kumosani TA, Moselhy SS, Asseri AM, Asseri AH (2012). "Detection of polycyclic aromatic hydrocarbons in different types of processed foods." Toxicology and Industrial Health. 29(3):300–304. doi:10.1177/074823371143393.

83. a, bSingh L, Varshney JG, Agarwal T (2016). "Polycyclic aromatic hydrocarbons formation and occurrence in processed food." Food Chemistry. 199:768–781. doi:10.1016/j.foodchem.2015.12.074.

84. ^Perera F (1981). "Carcinogenicity of airborne fine particulate benzo[a] pyrene: and appraisal of the evidence and need for control." Environmental Health Perspectives. 42:163–185. doi:10.1289/ehp.8142163.

85. a, b, cInternational Agency for Research on Cancer (IARC) (2011). "Polycyclic Aromatic Hydrocarbons and Associated Occupational Exposures, part 1, chapter 7." IARC. https://www.iarc.who.int/.

86. ^Bukowski B, Mokra K, Michalowicz J (2022). "Benzo[a] pyrene — Environmental occurrence, human exposure, and mechanisms of toxicity." International Journal of Molecular Sciences. 23:6348. doi:10.3390/ijms23116348.

87. ^Moorthy B, Chu C, Carlin DJ (2015). "Polycyclic aromatic hydrocarbons: From metabolism to lung cancer." Toxicological Sciences. 145(1):5-15. doi:10.1093/toxsci/kfv040.
88. ^Abdel-Shafy HI, Mansour MSM (2016). "A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation." Egyptian Journal of Petroleum. 25:107-123. doi:10.1016/j.ejpe.2015.03.011.
89. ^Agency for Toxic Substances and Disease Registry (ATSDR) (2023). "What Are Polycyclic Aromatic Hydrocarbons (PAHs)?" ATSDR. https://www.atsdr.cdc.gov/csem/polycyclic-aromatic-hydrocarbons/what_are_pahs.html.
90. a, bPreuss R, Angerer J, Drexler H (2003). "Naphthalene - an environmental and occupational toxicant." International Archives of Occupational and Environmental Health. 76:556-576. doi:10.1007/s00420-003-0458-1.
91. ^Yost EE, Galizia A, Kapraun DF, Persad AS, Vulimiri SV, Angrish M, Lee JS, Druwe IL (2021). "Health effects of naphthalene exposure: A systematic evidence map and analysis of potential considerations for dose response evaluation." Environmental Health Perspectives. 129:76002. doi:10.1289/EHP7381.
92. ^Bauer AK, Siegrist KJ, Wolff M, Nield L, Bruning T, Upham BL, Kafferlein HU, Plottner S (2022). "The carcinogenic properties of overlooked yet prevalent polycyclic aromatic hydrocarbons in human lung epithelial cells." Toxics. 10:28. doi:10.3390/toxics10010028.
93. ^Iwu GI, Lajide L, Madu PC, Isah IA (2024). "Assessment of polycyclic aromatic hydrocarbon (PAH) profiles in heat-processed meat and fish: a study on health risk evaluation." Discover Food. 4:46. doi:10.1007/s44187024-00116-5.
94. ^Olesen LD (2013). "Chapter 13 - Polycyclic aromatic hydrocarbons (PAHs) in foods." Persistent Organic Pollutants and Toxic Metals in Foods. Woodhead Publishing Series in Food Science, Technology and Nutrition. 308-333. doi:10.1533/9780857098917.2.308.
95. ^Lin YJ, Liao PL, Wu YHS, Wang Y, Lin JT, Yang DJ (2024). "Evaluation of Appropriate Conditions for Efficient Simultaneous Determination of US EPA and EU Priority Polycyclic Aromatic Hydrocarbons in Various Food Categories and Assessment of Their Consumption Risk." Journal of Agricultural and Food Chemistry. 72(6):3113-3141. doi:10.1021/acs.jafc.3c05897.
96. ^Purcaro G, Barp L, Moret S (2016). "Determination of hydrocarbon contamination in foods: A review." Analytical Methods. 29:5755–5772. doi:10.1039/C6AY00655H.
97. ^Moret S, Dudine A, Conte LS (2000). "Processing effects on the polyaromatic hydrocarbon content of grapeseed oil." Journal of the American Oil Chemists' Society. 77(12):1289-1292. doi:10.1007/s11746-000-0203-5.
98. ^Olesen LD, Navaratnam MA, Jewula J, Jensen AH (2014). "PAH in some brands of tea and coffee." Polycyclic Aromatic Compounds. 35(1):74-90. doi:10.1080/10406638.2014.918554.
99. ^Potocnik T, Kosir IJ (2016). "Influence of roasting temperature of pumpkin seed on PAH and aroma formation." European Journal of Lipid Science and Technology. 119:1500593. doi:10.1002/ejlt.201500593.
100. ^Goker G, Kiralan S, Tekin A, Erdogdu F (2021). "Formation kinetics of polycyclic aromatic hydrocarbons (PAHs) during drying process of olive pomace." Food Chemistry. 345:128856. doi:10.1016/j.foodchem.2020.128856.
101. ^Gao P, Silva EB, Townsend T, Liu X, Ma LQ (2019). "Emerging PAHs in urban soils: Concentrations, bioaccessibility, and spatial distribution." Science of The Total Environment. 670:800-805. doi:10.1016/j.scitotenv.2019.03.247.
102. ^Esmaelli A, Knox O, Juhasz A, Wilson SC (2021). "A comparison of in-vitor PAH bioaccessibility in historically contaminated soils: implications for risk management." Soil and Sediment Contaminations: An International Journal. 30:901-923. doi:10.1080/15320383.2021.1897083.
103. ^Kang Y, Man YB, Cheung KC, Wong MH (2012). "Risk Assessment of human exposure to bioaccessible phthalate esters via indoor dust around the pearl river delta." Environmental Science & Technology. 46:8422-8430. doi:10.1016/j.aca.2012.05.030.
104. ^Lorenzi D, Entwistle J, Cave M, Wragg J, Dean JR (2012). "The application of an in vitro gastrointestinal extraction to assess the oral bioaccessibility of polycyclic aromatic hydrocarbons in soils from a former industrial site." Analytica Chimica Acta. 735:54-61. doi:10.1016/j.aca.2012.05.030.
105. ^Castel R, Tassistro V, Lebarillier S, Dupuy N, Noack Y, Orsière T, Malleret L (2024). "Chemical and genotoxic characterization of bioaccessible fractions as a comprehensive in vitro tool in assessing the health risk due to dust-bound contaminant ingestion." Environmental Science and Pollution Research. doi:10.1007/s11356-024-33248-3.
106. ^Cedergreen N (2014). "Quantifying Synergy: A Systematic Review of Mixture Toxicity Studies within Environmental Toxicology." PloS one. 9:e96580. doi:10.1371/journal.pone.0096580.
107. ^Rangel FAL, Niemi JVL, Kudlak B, Williams MJ, Jonsson J, Schioth HB (2022). "Role of the Synergistic Interactions of Environmental Pollutants in the Development of Cancer." Global Environmental and Occupational Health. 6:e2021GH000552. doi:10.1029/2021GH000552.
108. ^Franco CFJ, de Resende MF, de Almeida Furtado L, Brasil TF, Eberlin MN, Netto ADP (2017). "Polycyclic aromatic hydrocarbons (PAHs) in street dust of Rio de Janeiro and Niterói, Brazil: Particle size distribution, sources and cancer risk assessment." Science of the Total Environment. 599-600:305-313. doi:10.1016/j.scitotenv.2017.04.060.

109. ^Cesila CA, Souza MCO, Cruz JC, Bocato MZ, Campíglia AD, Barbosa F (2023). "Biomonitoring of polycyclic aromatic hydrocarbons in Brazilian pregnant women: Urinary levels and health risk assessment." Environmental Research. 235:116571. doi:10.1016/j.envres.2023.116571.
110. ^Agency for Toxic Substances and Disease Registry (ATSDR) (2021). "What Health Effects Are Associated With PAH Exposure?" ATSDR. https://www.atsdr.cdc.gov/csem/polycyclic-aromatic-hydrocarbons/health_effects.html.
111. a, b, cGarcia LP, Gomes FML, Tfouni S, Vicente E, Savi GD, Santos K, Scussel VM (2017). "Polycyclic aromatic hydrocarbons in commercial brands of dry whole soybeans for direct human consumption." Food Additives and Contaminants. 10:10-15. doi:10.1080/19393210.2016.1240244.
112. ^Junior ALSS, Nascimento MM, Santos AG, Lôbo IP, Jesus RM (2022). "Occurrence of polycyclic aromatic compounds in guarana (Paullinia cupana) seeds subjected to different drying processes." Applied Food Research. 2(1):100110. doi:10.1016/j.afres.2022.100110.
113. a, bLima RF, Dionello RG, Peralba MCR, Barrionuevo S, Radunz LL, Júnior FWR (2017). "PAHs in corn grains submitted to drying with firewood." Food Chemistry. 215:165-170. doi:10.1016/j.foodchem.2016.07.164.
114. ^Escarrone ALV, Caldas SS, Furlong EB, Meneghetti VL, Fagundes CAA, Arias JLO, Primel EG (2014). "Polycyclic aromatic hydrocarbons in rice grain dried by different processes: Evaluation of quick, easy, cheap, effective, rugged and safe extraction method." Food Chemistry. 146:597-602. doi:10.1016/j.foodchem.2013.09.006.
115. ^Prata R, López-Ruiz R, Nascimento LES, Petrarca MH, Godoy HT, Frenich AG, Arrebola FJ (2024). "Method validation for GC-measurable pesticides and PAHs in baby foods using QuEChERS-based extraction procedure." Journal of Food Composition and Analysis. 129:106062. doi:10.1016/j.jfca.2024.106062.
116. ^Machado AMR, Cardoso MG, Dórea HS, Emídio ES, Silva MMS, Anjos JP, Saczk AA, Nelson DL (2014). "Contamination of cachaça by PAHs from storage containers." Food Chemistry. 146:65-70. doi:10.1016/j.foodchem.2013.08.113.
117. ^Silva RMP, Resende O, Bessa JFV, Gomes FML, Tfouni SAV, Almeida AB (2020). "Polycyclic aromatic hydrocarbons in soybean grains." Heliyon. 6:e05533. doi:10.1016/j.heliyon.2020.e05533.
118. ^Oliveira M, Portella CDG, Ramalhosa MJ, Delerue-Matos C, Sant'Ana LS, Morais S (2020). "Polycyclic aromatic hydrocarbons in wild and farmed white mouth croaker and meager from different Atlantic Ocean fishing areas: Concentrations and human health risk assessment." Food and Chemical Toxicology. 146:111797. doi:10.1016/j.fct.2020.111797.
119. a, bSantos RR, Orlando RM, Cardeal ZL, Menezes HC (2021). "Assessment of polycyclic aromatic hydrocarbons and derivatives in beer using a new cold fiber-solid phase microextraction system." Food Control. 126:108104. doi:10.1016/j.foodcont.2021.108104.
120. a, bPissinatti R, Nunes CM, Souza AG, Junqueira RG, Souza SVC (2015). "Simultaneous analysis of 10 polycyclic aromatic hydrocarbons in roasted coffee by isotope dilution gas chromatography-mass spectrometry: Optimization, in house method validation and application to an exploratory study." Food Control. 51:140-148. doi:10.1016/j.foodcont.2014.11.003.
121. ^Menezes HC, Breno PP, Paiva MJN, Barcelos SMR, Macedo DFD, Cardeal ZL (2015). "Determination of polycyclic aromatic hydrocarbons in artisanal cachaça by DI-CF-SPME-GC/MS." Microchemical Journal. 118:272-277. doi:10.1016/j.microc.2014.08.008.
122. ^Santos RR, Leal LDV, Cardeal ZL, Menezes HC (2019). "Determination of polycyclic aromatic hydrocarbons and their nitrated and oxygenated derivatives in coffee brews using an efficient cold fiber-solid phase microextraction and gas chromatography mass spectrometry method." Journal of Chromatography A. 1584:64-71. doi:10.1016/j.chroma.2018.11.046.
123. ^Tfouni SAV, Serrate CS, Leme FM, Camargo MCR, Teles CRA, Cipolli KMVAB, Furlani RPZ (2013). "Polycyclic aromatic hydrocarbons in coffee brew: Influence of roasting and brewing procedures in two Coffea cultivars." LWT - Food Science and Technology. 50:526-530. doi:10.1016/j.lwt.2012.08.015.
124. ^Magalhães KM, Carreira RS, Filho JSR, Rocha PP, Santana FM, Yogui GT (2022). "Polycyclic aromatic hydrocarbons (PAHs) in fishery resources affected by 2019 oil spill in Brazil: Short-term environmental health and seafood safety." Marine Pollution Bulletin. 175:113334. doi:10.1016/j.marpolbul.2022.113334.
125. ^Veiga LLA, Amorim H, Moraes J, Silva MC, Raices RSL, Quiterio SL (2014). "Quantification of polycyclic aromatic hydrocarbons in toasted guarana (Paullinia cupana) by high-performance liquid chromatography with a fluorescence detector." Food Chemistry. 152:612-618. doi:10.1016/j.foodchem.2013.11.154.
126. ^Silva MC, Oliveira MLG, Augusti R, Faria AF (2019). "Simultaneous extraction of pesticides and polycyclic aromatic hydrocarbons in brazilian cachaça using a modified Qu|EChERS method followed by gas chromatography coupled to tandem mass spectrometry." Journal of Agricultural and Food Chemistry. 67:399-405. doi:10.1021/acs.jafc.8b04682.
127. a, bTfouni SAV, Reis RM, Kamikata K, Gomes FML, Morgano MA, Furlani RPZ (2018). "Polycyclic aromatic hydrocarbons in teas using QuEChERS and HPLC-FLD." Food Additives and Contaminants: Part B. 11:146-152. doi:10.1080/19393210.2018.1440638.

Declarations

Funding: This research was supported by the Sao Paulo Research Foundation (FAPESP - process numbers 2022/06443-0, 2023/11634-2, 2024/03034-8, and 2024/03041-4).

Potential competing interests: No potential competing interests to declare.