

HIDROKARBON AROMATIK POLISIKLIK PADA SATE AYAM YANG DIPASARKAN MELALUI PLATFORM DIGITAL LAYANAN PESAN ANTAR MAKANAN DI KOTA MALANG

POLYCYCLIC AROMATIC HYDROCARBONS IN CHICKEN SATAY MARKETED THROUGH DIGITAL FOOD-DELIVERY PLATFORMS IN MALANG CITY

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Abstract. *Chicken satay is a grilled meat product that may contain polycyclic aromatic hydrocarbons (PAHs), a group of process contaminants that includes carcinogenic compounds formed during high-temperature cooking. This study aimed to determine PAH concentrations in chicken satay marketed through digital food delivery platforms in Malang City, Indonesia. A total of 35 samples were collected using purposive sampling from eligible skinless chicken satay vendors listed on GrabFood, GoFood, and ShopeeFood as part of a market survey. The concentrations of eight PAH compounds (PAH8), namely benzo[a]pyrene (BaP), benzo[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), dibenzo[a,h]anthracene (DahA), benzo[g,h,i]perylene (BgP), and indeno[1,2,3-c,d]pyrene (IcP), were determined using Gas Chromatography–Flame Ionization Detection (GC–FID). The results showed that 31 of the 35 samples (88.6%) contained at least one detectable PAH8 compound, whereas four samples showed no detectable PAHs. Among the detected compounds, the highest concentration was observed for BaP (4.715 µg/kg), while all detected BaP concentrations remained below the maximum level of 5 µg/kg established by Commission Regulation (EU) 2023/915. Overall, PAHs were detected in most commercially available chicken satay samples purchased through digital food delivery services. The observed variation among samples suggests that differences in grilling practices among vendors may influence PAH formation, emphasizing the importance of standardized grilling practices and routine monitoring to minimize consumer exposure to PAHs.*

Keywords : *Benzo[a]pyrene, GC-FID, Grilling, Food contaminant, PAH8*

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INTRODUCTION

Chicken meat consumption in Indonesia has shown a consistent upward trend over the years. Data indicate that per capita consumption increased from 5.67 kg/person/year in 2017 to 7.46 kg/person/year in 2023, and is projected to reach 8.47 kg/person/year in 2025 (Natsir et al., 2026). This increa-

se is driven by several factors, including growing public awareness of the importance of animal protein intake in meeting nutritional requirements and population growth, which contributes to higher demand for livestock-based food products. In addition, chicken meat enjoys high consumer acceptance due to its favorable sensory characteris-

tics, relatively affordable price, and considerable nutritional value (Yunita *et al.*, 2026). The nutrient composition of 100 g of chicken meat consists of 23.06% protein, 7% fat, 0.98% minerals, and provides 135 kcal of energy (Debnath, 2025).

Chicken satay is a popular meat dish in Indonesia, typically prepared by grilling over charcoal. While this cooking method imparts a distinctive flavor, it also has the potential to generate hazardous compounds, including Polycyclic Aromatic Hydrocarbons (PAHs) (Yunita *et al.*, 2023). PAHs are a class of organic compounds formed as a result of incomplete combustion of organic materials and are known to exhibit mutagenic and carcinogenic properties (Das *et al.*, 2023). The formation of PAHs in food products, particularly grilled meat, is influenced by several factors, including high cooking temperatures, duration of grilling, type of fuel used, and direct exposure of the food to combustion smoke (Saputro *et al.*, 2022; Jin, 2025). Furthermore, fat drippings onto the heat source can generate smoke containing PAHs precursors, which subsequently re-deposit onto the surface of the meat, thereby increasing PAHs levels. This effect is more pronounced in products cooked to higher degrees of doneness, as indicated by darker or charred surface coloration (Sampaio *et al.*, 2021).

Food safety evaluation related to PAHs contamination is commonly conducted using a group of indicator compounds known as PAH8, which includes benzo[a]pyrene (BaP), benzo[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), dibenzo[a,h]anthracene (DahA), benzo[g,h,i]perylene (BgP), and indeno[1,2,3-c,d]pyrene

(IcP) (Amin *et al.*, 2024). The PAH8 group is widely applied because it provides a comprehensive representation of PAHs contamination levels, as most of these compounds exhibit high toxicity and several have been classified as carcinogenic or potentially carcinogenic to humans. PAHs constitute one of the largest classes of chemical carcinogens. They are composed of aromatic hydrocarbons containing two or more fused benzene rings arranged in a stable structural configuration. PAHs can enter the human body through multiple exposure pathways, including inhalation of air contaminated with combustion-derived smoke and the consumption of contaminated food or beverages (Shamsudin *et al.*, 2020).

The development of digital technology has significantly transformed consumer purchasing behavior, leading to increased demand for ready-to-eat foods through online food delivery platforms such as GrabFood, GoFood, and ShopeeFood (Yulita *et al.*, 2023). This trend has expanded the distribution and consumption of chicken satay in urban areas. Compared with conventional dining, foods marketed through online platforms are prepared by numerous vendors using different grilling practices that cannot be directly observed by consumers, making food safety assessment increasingly important. Variations in grilling temperature, cooking duration, fuel type, and food-handling practices may influence the formation of polycyclic aromatic hydrocarbons (PAHs), thereby increasing variability in contaminant levels among products (Yunita & Rahayu, 2025). Previous studies have shown that PAHs formation in grilled meat is affected by cooking temperature, grill-

ling duration, pyrolysis, and direct exposure to combustion smoke (Saputro *et al.*, 2022). However, studies investigating PAHs contamination in chicken satay marketed through online food delivery platforms, particularly in Malang City, remain limited. Therefore, this study provides scientific evidence to support food safety risk assessment and strengthen the monitoring of ready-to-eat foods distributed through digital platforms.

Based on the above description, the specific objective of this study is to determine the profile of PAHs in various commercial chicken satay samples in the vicinity of Malang City, East Java, obtained through online food delivery platforms such as GrabFood, GoFood, and ShopeeFood. This study is expected to provide scientific information on the level of PAHs contamination in commercial chicken satay products and to serve as a basis for improving food safety practices and developing safer processing methods for consumers. Furthermore, the findings are anticipated to contribute to the strengthening of food safety.

MATERIALS AND METHODS

1. Materials

This study employed laboratory instruments including a graduated cylinder, rotary evaporator (Buchi), vacuum pump, 1.00 mm sieve, analytical balance (AI.204), laboratory oven (Model 501), gas chromatography system equipped with a flame ionization detector (GC-FID), digital balance (Kern), blender (Philips), freezer (Sharp), spoons, aluminum foil, Styrofoam boxes, and ice packs. The samples analyzed consisted of commercially available chicken satay collected from Malang City. The chemicals used for PAH analysis included a PAH8

standard mixture, anhydrous sodium sulfate (analytical grade, Merck, Darmstadt, Germany), silica gel 60 (70–230 mesh, Merck, Darmstadt, Germany), activated alumina (activity grade I, Merck, Darmstadt, Germany), *n*-hexane and dichloromethane (HPLC grade, Merck, Darmstadt, Germany) as extraction solvents, distilled water, helium gas (99.999% purity) as the carrier gas, and hydrogen gas (99.999% purity) as the fuel gas for gas chromatography–flame ionization detection (GC-FID).

2. Sampling Methods

This study was designed as a market survey of commercially available chicken satay marketed through digital food delivery platforms in Malang City, Indonesia. The sampling frame consisted of all chicken satay vendors operating within the administrative boundaries of Malang City and actively listed on GrabFood, GoFood, or ShopeeFood. Vendor identification and eligibility screening were conducted through systematic searches of the three digital platforms during December 2025. Vendors appearing on more than one platform were identified based on their business name, address, and contact information, and duplicate listings were treated as a single sampling unit. Samples were collected using a non-probability sampling method with a purposive sampling technique (Tajik *et al.*, 2025). The inclusion criteria comprised vendors selling low-fat chicken satay, defined as satay prepared from skinless chicken meat with no visible fat attached to the skewers, located within Malang City, and actively operating through at least one digital food delivery platform. Based on the eligibility assessment, 35 unique vendors met all predefined criteria and were included in the study. One order

was purchased from each vendor, resulting in 35 independent market samples, with each order consisting of one serving of ready-to-eat chicken satay. Upon receipt at the laboratory, each sample was homogenized for 3 min using a Philips blender to obtain a uniform sample matrix. The homogenized samples were then individually wrapped in aluminum foil, placed in Styrofoam boxes containing ice packs, and stored at -20°C until subsequent PAH extraction and analysis using gas chromatography – flame ionization detection (GC–FID).

3. Data Collection

Data collection included sample information and laboratory analytical results. The primary dataset consisted of 35 independent chicken satay samples, with one sample representing one eligible vendor. For laboratory analysis, 10 g of each homogenized sample was used for PAH extraction after homogenization for 3 min using a Philips blender. The concentrations of eight polycyclic aromatic hydrocarbons (PAH8), namely benzo[a]pyrene (BaP), benzo[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), dibenzo[a,h]anthracene (DahA), benzo[g,h,i]perylene (BgP), and indeno[1,2,3-c,d]pyrene (IcP), were determined using gas chromatography–flame ionization detection (GC–FID). Each sample was extracted once, and the resulting extract was analyzed in triplicate. The triplicate measurements represented analytical replicates of the same extract and were used solely to evaluate analytical precision; therefore, they were not considered independent market samples or biological replicates. The analytical results were expressed as the mean $\pm$ standard deviation (SD) of the

triplicate measurements for each sample and were subsequently used to evaluate PAH contamination in commercially available chicken satay marketed through digital food delivery platforms in Malang City.

4. Sample Preparation

Chicken satay samples obtained from commercial vendors in Malang City through online food delivery platforms (GrabFood, GoFood, and ShopeeFood) were individually weighed (10 g) and homogenized for 3 min using a Philips blender until a uniform consistency was achieved to ensure an even distribution of polycyclic aromatic hydrocarbons (PAHs) throughout the sample matrix. The homogenized samples were transferred into zip-lock plastic bags wrapped with aluminum foil to minimize oxidation and moisture loss during storage. Subsequently, the samples were stored in a Sharp freezer at -20°C for 24 h prior to PAH extraction and analysis.

5. PAHs Analysis

Polycyclic aromatic hydrocarbons (PAHs) were determined using a gas chromatography system equipped with a flame ionization detector (GC–FID). For each analysis, 10 g of homogenized chicken satay was extracted with a dichloromethane / n-hexane mixture (1:1, v/v) for 18 h at 45°C . Following extraction, the organic phase containing PAHs was separated and dehydrated using anhydrous sodium sulfate before purification. The extract was subsequently cleaned using a glass chromatography column packed with silica gel 60 (70–230 mesh) and activated alumina (activity grade I) at an approximate ratio of 1:1 (w/w) to remove interfering compounds. The purified aromatic fraction containing

PAHs was collected and analyzed using GC–FID. Quantification of benzo[a]pyrene (BaP), benzo[a]anthracene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), dibenzo[a,h]anthracene (DahA), benzo[g,h,i]perylene (BgP), and indeno[1,2,3-c,d]pyrene (IcP) was performed using the external standard calibration method according to Coroian *et al.* (2020). The analytical method had a common limit of detection (LOD) of 0.04 µg/kg, and all analytical procedures were performed under identical laboratory conditions to ensure consistency among samples.

5. Data Analysis

PAH concentration data were processed using Microsoft Excel 2021. The analytical results were expressed as the mean $\pm$ standard deviation (SD) of triplicate analytical measurements for each sample. Values below the method limit of detection (LOD) were reported as not detected (ND) and were excluded from quantitative concentration summaries. The concentrations of individual PAHs were evaluated descriptively and compared with the maximum levels established by Commission Regulation (EU) 2023/915, namely 5 µg/kg for benzo[a]pyrene (BaP) (Sampaio *et al.*, 2021; Cho & Nam, 2025). No inferential statistical analysis was performed; therefore, the results are presented descriptively without implying causal relationships among variables.

RESULTS AND DISCUSSION

1. Benzo[a]pyrene (BaP)

The analysis revealed that benzo[a]pyrene (BaP) was detected in only a few chicken satay samples, whereas most samples were below the detection limit. As presented in Table 1, the highest BaP concentration was obser-

ved in sample SA27 (4.715 µg/kg), followed by samples SA9 and SA25. This variation indicates that BaP formation did not occur uniformly across all samples but was strongly influenced by differences in grilling conditions. The wide variability in BaP concentrations suggests that grilling temperature, duration of heat exposure, distance between the meat and the heat source, and the frequency of fat dripping onto the charcoal substantially affected BaP formation (Sahin *et al.*, 2020). At elevated temperatures, the pyrolysis of lipids and proteins generates PAH precursors that are subsequently transported by smoke and redeposited onto the meat surface, resulting in increased BaP accumulation (Palade *et al.*, 2023). These findings imply that differences in BaP concentrations among samples are more likely attributable to variations in grilling practices than to differences in the intrinsic characteristics of the raw meat. Because all samples were collected from vendors operating through online food delivery platforms, the observed variability further indicates that the marketing channel itself was unlikely to influence BaP formation. Instead, the differences primarily reflected the heterogeneity of grilling practices among individual vendors offering chicken satay through GrabFood, GoFood, and ShopeeFood.

The visual characteristics of the grilled products, particularly darker or charred surface coloration, were positively associated with higher BaP concentrations (Matondo & Issa-Zacharia, 2026). Samples exhibiting a greater degree of doneness generally contained higher BaP levels, suggesting that more intense thermal exposure promoted more extensive pyrolytic reactions and

consequently enhanced PAH formation. Therefore, excessive browning or charring may serve not only as an indicator of cooking intensity but also as a practical indicator of increased BaP contamination resulting from uncontrolled grilling conditions. These findings are consistent with those reported by Lee et al. (2016), who demonstrated that increasing grilling intensity was

directly associated with elevated PAH formation in meat products. This interpretation highlights that process control during grilling plays a more critical role in BaP formation than the raw material itself, emphasizing the importance of optimizing grilling techniques to improve food safety regardless of the marketing platform used.

Table 1. Results of PAH8 Level Analysis in Chicken Satay Samples

Sampling	BaP (µg/kg)	BaA (µg/kg)	Chr (µg/kg)	BbF (µg/kg)	BkF (µg/kg)	DahA (µg/kg)	BgP (µg/kg)	IcP (µg/kg)
SA1	nd	nd	nd	nd	nd	nd	nd	nd
SA2	nd	2.230 ± 0.00	0.385 ± 0.007	nd	nd	nd	nd	nd
SA3		0.455 ± 0.007	0.585 ± 0.007	nd	nd	nd	nd	nd
SA4	nd	0.241 ± 0.00	nd	nd	nd	nd	nd	nd
SA5	nd	nd	nd	nd	nd	nd	nd	nd
SA6	nd	0.295 ± 0.007	0.615 ± 0.007	nd	nd	nd	nd	nd
SA7	1.495 ± 0.007	1.110 ± 0.014	1.295 ± 0.021	1.830 ± 0.014	nd	nd	nd	1.160 ± 0.014
SA8	nd	1.265 ± 0.007	0.890 ± 0.014	nd	nd	nd	nd	nd
SA9	3.615 ± 0.007	3.625 ± 0.007	3.830 ± 0.014	2.485 ± 0.007	nd	nd	nd	nd
SA10	nd	nd	2.395 ± 0.007	nd	nd	nd	nd	nd
SA11	nd	0.485 ± 0.007	2.790 ± 0.014	0.335 ± 0.007	nd	nd	nd	nd
SA12	2.435 ± 0.007	1.050 ± 0.014	1.545 ± 0.021	1.030 ± 0.014	nd	nd	nd	nd
SA13	nd	0.345 ± 0.007	0.760 ± 0.014	2.435 ± 0.007	nd	nd	nd	nd
SA14	2.655 ± 0.007	0.880 ± 0.014	1.230 ± 0.014	2.605 ± 0.007	nd	nd	0.265 ± 0.007	1.575 ± 0.021
SA15	nd	1.375 ± 0.007	0.615 ± 0.007	0.255 ± 0.007	nd	nd	nd	nd
SA16	nd	0.840 ± 0.014	1.150 ± 0.014	0.305 ± 0.007	nd	nd	nd	nd
SA17	nd	0.605 ± 0.007	1.355 ± 0.021	0.295 ± 0.007	nd	nd	nd	nd
SA18	nd	0.23 ± 0.00	0.455 ± 0.007	0.21 ± 0.00	nd	nd	nd	nd
SA19	nd	nd	nd	nd	nd	nd	nd	nd
SA20	nd	0.665 ± 0.007	1.140 ± 0.014	0.375 ± 0.007	nd	nd	nd	nd
SA21	nd	nd	nd	nd	nd	nd	nd	nd
SA22	nd	0.425 ± 0.007	0.705 ± 0.007	0.425 ± 0.007	nd	nd	nd	nd
SA23	nd	0.505 ± 0.007	0.695 ± 0.007	2.275 ± 0.007	nd	nd	nd	nd
SA24	0.575 ± 0.007	2.050 ± 0.014	1.245 ± 0.021	0.695 ± 0.007	nd	nd	nd	nd
SA25	3.080 ± 0.014	1.475 ± 0.021	1.645 ± 0.021	1.265 ± 0.021	0.545 ± 0.007	1.00 ± 0.014	0.625 ± 0.007	1.180 ± 0.014
SA26	2.295 ± 0.035	2.730 ± 0.042	2.820 ± 0.042	2.335 ± 0.035	nd	nd	0.625 ± 0.007	3.505 ± 0.049
SA27	4.715 ± 0.007	1.230 ± 0.014	1.665 ± 0.021	1.060 ± 0.014	nd	nd	nd	1.595 ± 0.021
SA28	nd	0.485 ± 0.007	0.800 ± 0.014	nd	nd	nd	nd	nd
SA29	nd	2.575 ± 0.007	0.910 ± 0.014	1.405 ± 0.007	nd	nd	nd	nd
SA30	nd	0.685 ± 0.007	1.245 ± 0.021	0.505 ± 0.007	nd	nd	nd	nd
SA31	nd	1.140 ± 0.014	2.180 ± 0.028	0.850 ± 0.014	nd	nd	nd	nd
SA32	nd	2.465 ± 0.007	0.790 ± 0.014	0.325 ± 0.007	nd	nd	0.325 ± 0.007	nd
SA33	1.315 ± 0.021	1.830 ± 0.028	2.010 ± 0.028	1.555 ± 0.021	0.605 ± 0.007	0.860 ± 0.014	0.605 ± 0.007	1.090 ± 0.014
SA34	2.050 ± 0.028	nd	0.475 ± 0.007	nd	nd	nd	nd	nd
SA35	nd	0.735 ± 0.007	1.305 ± 0.021	0.615 ± 0.007	nd	1.495 ± 0.021	nd	nd

*Mean within analys duplo; sd (standard deviation); nd (not detected);
100 gr @sample chicken satay

BaP has been reported to induce DNA damage and genetic mutations in human cells and has been classified as a Group 1 carcinogen by the International Agency for Research on Cancer, indicating sufficient evidence of carcinogenicity in humans (Bukowska *et al.*, 2022). The maximum permissible BaP concentration in smoked meat and smoked meat products is 5.0 µg/kg (Ledesma *et al.*, 2015). In the present study, all detected BaP concentrations remained below this regulatory limit, although the concentration observed in sample SA27 approached the maximum allowable level. This finding suggests that the grilling practices employed by some vendors may increase BaP concentrations to levels approaching regulatory thresholds if grilling temperature and cooking duration are not consistently controlled. Considering the rapid expansion of online food delivery services, these findings highlight the importance of implementing standardized grilling practices and routine food safety monitoring among vendors participating in digital food delivery platforms. Such measures are essential to ensure that ready-to-eat chicken satay marketed through online platforms consistently complies with food safety standards while minimizing long-term consumer exposure to dietary PAHs.

2. Benzo[a]anthracene (BaA)

Benzo[a]anthracene (BaA) was detected in the majority of chicken satay samples at varying concentrations, indicating that it is one of the predominant PAHs generated during the grilling process. The highest BaA concentration was observed in sample SA9 (3.625 µg/kg), followed by samples SA26 and SA32, suggesting that these samples were exposed to more

intensive thermal conditions than the remaining samples. The widespread occurrence of BaA demonstrates that its formation is strongly associated with common grilling practices rather than isolated processing events. Variations in BaA concentrations among samples further indicate that differences in grilling temperature, cooking duration, charcoal combustion efficiency, and the proximity of the meat to the heat source substantially influenced its formation (Amin *et al.*, 2024). During high-temperature grilling, the pyrolysis of lipids and proteins generates PAH precursors that subsequently undergo complex condensation reactions to form BaA, while technical factors such as fuel type, grill configuration, and grilling technique further determine the extent of its accumulation (Zhang *et al.*, 2025). These findings suggest that the observed differences in BaA concentrations primarily reflect heterogeneity in grilling practices among vendors rather than differences in the quality of the raw meat. Because all samples were obtained from vendors operating through online food delivery platforms, the observed variability further indicates that the marketing channel itself was unlikely to influence BaA formation. Instead, the differences primarily reflected the diversity of grilling practices among individual vendors supplying chicken satay through GrabFood, GoFood, and ShopeeFood.

The high detection frequency of BaA indicates that this compound may serve as a practical indicator for evaluating PAH contamination in grilled meat products, supporting the recommendation of the European Food Safety Authority to include BaA among the priority PAHs for food safety assessment (Sampaio *et al.*, 2021). More

importantly, the consistent detection of BaA across most samples suggests that routine grilling conditions commonly employed by vendors may continuously promote its formation, even when concentrations vary among samples. This finding implies that consumers ordering chicken satay through online food delivery platforms may be exposed to different BaA concentrations depending on the grilling practices of individual vendors rather than the delivery platform itself. Therefore, reducing BaA formation requires improvements in grilling practices, including better temperature control, minimizing direct flame contact, and preventing excessive fat dripping onto the charcoal. Standardizing these practices among vendors participating in online food delivery services could contribute to more consistent product quality and enhanced food safety.

Although the toxicological potency of BaA is lower than that of benzo[a]pyrene (BaP), with a Toxic Equivalency Factor (TEF) of approximately 0.1 relative to BaP (TEF = 1), its contribution to the overall carcinogenic burden of PAH mixtures should not be underestimated (Bukowska *et al.*, 2022). Consequently, lower BaA concentrations relative to BaP correspond to proportionally lower carcinogenic potency (Conchione *et al.*, 2025). Nevertheless, because BaA was detected in most samples, its widespread occurrence may substantially contribute to cumulative dietary PAH exposure over time. This finding emphasizes that food safety evaluation should consider not only compliance with individual PAH concentrations but also the combined occurrence of multiple PAHs. Given the increasing reliance on online food

delivery services, regular monitoring and the implementation of standardized grilling practices among vendors are essential to ensure that ready-to-eat chicken satay marketed through digital platforms consistently meets food safety standards while minimizing long-term consumer exposure to PAHs.

3. Chrysene (Chr)

Chrysene (Chr) was detected in most chicken satay samples, exhibiting a wide range of concentrations across the analyzed products. The highest Chr concentration was observed in sample SA9 (3.830 µg/kg), indicating that this compound was consistently generated under the grilling conditions commonly employed by the vendors. Unlike several PAHs that were detected only in a limited number of samples, the widespread occurrence of Chr suggests that its formation is less dependent on isolated processing events and more closely associated with routine thermal processing practices (Adeyeye & Ashaolu, 2022). The observed variability among samples further indicates that differences in grilling intensity and process control influenced the extent of Chr accumulation. Prolonged heat exposure and inadequate process control are known to promote the formation of PAHs by increasing the thermal degradation of organic compounds, thereby contributing to higher Chr concentrations (Mastanjević *et al.*, 2026). These findings indicate that excessive thermal treatment primarily affects the formation and accumulation of PAHs rather than merely altering product characteristics. Because all samples were collected from vendors operating through online food delivery platforms, the observed differences in Chr concentrations are more likely attributable to variations in grilling practices

among individual vendors than to the marketing channel itself. Consequently, consumers purchasing chicken satay through GrabFood, GoFood, and ShopeeFood may receive products with different PAH profiles depending on the cooking practices adopted by each vendor.

Chrysene is not classified among the primary PAHs with sufficient evidence of carcinogenicity in humans. According to the International Agency for Research on Cancer, Chr is categorized as a Group 2B carcinogen (possibly carcinogenic to humans), indicating limited evidence of carcinogenicity in humans (Adeyeye & Ashaolu, 2022). Furthermore, Chr is included in the PAH4 group recommended by the European Food Safety Authority as a key indicator for assessing PAH-related risks in food (Wu *et al.*, 2025). The relatively high detection frequency observed in this study therefore reinforces the value of Chr as an indicator compound for evaluating the consistency of thermal processing and the overall occurrence of PAHs in grilled meat products. In the context of online food delivery services, the consistent detection of Chr across samples indicates the importance of implementing standardized grilling practices among vendors to ensure more uniform product quality and food safety. The concentrations of Chr observed in the present study were generally lower than those of benzo[a]pyrene (BaP) and remained within the acceptable range for PAH4 (Sahin *et al.*, 2020). Nevertheless, the frequent occurrence of Chr across the analyzed samples suggests that consumer exposure is more likely to result from repeated consumption of grilled products obtained from different

vendors than from a single highly contaminated sample. This finding highlights the importance of evaluating PAHs as a mixture rather than considering each compound individually, since cumulative exposure may increase the overall toxicological burden. Given the continued expansion of online food delivery platforms, routine monitoring of PAH contamination and the implementation of standardized grilling practices among participating vendors are essential to ensure that ready-to-eat chicken satay marketed through digital platforms consistently complies with food safety standards while minimizing long-term consumer exposure to PAHs.

4. Benzo[b]fluoranthene (BbF)

Benzo[b]fluoranthene (BbF) showed considerable variability among the chicken satay samples marketed through ShopeeFood, GrabFood, and GoFood in Malang City, ranging from non-detectable (nd) to 2.605 µg/kg, with the highest concentration observed in sample SA14. Several samples showed no detectable BbF, indicating that its occurrence varied among chicken satay products offered by different vendors through these digital food-delivery platforms. This variation may be associated with differences in grilling practices and processing conditions applied by individual vendors. Previous studies have reported that technical factors, including cooking temperature, roasting duration, and fat dripping onto the heat source, can influence the formation of BbF and other PAHs during grilling (Conchione *et al.*, 2025). Because the present study did not directly measure grilling temperature, cooking duration, or fat-dripping intensity, these factors should be considered as possible contributors

rather than direct determinants of the BbF concentrations observed. Processing conditions may also influence product quality because excessive heating can promote protein denaturation and reduce water-holding capacity, resulting in greater cooking loss and firmer meat texture (Apriani *et al.*, 2024). Conversely, appropriate marination may help maintain meat tenderness and suppress reactions associated with PAH formation through improved water retention and inhibition of oxidative reactions (Yunita *et al.*, 2023). Organic acids and antioxidant compounds in marinades may further contribute to desirable organoleptic characteristics and meat texture (Yasmin *et al.*, 2023; Yunita *et al.*, 2025). Therefore, differences in BbF concentrations among chicken satay marketed through ShopeeFood, GrabFood, and GoFood may reflect variation in vendor-level grilling and preparation practices rather than differences attributable to the digital food-delivery platforms themselves.

Benzo[b]fluoranthene is a high molecular weight PAH and is included in the PAH4 group because of its toxicological relevance (Sumer & Oz, 2023). The detection of BbF at concentrations ranging from non-detectable levels to 2.605 µg/kg demonstrates that chicken satay marketed through digital food-delivery platforms in Malang City may exhibit different levels of PAH contamination depending on the processing practices used by individual vendors. The use of ShopeeFood, GrabFood, and GoFood as marketing and distribution channels provides consumers with convenient access to ready-to-eat chicken satay, but the digital platform does not standardize the thermal processing conditions used by each vendor.

Consequently, differences in grilling temperature, grilling duration, fuel or heat-source characteristics, and fat exposure during grilling may contribute to differences in BbF formation among products available on these platforms. These findings highlight the importance of vendor-level food safety control for ready-to-eat grilled meat products marketed through digital food-delivery services. Routine monitoring of BbF together with the other PAH4 compounds, combined with standardized grilling practices and appropriate marination procedures, may help minimize PAH formation and improve the consistency and safety of chicken satay products marketed through ShopeeFood, GrabFood, and GoFood in Malang City.

5. Benzo[k]fluoranthene (BkF)

As presented in Table 1, benzo[k]fluoranthene (BkF) was detected in only two of the analyzed chicken satay samples, namely SA25 (0.545 µg/kg) and SA33 (0.605 µg/kg), while the remaining samples showed concentrations below the analytical detection limit of 0.04 µg/kg. The low detection frequency indicates that BkF was not consistently present among the chicken satay products marketed through GrabFood, GoFood, and ShopeeFood in Malang City. The occurrence of BkF in selected samples may be related to differences in thermal processing conditions among vendors. Previous research has indicated that grilling parameters, including grill configuration, distance between the meat and heat source, combustion intensity, cooking duration, turning frequency, and control of the grilling process, can influence the thermal environment and consequently affect PAH formation (Zhang *et al.*, 2025). However, these

processing parameters were not directly measured in the present study; therefore, their contribution to BkF occurrence should be interpreted as a plausible explanation rather than a demonstrated causal relationship. The variation observed among samples is more appropriately interpreted as reflecting differences in vendor-level preparation and grilling practices. Importantly, the digital food-delivery platforms investigated in this study functioned as marketing and distribution channels and were not themselves sources of thermal PAH formation. Thus, the presence or absence of BkF among products available through GrabFood, GoFood, and ShopeeFood is more likely to reflect differences in the preparation practices of individual vendors. This finding is relevant to online food-delivery systems because consumers may encounter products with different levels of BkF despite purchasing the same type of food through similar digital channels.

Benzo[k]fluoranthene is a high-molecular-weight PAH with toxicological relevance and is not included in the PAH4 group, which comprises benzo[a]pyrene (BaP), benzo[a]anthracene (BaA), benzo[b]fluoranthene (BbF), and chrysene (Chr) (Sampaio et al., 2021). Although BkF was detected in only two samples in the present study, its occurrence demonstrates that high-molecular-weight PAHs can be present in ready-to-eat chicken satay marketed through digital food - delivery platforms. The concentrations detected in SA25 and SA33 were relatively close to each other, suggesting that BkF occurrence was limited to specific products rather than being uniformly distributed across the sampled chicken satay. Because the present study evaluated the final food products rather

than experimentally manipulating grilling conditions, the results should not be interpreted as evidence that a particular grilling parameter caused BkF formation. Instead, the findings provide an indication of variability in PAH contamination among commercially prepared products and support the need for greater attention to vendor-level process control. Standardized grilling practices, appropriate management of heating conditions, and routine monitoring of BkF together with other relevant PAHs may contribute to reducing variability in contamination and improving the consistency and safety of chicken satay marketed through GrabFood, GoFood, and ShopeeFood in Malang City. Such measures are particularly relevant to digital food-delivery systems, where consumers have limited visibility of the actual food preparation conditions used by individual vendors.

6. Dibenzo[a,h]anthracene (DahA)

Dibenzo[a,h]anthracene (DahA) was detected in only a small proportion of the analyzed chicken satay samples, with most samples showing concentrations below the analytical detection limit of 0.04 µg/kg. Detectable concentrations were found in samples SA25 (1.000 µg/kg), SA33 (0.860 µg/kg), and SA35 (1.495 µg/kg), indicating that DahA occurrence was relatively limited across the sampled products. The sporadic detection of DahA may be associated with differences in thermal processing conditions among individual vendors. Previous research has reported that heat management, cooking duration, charcoal combustion, and other grilling conditions can influence the formation of high-molecular weight PAHs in grilled foods (Kaltah et al., 2024). However, these

processing parameters were not directly measured in the present study, and their contribution to DahA formation therefore cannot be established from the current data. The observed variability should instead be interpreted as an indication of differences in the processing conditions used by individual vendors. All samples were obtained from chicken satay vendors operating through GrabFood, GoFood, and ShopeeFood in Malang City; therefore, the differences in DahA detection are more appropriately considered in relation to vendor-level food preparation and grilling practices rather than the digital food-delivery platforms themselves. This distinction is important because the platforms function primarily as marketing and distribution channels, whereas PAHs are generated during food processing. Consumers purchasing chicken satay through these platforms may consequently encounter products with different levels of high-molecular-weight PAHs depending on the preparation and grilling practices adopted by individual vendors.

Dibenzo[a,h]anthracene is a high-molecular-weight PAH of toxicological concern because of its potential carcinogenic properties (Rekha *et al.*, 2026). Although DahA was detected in only three samples, its presence indicates that measurable high-molecular-weight PAHs can occur in ready-to-eat chicken satay marketed through digital food-delivery platforms. The concentrations observed in SA25, SA33, and SA35 also demonstrate that DahA contamination was not uniformly distributed among the sampled products. These findings should be interpreted in the context of the broader PAH profile and the applicable food-safety criteria,

particularly because different PAH groupings may be used for dietary exposure and risk assessment (Sampaio *et al.*, 2021). Since grilling conditions were not experimentally controlled or quantitatively characterized in this study, the results do not establish a direct causal relationship between specific grilling parameters and DahA formation. Nevertheless, the detection of DahA in selected products highlights the relevance of vendor-level process control in managing PAH contamination. Consistent grilling practices, appropriate management of heating conditions, and routine monitoring of relevant high-molecular-weight PAHs may help reduce variability in contamination and support the safety and quality of chicken satay marketed through GrabFood, GoFood, and ShopeeFood in Malang City.

7. Benzo[g,h,i]perylene (BgP)

As presented in Table 1, benzo [g,h,i]perylene (BgP) was detected in only a limited proportion of the analyzed chicken satay samples, with most samples showing concentrations below the analytical detection limit of 0.04 µg/kg. Detectable concentrations were observed in samples SA14 (0.265 µg/kg), SA25 (0.625 µg/kg), SA26 (0.625 µg/kg), SA32 (0.325 µg/kg), and SA33 (0.605 µg/kg). The limited detection frequency indicates that BgP occurrence was not uniform across the sampled chicken satay products. This variability may be related to differences in thermal processing conditions among individual vendors. Previous research has indicated that fuel management, heat intensity, cooking duration, and other grilling conditions can influence the formation of high-molecular-weight PAHs by generating different thermal environments during cooking

(Nizio *et al.*, 2023). However, these processing parameters were not directly measured in the present study; therefore, their specific contribution to the observed BgP concentrations cannot be established. The differences observed among samples should consequently be interpreted as potential variation in vendor-level processing practices rather than evidence of a direct causal relationship between a specific grilling parameter and BgP formation. Since all samples were collected from vendors operating through GrabFood, GoFood, and ShopeeFood in Malang City, the variation in BgP concentrations may reflect differences in food preparation and grilling practices among individual vendors rather than characteristics of the digital food-delivery platforms themselves. These platforms primarily serve as marketing and distribution channels, connecting consumers with products prepared under vendor-specific processing conditions. Consequently, consumers purchasing chicken satay through these platforms may encounter different levels of BgP depending on the preparation and grilling practices adopted by individual vendors.

Benzo[g,h,i]perylene is a high-molecular-weight PAH relevant to the assessment of PAH contamination in food. According to the International Agency for Research on Cancer (IARC), BgP is classified in Group 3, indicating that it is not classifiable as to its carcinogenicity to humans based on the available evidence (Amponsah *et al.*, 2024). Although BgP was detected in only five samples, its occurrence demonstrates that high-molecular-weight PAHs can be present in ready-to-eat chicken satay marketed through digital food-delivery platforms. The relatively low detection

frequency indicates that BgP was not consistently present across the sampled products, suggesting variability in the conditions under which the chicken satay was prepared and grilled. The presence of BgP should also be considered within the broader PAH contamination profile, particularly when PAH8-based approaches are used in food-safety assessment (Sahoo *et al.*, 2026). Because the present study evaluated commercially prepared products without experimentally controlling or quantitatively characterizing grilling conditions, the findings cannot establish a direct relationship between individual processing parameters and BgP formation. Nevertheless, the detection of BgP in selected products highlights the relevance of vendor-level process control for managing variability in PAH contamination. Consistent grilling practices, appropriate management of heating conditions, and routine monitoring of BgP together with other relevant PAHs may help reduce variability in contamination and support the safety and quality of chicken satay marketed through GrabFood, GoFood, and ShopeeFood in Malang City.

8. Indeno[1,2,3-c,d]pyrene (IcP)

Indeno[1,2,3-c,d]pyrene (IcP) was detected in a limited proportion of the analyzed chicken satay samples, with most samples showing concentrations below the analytical detection limit of 0.04 µg/kg. Detectable concentrations were observed in samples SA7 (1.160 µg/kg), SA14 (1.575 µg/kg), SA25 (1.180 µg/kg), SA26 (3.505 µg/kg), SA27 (1.595 µg/kg), and SA33 (1.090 µg/kg), with the highest concentration recorded in SA26. The limited and uneven occurrence of IcP indicates substantial variability in its distribution among the sampled chicken satay

products. This variability may be associated with differences in thermal processing conditions among individual vendors. Previous research has reported that high-molecular-weight PAHs tend to occur less frequently in grilled meat products than lower-molecular-weight PAHs, reflecting differences in their behavior and formation during thermal processing (Duedahl-Olesen & Ionas, 2022). Variations in heat management, cooking duration, fuel combustion, and overall grilling practices may create different thermal environments that contribute to differences in IcP occurrence. However, these processing parameters were not directly measured in the present study; therefore, their specific contribution to IcP formation cannot be determined from the available data. The observed variability should consequently be interpreted as a potential reflection of differences in vendor-level processing practices rather than evidence of a direct causal relationship between a specific grilling condition and IcP formation. Since all samples were obtained from vendors operating through GrabFood, GoFood, and ShopeeFood in Malang City, the variation in IcP concentrations may be related to differences in food preparation and grilling practices among individual vendors rather than characteristics of the digital food-delivery platforms. As marketing and distribution channels, these platforms provide access to products prepared under vendor-specific processing conditions. Consequently, consumers purchasing chicken satay through these platforms may encounter different IcP concentrations depending on the preparation and grilling practices applied by individual vendors.

Indeno[1,2,3-c,d]pyrene is a high-molecular-weight PAH of toxicological concern and is classified by the International Agency for Research on Cancer (IARC) as a Group 2B compound, indicating that it is possibly carcinogenic to humans (Nawar *et al.*, 2025). IcP is also included in the PAH8 group used in broader assessments of PAH contamination and dietary exposure (Adeyeye *et al.*, 2025). The detection of IcP in six samples demonstrates that high-molecular-weight PAHs can occur in ready-to-eat chicken satay marketed through digital food-delivery platforms in Malang City, although its occurrence was not uniform across the sampled products. The concentration detected in SA26 (3.505 µg/kg) was the highest among the IcP-positive samples, indicating notable variation in IcP levels among products. Because the present study evaluated commercially prepared chicken satay without experimentally controlling or quantitatively characterizing grilling conditions, the specific factors responsible for the higher concentration observed in SA26 cannot be identified. Nevertheless, the detection of IcP in selected products highlights the importance of vendor-level process control in managing variability in high-molecular-weight PAH contamination. Consistent grilling practices, appropriate management of thermal processing conditions, and routine monitoring of IcP together with other relevant PAH8 compounds may help reduce variability in PAH contamination and support the safety and quality of chicken satay marketed through GrabFood, GoFood, and ShopeeFood in Malang City.

CONCLUSION

PAH8 compounds were detected in 31 of 35 (88.6%) chicken satay samples marketed through GrabFood, GoFood, and ShopeeFood in Malang City, while four samples (11.4%) showed no detectable PAH8. BaP had the highest concentration among the detected PAH8 compounds, reaching 4.715 µg/kg, which remained below the maximum level of 5 µg/kg established by Commission Regulation (EU) 2023/915. The variability in PAH concentrations among samples may reflect differences in vendor-level grilling and food preparation practices. Standardization of grilling practices and routine monitoring of PAH are recommended to reduce variability in PAH occurrence and minimize potential consumer exposure to PAHs in ready-to-eat chicken satay marketed through digital food-delivery platforms in Malang City.

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