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Mitigation of Polycyclic Aromatic Hydrocarbons Formation in Goat Satay by Shallots Juices Marination

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ABSTRACT

This study aimed to mitigate the carcinogen formation of polycyclic aromatic hydrocarbons (PAHs) in charcoal-grilled goat satay by marinating raw goat-satay with shallots (*Allium cepa var. Ascalonicum*) juices. The experiment used a 2 x 4 split-plot factorial randomized block design. The experiment consisted of 2 treatments of 2 goat satay types (without and with sliced fat) and 4 treatments of marination with shallots juice at concentrations of 0%, 10%, 20%, and 30% (gmL^{-1} of fresh shallots in distilled water) for 60 minutes at 4 °C. A total of 24 samples of raw and grilled goat-satay were used for 3 replication groups. The marination with 10% and 20% shallots juices significantly reduced the BaP and BaA until they were not detected even though they increased the non-carcinogenic Pyr levels in the grilled goat-satay with and without sliced fat. The marination with 10%, 20%, and 30% shallots juice significantly prevented the formation of Phe, Ace, and Nap so that they were not detected in the grilled goat-satay with and without sliced fat. The marination with 30% shallots juice of raw goat-satay without sliced fat resulted in the highest antioxidant activities and detectable BaP levels (3.88 mg kg^{-1}).

Keywords: antioxidant; benzo(a)pyrene; goat satay; polycyclic aromatic hydrocarbons; shallots

INTRODUCTION

According to van der Zanden *et al.* (2014), the attention of consumers who are aware of food safety and health will eventually be focused on natural, organic, safer, and healthier foods. Food processing by heating, including grilling of goat satay, can have both beneficial and detrimental effects. According to Karmas & Harris (2012), the beneficial effects of heating food are killing pathogenic bacteria, increasing nutrient digestibility, improving sensory and functional qualities, increasing nutrient bioavailability, enriching nutrient quality, increasing food durability, releasing beneficial-bioactive compounds, and destroying anti-nutritional substances in the grilled meat. According to Lee *et al.* (2016), the detrimental impacts of the satay-grilling process are the formation of carcinogenic compounds of polycyclic aromatic hydrocarbons (PAHs) and the other carcinogens that endanger our health if consumed in the long term.

Until now, it is not well known the exact mechanism of PAHs formation in the grilled meat. When meat is in direct contact with flames, pyrolysis (incomplete combustion) of fat in meat can produce PAHs deposited on the meat's surface (Kim *et al.*, 2021). Lee *et al.* (2016) reported that open grilling of meat and fish using wood charcoal which produces a lot of smoke, has the potential to produce PAHs deposited on the surface of the grilled meat. This PAH production is due to the pyrolysis of fat materials dripping from the inside part of the meat or fish when in direct contact with flames. According to Rose *et al.* (2015), although the meat is not in direct contact with the flames, the droplets of fat into the flames trigger pyrolysis and the PAHs formation that can contaminate the surface of the grilled meat. Meat-fat levels, temperature, and time of grilling greatly determine the PAHs formation in charcoal-grilled meat. According to Viegas *et al.* (2012), incomplete combustion of charcoal, wood, oil, garbage, or other materials containing carbon is the main source of PAHs formations. According to García-Lomillo *et al.* (2017), heavy PAHs with an aromatic ring N_3 can be produced from fat droplets of meat that fall onto the charcoal during the grilling process. According to Wang *et al.* (2019), intense heat above 200 °C can trigger the pyrolysis of organic matter, especially from fat, resulting in nonpolar and lipophilic PAHs. According to Lu *et al.* (2018), radical reactions from oxidation and decomposition are involved in the PAHs formation.

Temperature is a key factor for PAHs production. Therefore, controlling exposure to heating and humid-

ity can help reduce the PAH formations (Min *et al.*, 2018). Although it is important to control temperature exposure, Wang *et al.* (2019) have shown in their study that PAHs formation can be inhibited threefold through the method of marination with bioactive compounds compared to the method of temperature reduction. One of the bioactive compounds that play an important role and are widely available in the natural environment are organosulfur compounds (OSC). Jones (2015) reported that reactive oxygen species (ROS) could be neutralized by OSC. In addition, the OSC can also determine the redox status of thiol/disulfide in signaling and sensing.

Munday (2012) reported that many vegetables contain OSC, one of the main groups, namely the genus *Allium* (family *Amaryllidaceae*), which contains S-alk(en) yl-L-cysteine sulfoxide are garlic, onions, shallots, leeks, and chives. Shallots (*Allium cepa var. Ascalonicum*) have been used by the Indonesian ancestors in every serving of satay. Based on the results of our analyzes in the laboratory in the preliminary study, shallots have antioxidant activity (diphenyl-picrylhydrazyl, DPPH scavenging activity) of 62.23% with a total flavonoid and total phenolic contents of 0.09% and 0.12%, respectively. The OSC and natural antioxidants in shallots will be deposited into the raw goat-satay through marination for 60 minutes at 4 °C. So that the grilling of goat satay can prevent the formation of PAHs, especially the type of benzo(a)pyrene (BaP), which is carcinogenic. The purpose of this study was to mitigate the carcinogen formation of 6 PAHs types [benzo(a)pyrene (BaP), benzo(a)anthracene (BaA), naphthalene (Nap), acenaphthene (Acp), phenanthrene (Phe), and pyrene (Pyr)] in charcoal-grilled goat satay by marination of raw goat-satay with shallots (*Allium cepa var. Ascalonicum*) juices at various concentrations.

MATERIALS AND METHODS

Goat Meat and Shallots Juice Preparations

The fresh meat of young goats used in the experiment was obtained from female goats less than one year old. All of the goat's teeth were still milk teeth. The goat species was a composite "Kacang" goat (cross-breed between Boer and "Peranakan Etawah, PE" or Boerwa goat) from local goat farms and butcher in Batu Municipality. The meats used were the loins and rumps. Shallots were obtained directly from farmers at the shallot center in Torongrejo Village, Batu Municipality. Shallots juices were made by mixing clean shallots skin with distilled water in gmL^{-1}. Shallots were weighed as many as 100 g, 200 g, and 300 g and blended (Philips) in 1000 mL of distilled water. Distilled water was bought from LSIH, a central laboratory in the University of Brawijaya. Based on our laboratory analysis, 10%, 20%, and 30% shallots juices had antioxidant activity (diphenyl-picrylhydrazyl, DPPH scavenging activity) of 27.82%, 42.14%, and 49.35%, respectively. The DPPH or 2,2-diphenyl-1-picrylhydrazyl used was Aldrich, Merck, Germany.

Raw Goat-Satay Preparation

The fresh goat meat obtained from the butcher was not aged in the chiller. The goat meat that had been trimmed or removed from its fat and connective tissue were cut perpendicular to the meat fibers to form dice with a size of 1x1x1 cm. Then the dices of meats were stabbed with bamboo skewers, with a total of 4 dices of meat per skewer for the type of goat satay without sliced fat. For the goat satay with sliced fat, the amount was 3 dices of meat and 1 sliced fat per skewer. The goat fats used were the fats that cover the goat stomach. The fat sheets were cut into 1x5 cm and folded 5 folds before being stabbed with a bamboo skewer. The experiment was carried out in 3 replications, and each treatment consisted of 10 skewers of raw goat-satay weighing about 100-150 g.

Marination of Raw Goat-Satay

The raw goat-satay (10 skewers or about 100-150 g per treatment) were marinated in 10%, 20%, and 30% shallots juices (1:1 for raw goat-satay and juices) for 60 minutes at 4 °C in a closed container and tightly wrapped in aluminum foil to prevent oxidation. The marination time of 60 minutes was considered sufficient to deposit the bioactive compounds of antioxidant and OSC in the shallot juices into the raw goat-satay as free water held in the space between actin (thin filament) and myosin (thick filament). A temperature of 4 °C was used to keep the raw goat-satays soaked in shallots juices are safe from pathogenic microbial contamination. The raw goat-satay samples were prepared for chemical analysis after the marination process.

Chemical Analyzes of Marinated Raw Goat-Satay

The fat contents of raw goat-satays were determined by Soxhlet analysis (AOAC, 2019). The protein contents of raw goat-satays were determined by Kjeldahl analysis (AOAC, 2019). Total organic matter, moisture, and ash contents of raw goat-satays were determined by the gravimetric method (AOAC, 2019). The carbohydrate contents of raw goat-satay were determined by the formula 100% - (ash + moisture + fat + protein). Lipid oxidations in raw goat-satay were confirmed by the thiobarbituric acid reactive substances (TBARS) method (AOAC, 2019). The antioxidant activities were determined by the free radical scavenging method using diphenyl-picrylhydrazyl (DPPH) radicals (AOAC, 2019). All chemical analyses were done in duplicate, and all treatments within a replication were analyzed simultaneously to minimize the variation in the analyses due to time.

Charcoal Grilling of Raw Goat-Satay

Marinated raw goat-satays were grilled until very well-done using wood charcoal for 6 minutes with a temperature of 531.063 ± 30.559 °C and 0.5-1 cm distance

from flames. The commercial wood-charcoal used was purchased from the big market of Batu Municipality. The infrared thermometer used was the GM320S (China) version, which can measure temperatures in the range of -50 to 600 °C with an accuracy of ±1.5 °C (0-600 °C) and ±3 °C (-50-0 °C). The grilling of marinated raw goat-satay was done by 25 years experienced chef at a famous satay restaurant, RM. Mesir at Batu Municipality, East Java. During the grilling process, an electric fan was used to keep the charcoal burning, and a hand fan was also used to expel the smoke that forms. Every half minute, a reversal was done to prevent severe burns. Charcoal-grilled goat-satay samples were prepared for analyzes of 6 types of PAHs using gas chromatography (GC).

Analyzes of PAHs in Charcoal-Grilled Goat Satay

Analyzes of 6 types of PAHs were determined using the modified method of Chen & Chen (2004). A total of ± 5 g of sample was added with 10 mL of 0.5 N NaOH. The mixture was heated in a water bath at 80 °C for ± 3 hours. Then it was cooled, added 10 mL of distilled water, and extracted with 20 mL of diethyl ether: petroleum ether (1:1). The resulting extract was taken from the top layer, and it was concentrated in a water bath at a temperature of 50 °C. The concentrate obtained was added with 1 mL of dichloromethane. As much as 1 μL of the sample and the standard were injected into the gas chromatography (Shimadzu GC–2010, Kyoto, Japan). The gas chromatography (GC) column used was Agilent J&W HP-5 (California, USA) with a length of 30 cm, inner diameter of 0.32 mm, film thickness of 0.25 μm, column oven temperature program with a rate of 5 °C per minute until 310 °C and a hold time of 12 minutes, and a total running time of 58 minutes. The temperature of the flame ionization detector (FID) was 310 °C with a carrier gas in the form of helium and an airflow of 400 mL per minute. The injector used has a volume of 1 μL with a temperature of 310 °C and pressure of 8.4249 psi.

The PAHs standard used was a mixture of 6 types of PAHs standards, namely benzo(a)pyrene (BaP), benzo(a) anthracene (BaA), naphthalene (Nap), acenaphthene (Acp), phenanthrene (Phe), and pyrene (Pyr) each with concentration series. All standard PAHs were purchased from Merck, Germany. The limit of detection or concentration readings by GC for each PAHs compound was 1.23 mg kg^{-1} for BaP, 13.90 mg kg^{-1} for BaA, 4.10 mg kg^{-1} for Nap, 5.88 mg kg^{-1} for Acp, 3.41 mg kg^{-1} for Phe, and 23.03 mg kg^{-1} for Pyr. The calculation of the concentration of each PAHs compound was obtained from calculating the peak area of each standard solution of each PAHs compound, a linear regression equation will be obtained, i.e., Y= BX + A, so that the X value will be obtained, then the values of each PAHs compound was calculated by the formula: PAHs levels = (X x final volume) x $(\text{weight of sample})^{-1}$. The X values were concentration readings by GC, and the final volume resulting from sample extraction was 1 mL.

Experimental Design and Data Analyzes

The experiment consisted of 2 treatments of 2 types of goat satay (without and with sliced fat) and 4 treatments of shallots juice marination at concentrations of 0%, 10%, 20%, and 30% (gmL^{-1} of fresh shallots and distilled water) for 60 minutes at 4 °C. A total of 24 samples of raw and grilled goat-satay were used for 3 replication groups. Statistical analysis was performed for all measurement data using the SPSS procedures (version 25.0) using analysis of variance (ANOVA). The differences between treatments were tested further using the Tukey test. The significance level was determined at $p<0.05$.

RESULTS

Antioxidant Activity, Fat Content, and Lipid Oxidation of Raw Goat-Satay

The antioxidant activities of marinated raw goat-satay measured by the diphenyl-picrylhydrazyl (DPPH) scavenging activities method are presented in Table 1. There were significant differences ($p<0.05$) in antioxidant activities between unmarinated (0%) and marinated raw goat-satay (10%, 20%, and 30%). There were the greater the concentration of shallots juice, the greater the antioxidant activity. This result corresponded to the antioxidant activities of shallots juices at concentrations of 10%, 20%, and 30%, having DPPH of 27.82%; 42.14%; and 49.35%, respectively. The highest antioxidant activities of marinated raw goat-satays were achieved at a concentration of 30% shallots juice with and without sliced fat, i.e., 57.12% and 56.47%, respectively. The antioxidant compounds in shallots were deposited into the goat meat through the marination process. The high amount of antioxidant compounds deposited into the goat meat can delay the process of lipid oxidation in marinated raw goat-satay. The antioxidant activities of natural antioxidants (indigenous) in unmarinated raw goat-satay with sliced fat and without sliced fat were 18.99% and 31.42%, respectively.

The fat contents of marinated raw goat-satays are presented in Table 1. The fat contents were certainly higher in marinated raw goat-satay with sliced fat than without sliced fat. The ranges of the fat content of marinated raw goat-satay with sliced fat and without sliced fat were 12.57%-18.36% and 1.50%-2.95%, respectively. In the raw goat-satay without sliced fat, there were no significant differences in the fat contents with different doses of shallot juice (10%, 20%, and 30%) treatments, but they were significantly different when compared to control 2. Apparently, the marination with shallots juices significantly increased the fat contents of marinated raw goat-satay without sliced fat. On the group of raw goat-satay with sliced fat, the fat content in control 1 was very significantly ($p<0.05$) higher than the other samples. It seems that the shallots juice marination significantly reduced the fat contents of the marinated raw goat-satay with sliced fat. This result was in contrast to the marinated raw goat satay without sliced fat.

TBARS values or total MDA of marinated raw goat-satay at concentrations of 0%, 10%, 20%, and 30% treat-

ments are presented in Table 1. The TBARS values were detected in all raw goat-satay samples, which means that all samples before grilling had lipid oxidation. The TBARS values of raw goat-satay without shallots or unmarinated (control 1 and control 2) were significantly different ($p<0.05$) from the TBARS values of marinated raw goat-satay either with or without sliced fat. On the marinated raw goat-satay without sliced fat at doses of 10%, 20%, and 30% treatments had a significantly lower TBARS value ($p<0.05$) than control 1 (without marination). In contrast, marinated raw goat-satay with sliced fat at doses of 10%, 20%, and 30% had significantly higher TBARS values ($p<0.05$) than control 2 (without marination). The ranges of concentrations of MDA in marinated raw goat-satay with and without sliced fat were 0.59-0.96 mg kg^{-1} and 0.47-1.26 mg kg^{-1}, respectively. Raw goat-satay with high-fat contents tended to have a high TBARS value.

Protein, Carbohydrate, Moisture, and Ash Contents of Raw Goat-Satay

Table 1 presents the crude protein contents of unmarinated and marinated raw goat-satays with shallots juice at various concentrations. The protein contents of unmarinated raw goat-satays (control 1 and control 2) were significantly different ($p<0.05$) from the protein content of marinated raw goat-satay. Marinated raw goat-satay at doses of 10%, 20%, and 30% shallots juice without or with sliced fat had significantly lower protein contents compared to control 1 and 2. The protein contents of goat meat tended to be higher in raw goat-satay without sliced fat than with sliced fat. The ranges of protein contents of raw goat-satay with and without sliced fat were 13.20%-15.74% and 15.77%-18.99%, respectively.

Moisture contents of marinated raw goat satay are presented in Table 1. There were significant differences ($p<0.05$) in moisture contents between unmarinated raw goat-satays (control 1 and 2) and marinated raw goat-satay. The goat meats marinated with shallots juice at doses of 10%, 20%, and 30% had significantly greater moisture contents compared to control 1 and 2. The moisture contents of goat meat tended to be higher in raw goat-satay without sliced fat than raw goat-satay with sliced fat. The ranges of moisture contents of the raw goat-satay with sliced fat and without sliced fat were 64.17%-71.55% and 76.81%-79.42%, respectively.

The carbohydrate contents of raw goat-satay tended to be no significant differences between control 1 and 2 with raw goat-satay marinated with shallots juice at doses of 10%, 20%, and 30% or between raw goat-satays without sliced fat and with sliced fat. The ranges of carbohydrate contents of raw goat-satay without sliced fat and with sliced fat were 0.18%-1.65% and 0.65%-1.66%, respectively.

The ash contents of raw goat-satays with or without sliced fat were significantly lower ($p<0.05$) in marinated raw goat-satay with shallots juice at doses of 10%, 20%, and 30% compared to control 1 and 2. Total organic matters of marinated raw goat-satays were significantly different ($p<0.05$). The total organic matters in unmarinated raw goat-satays (control 1 and 2) tended to be higher than those in marinated raw goat-satays with or without sliced fat.

PAHs Levels of Charcoal-Grilled Goat Satay

The levels of benzo(a)pyrene (BaP) and other PAHs in the charcoal-grilled goat satays are presented in Table 2. The levels of BaP in both grilled goat-satays with sliced fat or without sliced fat in our study exceeded the safe limits set by the International Agency for Research on Cancer (IARC), World Health Organization (IARC-WHO), Europe Union (EU), and the National Agency of Food and Drug Control, Republic of Indonesia (BPOM RI). They have set a safe limit for BaP in heated meat and processed meat at the concentration of 0.005 mg kg^{-1}.

Our study showed that marinating raw goat-satays with shallots juice can reduce the levels of PAHs for the BaP. Organosulfur compounds (OSC) and anti-

Table 1. Antioxidant activity, malonaldehyde, and chemical contents of raw goat satay treated by different levels of shallots juices and with or without sliced fat

Variables	Unit	Raw goat-satay with sliced fat				Raw goat-satay without sliced fat			
		Control 1	T10F	T20F	T30F	Control 2	T10L	T20L	T30L
Antioxidant activity (DPPH)	%	18.99±0.16^{h}	39.93±0.16^{d}	51.88±0.16^{c}	57.12±0.17^{a}	31.42±0.16^{g}	32.09±0.15^{f}	39.20±0.08^{e}	56.47±0.16^{b}
Levels of malondialdehyde	mg kg^{-1}	0.59±0.02^{e}	0.96±0.02^{b}	0.75±0.00^{c}	0.686±0.01^{d}	1.26±0.02^{a}	0.47±0.01^{f}	0.58±0.01^{e}	0.93±0.00^{b}
Total organic matter	%	46.77±0.07^{b}	38.88±0.08^{c}	49.06±0.10^{a}	39.05±0.04^{c}	33.32±0.13^{d}	28.81±0.07^{f}	30.46±0.08^{e}	30.64±0.04^{e}
Ash	%	0.92±0.00^{bc}	0.69±0.01^{e}	0.73±0.02^{de}	0.71±0.02^{de}	1.08±0.05^{a}	1.03±0.10^{ab}	0.83±0.01^{cd}	0.92±0.05^{bc}
Moisture	%	64.17±0.06^{e}	68.09±0.07^{d}	71.55±0.27^{c}	68.87±0.32^{d}	76.81±0.42^{b}	79.42±0.19^{a}	78.71±0.29^{a}	78.61±0.47^{a}
Fat	%	18.36±0.55^{a}	17.85±0.12^{a}	12.57±0.10^{c}	15.24±0.33^{b}	1.50±0.24^{e}	2.95±0.05^{d}	2.27±0.11^{d}	2.38±0.19^{d}
Protein	%	15.74±0.14^{c}	13.20±0.13^{e}	14.04±0.05^{d}	13.54±0.11^{de}	18.99±0.19^{a}	15.97±0.09^{cd}	15.77±0.09^{c}	16.44±0.42^{d}
Carbohydrate	%	0.82±0.36^{bcd}	0.18±0.08^{d}	1.12±0.11^{bcd}	1.65±0.74^{ab}	1.62±0.04^{abc}	0.65±0.04^{cd}	2.43±0.49^{a}	1.66±0.19^{ab}

Note: $^{a-h}$ Means in the same row with different superscripts differ significantly ($p<0.05$). nd= not detected; DPPH= diphenyl-picrylhydrazyl; Control 1= unmarinated raw/grilled goat-satay with sliced fat; Control 2= unmarinated raw/grilled goat-satay without sliced fat; T10F= marinated raw/grilled goat-satay with sliced fat of 10% shallots juice; T20F= marinated raw/grilled goat-satay with sliced fat of 20% shallots juice; T30F= marinated raw/grilled goat-satay with sliced fat of 30% shallots juice; T10L= marinated raw/grilled goat-satay without sliced fat of 10% shallots juice; T20L= marinated raw/grilled goat-satay without sliced fat of 20% shallots juice; T30L= marinated raw/grilled goat-satay without sliced fat of 30% shallots juice.

Table 2. Cooking loss, cook yield, and PAHs contents of charcoal-grilled goat satay treated by different levels of shallots juices and with or without sliced fat

Variables	Unit	Charcoal-grilled goat satay with sliced fat				Charcoal-grilled goat satay without sliced fat			
		Control 1	T10F	T20F	T30F	Control 2	T10L	T20L	T30L
Cooking loss	%	38.75±0.85^{b}	40.78±0.62^{a}	36.54±0.65^{cd}	33.98±0.62^{e}	36.59±0.85^{c}	37.27±0.64^{bc}	33.99±0.63^{e}	34.62±0.57^{de}
Cook yield	%	61.25±0.85^{de}	59.22±0.77^{e}	63.46±0.43^{bc}	66.02±0.68^{a}	63.42±0.79^{bc}	62.73±0.65^{d}	65.99±0.77^{a}	65.38±0.73^{ab}
Benzo(a)pyrene (BaP)	mg kg^{-1}	0.39±0.01	nd	nd	nd	nd	nd	nd	3.88±0.01
Benzo(a)antharacene (BaA)	mg kg^{-1}	2.24±0.01^{f}	2.28±0.01^{ef}	0.45±0.01^{g}	11.09±0.01^{a}	7.20±0.07^{b}	3.03±0.01^{d}	4.03±0.01^{c}	2.32±0.01^{e}
Pyrene (Pyr)	mg kg^{-1}	8.32±0.01^{e}	18.19±0.01^{c}	10.59±0.00^{d}	nd	1.06±0.03^{g}	7.93±0.02^{f}	248.02±0.01^{a}	239.84±0.07^{b}
Phenanthrene (Phe)	mg kg^{-1}	nd	nd	nd	0.542±0.01	nd	nd	nd	nd
Acenaphthene (Acp)	mg kg^{-1}	nd	nd	nd	nd	nd	nd	nd	nd
Naphthalene (Nap)	mg kg^{-1}	nd	nd	nd	nd	nd	nd	nd	nd

Note: $^{a-h}$ Means in the same row with different superscripts differ significantly ($p<0.05$). nd= not detected; Control 1= unmarinated raw/grilled goat-satay with sliced fat; Control 2= unmarinated raw/grilled goat-satay without sliced fat; T10F= marinated raw/grilled goat-satay with sliced fat of 10% shallots juice; T20F= marinated raw/grilled goat-satay with sliced fat of 20% shallots juice; T30F= marinated raw/grilled goat-satay with sliced fat of 30% shallots juice; T10L= marinated raw/grilled goat-satay without sliced fat of 10% shallots juice; T20L= marinated raw/grilled goat-satay without sliced fat of 20% shallots juice; T30L= marinated raw/grilled goat-satay without sliced fat of 30% shallots juice. The limit of detection or concentration readings by GC for each PAHs compound was BaP of 1.23 mg kg^{-1}, BaA of 13.90 mg kg^{-1}, Nap of 4.10 mg kg^{-1}, Acp of 5.88 mg kg^{-1}, Phe of 3.41 mg kg^{-1}, and Pyr of 23.03 mg kg^{-1}. The PAHs concentration was calculated by the following formula: PAHs concentration= (concentration readings by GC x final volume) x (weight of sample)$^{-1}$.

oxidants in shallots can reduce the oxidation process in the grilled goat meat, resulting in the formation of dangerous compounds such as BaP. Marination of raw goat-satay with shallots juice was proven to reduce the BaP levels of grilled goat-satay until it was undetectable. Control 1 or unmarinated grilled goat-satay with sliced fat showed a BaP level of 0.39 ± 0.01 mg kg$^{-1,}$ while in the marinated grilled goat-satay, BaP was not detected in the doses of 10%, 20%, or 30% shallots-juice treatments. Control 2 or unmarinated grilled goat-satay without sliced fat contained sufficient natural antioxidants to inhibit the formation of BaP so that it was not detected. Control 2 contained levels of natural antioxidants of 31.42%, lower than marinated raw goat-satay without sliced fat at doses of 10%, 20%, or 30% shallots juice. On the other hand, BaP was detected at the level of 3.88 mg kg^{-1} in marinated grilled goat-satay without sliced fat at a dose of 30% shallots juices (T3-L) which had the highest antioxidant activity (56.47%) compared to those marinated shallots juice at doses of 0%, 10%, and 20% treatments.

Benzo(a)anthracene (BaA) was detected in all grilled goat-satay samples, as shown in the data presented in Table 2. BaA levels tended to be higher in grilled goat-satay with sliced fat than that without sliced fat. The ranges of BaA levels in the grilled goat-satay with sliced fat and without sliced fat were 0.45-11.09 mg kg^{-1} and 2.32-7.20 mg kg^{-1}, respectively. Marinated grilled goat-satay without sliced fat had significantly lower levels of BaA than unmarinated samples (control 2). Grilled goat-satay with sliced fat marinated with 30% treatment (T3-F) had the highest antioxidant activity (57.12%) and contained the highest BaA (11.09 mg kg^{-1}) compared to those marinated with 0%, 10%, and 20% shallots juice.

Pyrene (Pyr) was also detected in almost all grilled goat-satay samples in various treatments. The levels of Pyr in grilled goat-satay with sliced fat and without sliced fat ranged from undetectable to 18.19 mg kg^{-1} and 1.06-248.02 mg kg^{-1}, respectively. In fact, the Pyr level was detected to be higher in the sample of marinated grilled goat-satay without sliced fat at various concentrations compared to control 2, which was not marinated.

Phenanthrene (Phe) was not detected in almost all grilled goat-satay samples in various treatments. Phe was detected only in the grilled goat-satay with sliced fat marinated at a dose of 30% shallots juice (T3-F). Acenaphthene (Acp) and naphthalene (Nap) were not detected in all grilled goat-satay samples in various treatments.

DISCUSSION

Antioxidant Activity, Fat Content, and Lipid Oxidation of Raw Goat-Satay

The study results indicated that the raw goat-satay marinated with shallots juice was very effective in depositing the antioxidant compounds of shallots into the goat meat. Marination is a method of processing meat to give a flavor to the meat. At the same time, marination deposits specific bioactive compounds into the meat, including antioxidant compounds.

Shallots have antioxidant activity (DPPH scavenging activity) of 62.23% with a total flavonoid and total phenolic contents of 0.10% and 0.12%, respectively. Acheampong *et al.* (2016) reported that the phenolic compounds of shallots consist of alkaloids, flavonoids, glycosides, and tannins, which total about 0.001-0.124 TAE mg/25g or 11.30% (w/w) (TAE= tannic acid equivalents). These compounds have antioxidative capacities and can inhibit oxidation in food.

Slimestad *et al.* (2020) reported that red onion contains at least 25 types of flavonols, and one of the most important is the glycosyl quercetin derivative. These flavonols are the main pigments of red onions. The total flavonol content of red onions is about 1,92 mg kg^{-1} fresh weight.

Suleria *et al.* (2015) reported that flavonoid compounds and organosulfur compounds (OSC) from

shallots and onions or *Allium* species are very efficacious for health in addition to cooking spices. Jones (2015) argued that OSC could neutralize reactive oxygen species (ROS). In addition, the OSC can also determine the thiol/disulfide redox status in signaling and sensing.

Munday (2012) reported that genus *Allium* (family *Amaryllidaceae*) and genus *Brassica* are the two main groups of vegetables containing OSC with special properties. Well-known representations of the genus Allium containing S-alk(en)yl-L-cysteine sulfoxide are garlic, onions, shallots, leeks, and chives. Among the derivatives of onions, the most well-known organosulfur substances include dipropyl sulfide, dipropyl disulfide, dipropenyl sulfide, and dipropenyl disulfide. Yoshinari *et al.* (2012) reported that cycloalliin, dimethyl trisulfide, S-methyl-L-cysteine, S-methyl-L-cysteine sulfoxide, and S-propyl-L-cysteine sulfoxide are efficacious OSCs in onion extract.

According to Goncharov *et al.* (2021), in addition to having a chemo-preventive effect on carcinogenesis, several OSCs from *Allium* can also support carcinogenesis in several organs. OSC has been reported to inhibit the development of various tumors, as follows: skin (Wang *et al.*, 2012); large intestine (Lai *et al.*, 2012); stomach and small intestine (Kaneko *et al.*, 2012); breasts (Azarenko *et al.*, 2014); and pancreas (Ma *et al.*, 2014).

According to Bartosz (2013), antioxidant compounds can act with 3 specific roles. The first is scavenging free radicals and reactive species (reactive species= RS) in the initiation, propagation, and termination phases (when hydroperoxide breaks down). The second is chelating transition metals or binding catalysts metal ions. The third is donating electrons to stabilize fat molecules in the propagation and termination phases.

The antioxidant activities of natural antioxidants (indigenous) in unmarinated raw goat-satay in the study results were lower than those of Mirzaei *et al.* (2017). They had reported that goat meat has antioxidant activity (DPPH) of 42%.

The endogenous antioxidants in goat meat include the protein it contains. Mirzaei *et al.* (2017) reported that protein has strong antioxidant properties due to potential free radical scavengers and metal chelating agents. Histidine peptides such as carnosine and anserine have antioxidant properties. Purchas *et al.* (2014) reported that carnosine and anserine are the most abundant antioxidant histidyl dipeptide and antioxidants in meat.

Kim *et al.* (2019) reported that the levels of carnosine and anserine in the loin portion of goat meat were higher than the rump portion, i.e., 62.25 and 81.93 mg/100 g in the loin compared to 49.54 and 66.32 mg/100 g in the rump. According to Purchas *et al.* (2014), beef and lamb contain approximately 365 mg/100 g and 400 mg/100 g of carnosine, respectively.

Mateescu *et al.* (2012) reported that dipeptide proteins with antioxidant properties in meat are carnosine and anserine, which can scavenge reactive oxygen species and chelate metal ions. Johnson & Decker (2015) reported that carnosine is a potentially important dietary antioxidant because it is fully absorbed into the plasma. Escudero *et al.* (2013) reported that antioxidant peptides could bind metals and have the potential to act as hydrogen donors to stop free radical chain reactions in the body.

According to Johnson & Decker (2015), ubiquinone, glutathione, lipoic acid, spermine, carnosine, and anserine are some of the endogenous antioxidant compounds in meat. Purchas *et al.* (2014) reported that endogenous antioxidants in beef and lamb also include coenzyme Q10 (ubiquinone), which is about 2 mg/100 g. Jones (2015) reported that beef also contains the endogenous antioxidant glutathione, a component of the enzyme glutathione peroxidase, around 12–26 mg/100 g. According to William (2007) in Ahmad *et al.* (2018), glutathione levels in red meat are twice as high as in poultry. In addition, lamb meat also contains natural antioxidants, alpha-tocopherol or vitamin E around 0.44 mg/100 g.

According to Kumar *et al.* (2015), muscle membranes also consist of fat components. Muscle fat is also found between the muscle fibers as adipose tissue that stores triacylglycerol. According to Hajji *et al.* (2016), the fatty acid composition of lamb and goat meats are similar. As much as 45% of the total fatty acids are MUFA, monounsaturated fatty acids, and 10% are PUFA, polyunsaturated fatty acids.

According to William (2007) in Ahmad *et al.* (2018), every 100 g of lamb contains total omega, PUFA, MUFA, and SFA, saturated fatty acids around 0.157 g; 0.603 g; 2.066 g; and 1.730 g, respectively. Levels of omega 3 in beef and lamb are more than chicken or pork.

Johnson & Decker (2015) stated that meat contains pro-oxidants that are susceptible to oxidation, such as PUFA, cholesterol, protein, and pigments. According to Kumar *et al.* (2015), higher amounts of unsaturated fatty acids lead to oxidative processes of meat.

According to Farhadian *et al.* (2012), fat is more associated with the formation of PAHs because the lipophilic component is the main precursor for PAHs. Lipid oxidation causes fat to react with amino compounds. This causes the formation of substances such as melanoidin, which is brown in the Maillard reaction.

Szterk *et al.* (2012) reported that the incomplete burning of fat associated with pyrolysis, PAHs cannot be avoided during meat grilling at high temperatures. This supports higher PAHs levels in grilled meat. Dost & Ideli (2012) argued that the grilling process of satay could trigger the fat pyrolysis process, which produces PAHs in smoke that can contaminate the surface of the satay. Singh *et al.* (2020) also reported that the PAHs deposition and the smoke arose during grilling, which enveloped the beef satay.

The method of thiobarbituric acid reactive substances (TBARS) was used in our study to confirm the occurrence of lipid oxidation in raw goat-satay. The higher the TBARS value or the amount of malondialdehyde (MDA), the higher the lipid oxidation process in raw goat-satay.

According to Barriuso *et al.* (2013), the measurement results of lipid oxidation using the TBARS method by spectrophotometry were expressed as MDA, which is the most abundant secondary oxidation product. MDA is widely used to estimate lipid peroxidation in membrane and biological systems. The value of lipid

oxidation using the TBARS method tends to be too high because, in addition to measuring MDA, it also measures the other oxidized molecules.

The decline in the quality of meat and meat products related to the loss of nutritional value and safety of meat is mostly due to lipid peroxidation. According to Lorenzo *et al.* (2018) and Guyon *et al.* (2016), off-odor and off-flavor are caused by hexanal, propanal, and pentanal, which are secondary oxidation products. According to Kumar *et al.* (2015), rancid odor and off-flavor in meat are caused by ketones, aldehydes, alkanes, and other secondary oxidation products, which are stable and formed in the termination phase. According to Lorenzo *et al.* (2018), to prevent or delay the oxidation reaction in meat to have a longer shelf life, the industry adds synthetic or natural antioxidants in the formulation of meat products.

According to Bekhit *et al.* (2013), the transformation of oxidants and reducing agents is caused by the transfer of one or more electrons from an electron donor (reductant) to an electron acceptor (oxidant). Quality deterioration in food and pathological diseases in humans are significantly caused by oxidative reactions involving reactive nitrogen species (RNS) and reactive oxygen species (ROS). Oxidative processes and biochemical components in the muscle tissue system are highly dependent on the feed nutritional composition consumed. Instability in the function of the biological muscle system occurs when the oxidative potential of the muscle tissue system is less than optimal, resulting in the formation of free radicals and secondary oxidation product substrates in the muscle and meat.

Serpen *et al.* (2012) reported that higher levels of phospholipids in meat and meat products make them susceptible to oxidation. Phospholipids are rich in unsaturated fatty acids and are present in cell membranes. Unsaturated fatty acids cause lipid peroxidation and result in poor meat quality.

According to Cunha *et al.* (2018), enzyme activity, pH, the concentration of pro-oxidants, temperature, and protein and fat fractions compositions, which vary between various livestock species, greatly affect the oxidative meat stability. According to Falowo *et al.* (2014), the oxidative processes phenomenon in meat causes the formation of secondary compounds that can harm human health.

According to Kumar *et al.* (2015), the meat deterioration from slaughter, processing, and storage of meat is caused by an oxidative process resulting from disrupting the *in vivo* balance of the antioxidant and pro-oxidant systems. According to Bekhit *et al.* (2013), meat oxidation that occurs in postmortem conditions cannot be avoided, for example, changes in color pigments and lipids that cause meat color to deteriorate, as well as flavor and smell rancid making it less attractive to consumers. Animal genetics, feed nutrition, production management, and environmental conditions greatly affect the oxidative processes of muscle tissue in the animal's body. They are closely related to temperament, immune status, and the animal's ability to cope with stress.

According to Aguiar *et al.* (2016), the composition of fat and protein fractions greatly affects the effectiveness of natural antioxidants in meat. Kumar *et al.* (2015) stated that fat content and fatty acid composition directly affect oxidative stability. Lipid oxidation in meat will occur faster when the fat content and PUFA/SFA ratio are higher.

Contents of Protein, Carbohydrate, Moisture, and Ash of Raw Goat-Satay

According to Faustman & Suman (2017), the protein fraction contains myoglobin and ferrous iron, whose concentration can affect the rate of oxidation in meat. Lipid oxidation is catalyzed by reactive iron and the heme pigment in myoglobin, which is more concentrated in red and darker meats. According to Soladoye *et al.* (2015), protein oxidation results in the formation of cross-linking proteins, loss of sulfhydryl groups, and the formation of protein carbonyls so that protein digestibility and functionality are lost, color and texture changes, and worsens the quality of essential amino acids.

According to Falowo *et al.* (2014), free radicals are formed due to oxidative deterioration of fatty acids whose reactions depend on oxygen. According to Soladoye *et al.* (2015), covalent modifications in the side chains of amino acids are targets of protein oxidation caused by reactive oxygen species (ROS) or secondary oxidation products such as lipid oxidation catalyzed by myoglobin or metals.

According to Cunha *et al.* (2018), lipid oxidation and protein oxidation have a similar mechanism through free-radical chain reactions. When ROS separates a hydrogen atom from a protein, it produces a carbon-centered protein radical. According to Guyon *et al.* (2016), oxidations of lipid and protein initiate a similar pathway in which free radicals or ROS attack target molecules, initiating radical-chain reactions. There is an interaction between the two oxidative processes.

Pro-oxidant agents can cause changes in the physical properties of proteins from secondary oxidation-products of lipid oxidation, such as aldehydes reacting with proteins. In addition, hydrogen atoms from proteins can absorb peroxyl radicals from lipid oxidation to form alkoxyl and hydroxyl derivatives radicals. Protein oxidation will release iron due to the conversion of myoglobin to metmyoglobin which catalyzes lipid oxidation. The rate of lipid oxidation is strongly related to the higher concentrations of iron and myoglobin.

In addition, according to Faustman & Suman (2017), the oxidation rate of unsaturated fatty acids is strongly influenced by intermediate products such as peroxide and hydrogen superoxide anions from the formation of metmyoglobin. According to Estévez & Xiong (2019), lipid oxidation and protein oxidation processes are highly correlated with the reciprocal transfer of nonreactive species (such as hydroperoxides and hydrogen peroxide) and ROS between proteins and lipids.

Until now, there is still very limited information on the formation of PAHs by sugar and amino acid precursors. The available information is more about fat precursors in the formation of PAHs (Szterk, 2015). A study by

Sharma *et al.* (2003) reported the formation of polycyclic aromatic compounds (PAC) by amino acids (proline, asparagine, and tryptophan) at temperatures much higher than the commonly cooking temperature. Britt *et al.* (2004) reported an increase in PAH formed from the pyrolysis of amino acids and carbohydrates (proline and glucose) after the Maillard reaction.

According to Min *et al.* (2018), water and other materials can affect the formation of PAHs. Water provides a source of oxygen when heating, thus preventing incomplete combustion and causing an inhibitory effect.

PAHs Levels of Charcoal-Grilled Goat Satay

According to Zeng *et al.* (2014) and Khan (2015), high temperatures can degrade some bioactive antioxidant compounds, which at low concentrations can act protectively and vice versa at high concentrations can act as pro-oxidants. Kao *et al.* (2012) reported that the marination treatment (24 hours) increased fat-soluble PAHs.

The study results showed that the excessive concentration of antioxidants due to the already high endogenous antioxidants in the raw goat-satay plus natural antioxidants from the marinating of shallots juice before grilling the satay could trigger the formation of higher PAHs. According to Zeng *et al.* (2014); Khan (2015); Chen *et al.* (2017); Zeng *et al.* (2017); Zeng *et al.* (2018); Nuray & Oz (2019), the degree of PAHs inhibition will depend on the dose-dependent antioxidant concentration. The formation of PAHs carcinogens can be inhibited with moderate doses of antioxidants, and conversely, higher doses can even support the formation of PAHs.

According to Rahal *et al.* (2014), with the availability of heavy metals, antioxidants can act as pro-oxidants. When transition metals are available, some antioxidant flavonoids can act as pro-oxidants and be mutagenic in vitro. The structure of flavonoids largely determines the antioxidant activities and the copper-initiated pro-oxidant activities. The antioxidant activities of flavonoids require the OH substitution. Neither the antioxidant activities nor the copper-initiated pro-oxidant activities were found in flavone and flavanone, which have no OH substitution. They are the basic chemical structure of flavonoids. The number of free OH substitutions in the flavonoid structure also determines the copper-initiated pro-oxidant activities.

The pro-oxidant activities will be stronger as the number of OH substitutions increase. The antioxidant and pro-oxidant activities of flavonoids can be inactivated by O-methylation and probably also other O-modifications of the flavonoids OH substitution. Foods containing flavonoids are generally O-glycosides with sugars bound at the C3 position. The inactivation of metal-initiated pro-oxidant activities results from methylation or glycosidic modification of the OH substitution of flavonoids.

Sepahpour *et al.* (2018) reported that bioactive compounds and heating temperature were strongly related to the antioxidant capacity for PAHs inhibition. Excessive heating temperature can reduce antioxidant capacity (Zeng *et al*., 2014; Khan, 2015). PAHs inhibition is also determined by the type of raw food ingredients and the presence of certain PAHs precursors in the marinade itself (Sepahpour *et al.*, 2018; Rounds *et al*., 2012).

Fat and moisture contents also caused BaP levels to be detected in marinated grilled goat-satay without sliced fat with 30% shallots juice (T3-L) and unmarinated grilled goat-satay with sliced fat (control 1). The fat contents of T3-L were higher than control 2. Likewise, the fat contents in control 1 were higher, and the moisture contents were lower than marinated grilled goat-satay with sliced fat with 10%, 20%, or 30% shallots juice. According to Min *et al.* (2018), moisture and other materials can affect the PAHs formation. Moisture provides a source of oxygen when heating; thus, preventing incomplete combustion and causing an inhibitory effect.

According to Adiyastiti & Suryanto (2014), the BaP contents of charcoal-grilled goat satay were higher than gas grills. Charcoal is the result of wood pyrolysis in which there is a PAH content to contribute to the increasing amount of BaP. According to Irnanda *et al.* (2012), commercial charcoal-grilled chicken satay in Yogyakarta contains a BaP of 2.50-393.32 mg kg^{-1}, exceeding the safe limit set by BPOM RI, namely 5.00 $\mu g kg^{-1}$.

BaP levels in our study were higher than those reported by Jahurul *et al.* (2013), Aaslyng *et al.* (2013), and Ahmad Kamal *et al.* (2018), who reported BaP levels in beef satay in their study were more than 24 ng/g. IARC-WHO has categorized the only type of PAHs, namely BaP, as carcinogenic or class 1 (IARC, 2015). According to Mohammadi & Valizadeh-Kakhki (2018), BaP was identified as a marker of PAHs carcinogens in grilled beef and chicken.

According to Farhadian *et al.* (2012), fat droplets from the meat onto the flames cannot be avoided because the heat source is horizontal so that the BaP concentration formed is higher. The surface of the meat is less likely to be contaminated with PAHs compounds than the inside. PAHs compounds are produced through the pyrolysis process (incomplete combustion) as long as the meat is grilled with charcoal, and when the fat from the meat drips onto the flames, it will produce significant levels of PAHs during direct heating of the meat with charcoal. The fat levels influence pAHs production in meat and the distance of food from heat sources.

Ingredients of vegetable origin, such as spices, including shallots, contain bioactive compounds that can limit the formation of PAHs. Lu *et al.* (2018) reported that the formation of BaP in beef and chicken samples could be inhibited by ginger. Janoszka (2019) reported that the formation of PAHs in meat was reduced by 21%-48%, with the addition of garlic by 30%. Sinaga *et al.* (2016) reported that antioxidants from andaliman fruit juice decreased the BaP of grilled duck meat. The BaP content of grilled duck meat without marinated with andaliman fruit juice was 787 ng, while that of marinated was 295 ng. Cordeiro *et al.* (2020) reported that vinegar could be used to inhibit the formation of PAHs in meat.

Garlic, onions, shallots, leeks, and chives are well-known representatives of the genus *Allium* (family *Amaryllidaceae*), containing an organosulfur compound named S-alk(en)yl-L-cysteine sulfoxide. Neves *et al.* (2021) reported that the formation of PAHs could be reduced by adding seasonings before frying, grilling, or roasting meat with vegetables of the *Allium* genus (garlic, onions, shallots), pepper, and other seasonings containing phenolic compounds. The decrease in PAH is strongly related to the organosulfur compounds in vegetables of the *Allium* genus, which can suppress reactive species and prevent the formation of PAHs.

According to Janoszka (2011) in Adeyeye (2020), in domestic cooking, meat is often prepared with vegetables of the *Allium* genus in many cultures. Thermal decomposition cannot occur in food structures modified by antioxidant compounds in vegetables of the genus *Allium* added in the formulation. The composition of the food is enriched with antioxidant activity modulators and organosulfur compounds. The genus *Allium* contains the main organosulfur compounds in diallyl disulfide, diallyl sulfide, dipropyl disulfide, N-acetylcysteine, and cyst and cysteine. These resulted in the inhibition of the formation of PAHs in grilled meat with these ingredients.

Janoszka (2011) in Adeyeye (2020) argued that the decrease in PAHs concentration when heating food affects the characteristics of bioactive antioxidant compounds. According to Janoszka (2019), the modulation of antioxidant activity is the role of phenolic bioactive compounds, such as allicin in garlic and quercetin in shallots and onions. These phenolic bioactive compounds can also interact with intermediate products and suppress reactive species that contribute to PAH formation. According to Embuscado (2015), there are three roles of phenolic compounds, namely hydrogen donors, reducing agents, and single oxygen quenchers, so that they can modulate antioxidant activity.

Wongmaneepratip *et al.* (2019) has succeeded in inhibiting PAHs using organosulfur compounds, and Wang *et al.* (2019) has succeeded in inhibiting PAHs with the use of isolated phenolic compounds. According to Gibis & Weiss (2012), there is difficulty assessing which components contribute to the PAHs inhibition because marinades generally use a mixture of various spices. Marinating using spices rich in organosulfur and phenolic compounds has been shown to inhibit PAHs significantly. The main factor is the concentration of the organosulfur and phenolic bioactive compounds, not the marinade method with water or oil.

According to Viegas *et al.* (2012), heavy molecular weight PAHs such as BaA and BaP during grilling will remain on the meat surface because they are more stable. The IARC (2015) has classified BaA as possibly carcinogenic or class 2B. Possibly carcinogenic means that it can occur or not depending on the existing precursors. In the European Union (EU), BaA and BaP are heavy molecular weight PAHs that are monitored for food safety.

According to Viegas *et al.* (2012), the US-EPA (United States Environmental Protection Agency) has set 15 priority types of PAHs in monitoring environmental pollution, and the EU has set 8 types of heavy molecular weight PAHs (PAH8) in monitoring the presence of PAHs in food since 2005. The PAH8 are: benzo(a)pyrene (BaP), benzo(a)anthracene (BaA), benzo(g,h,i) pyrene (BgP), benzo(b)fluoranthene (BbF), dibenzo(a,h)anthracene (DhA), benzo(k)fluoranthene (BkF), indeno[1,2,3-cd]pyrene (IcP), and chrysene (Chr).

Aaslyng *et al.* (2013) noted that since 2002, BaP has been used as a marker in monitoring food safety from carcinogenic PAHs. BaP is not always detected in foods containing PAHs causes the EU to apply PAH4 as a carcinogenic PAH marker. The PAH4s are BaP, BaA, BbF, and Chr, which is limited to 30 $\mu g kg^{-1}$.

IARC (2015) has classified Pyr, Phe, and Acp as non-carcinogenic or class 3. Therefore, it remains safe for consumption even though they are present in grilled goat-satay. IARC also has classified Acp as non-carcinogenic or class 3 and Nap as possibly carcinogenic or class 2B. According to Viegas *et al.* (2012), Acp and Nap are mild PAHs that are more volatile and evaporate quickly.

The study results were not the same as those of Ahmad Kamal *et al.* (2018), who found Phe, Acp, and Nap to be PAHs mostly formed in the grilled meat. According to Kao *et al.* (2012), Nap is formed because the degradation products of lipid oxidation such as cyclohexane would be oxidized to a benzene ring structure during the healing process and then reacted with carbon compounds C_4 to form Nap.

CONCLUSION

Mitigating the carcinogen formation of polycyclic aromatic hydrocarbons (PAHs) in charcoal-grilled goat-satay has been successfully carried out by marination of raw goat-satay with 10% and 20% shallots juices. The 10% and 20% treatments significantly reduced the carcinogenic BaP and BaA to not detected levels even though they increased the non-carcinogenic Pyr levels in both grilled goat-satay with and without sliced fat. Marination of raw goat satay with 10%, 20%, and 30% shallots juices significantly prevented the formation of Phe, Acp, and Nap to undetectable in both grilled goat satay with and without sliced fat. Marinated raw goat-satay without sliced fat with 30% shallots juices resulted in the highest antioxidant activities and BaP formation (3.88 mg kg^{-1}).

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the manuscript.

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