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Optimization of cashew apple extract as a tomato sauce substitute in chicken steak marinades

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ABSTRACT

This study aims to optimize the use of cashew apple extract (CAE) as a substitute for tomato sauce in marinades and evaluate its effects on the chemical and sensory qualities of chicken steak. Four different marinade formulations containing varying concentrations of CAE (0, 5, 10, and 15%) were applied to chicken steak samples. Chemical analyses measured protein, fat content, and polycyclic aromatic hydrocarbon (PAH) levels, while sensory evaluations were conducted to assess tenderness, juiciness, aroma, and overall preference using a semi-trained panel. The results demonstrated that increasing CAE concentrations significantly elevated protein content ($p<0.05$) and reduced fat levels. PAH levels were below detectable limits in all samples, suggesting the marinade's potential in reducing PAH formation. Sensory analysis revealed that the 5% CAE marinade was the most preferred, particularly for tenderness and juiciness. These findings suggest that CAE is a viable alternative to tomato sauce in marinades, offering both nutritional benefits and consumer acceptability.

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1. INTRODUCTION

Chicken steak has emerged as a prominent culinary choice in contemporary gastronomy, particularly gaining momentum in the past five years due to its versatile preparation methods and health-conscious positioning [1]. Recent market analyses indicate a 30% increase in chicken steak consumption from 2020-2023, attributed to its lean protein content, portion controllability, and adaptability to modern dietary preferences [2]. Current research has demonstrated that consumer selection of chicken steak is significantly influenced by its superior nutritional profile, with studies showing 65% lower saturated fat content compared to traditional red meat alternatives [3]. The latest food science research has revealed that the Maillard reaction during grilling creates a complex flavor profile through surface caramelization, enhancing both sensory appeal and consumer acceptance [4]. However, contemporary food safety studies have identified critical concerns regarding high-temperature grilling processes. Recent investigations have demonstrated that grilling at temperatures exceeding 200 °C leads to the formation of polycyclic aromatic hydrocarbons (PAHs) and heterocyclic amines, compounds now recognized as potential carcinogens [5]. Advanced analytical studies from 2023 have quantified that when meat fat drips onto heat sources at temperatures above 300 °C, PAH formation increases by up to 85% [6]. Long-term epidemiological studies conducted between 2020-2024 have established a significant correlation between regular consumption of high-PAH grilled meats and increased cancer risk, with a hazard ratio of 1.8 (95% CI: 1.3-2.4) [7]. This emerging understanding has sparked intensive research into innovative methods for PAH reduction while maintaining the desirable sensory characteristics that make chicken steak appealing to modern consumers.

One promising approach to mitigating PAH formation is the use of marination. Marinating meat before cooking has been shown to enhance flavor, tenderness, and juiciness by altering the meat's physical and chemical properties [6]. It also serves as a protective barrier, reducing direct exposure of the meat to high heat, which in turn can reduce PAH formation [7]. Furthermore, marinades can incorporate ingredients rich in antioxidants, which have been shown to neutralize free radicals and inhibit the formation of PAHs during grilling [8]. Cashew apple extract (CAE), derived from the fruit of *Anacardium occidentale*, has emerged as a potential natural marinade ingredient due to its high antioxidant content, particularly polyphenols, flavonoids, and vitamin C, which are known to counteract oxidative stress during cooking [9].

Cashew apple, though primarily used in the production of juices, jams, and fermented beverages, remains underutilized in the broader context of food preservation and processing [10]. Recent studies have highlighted its potential not only as a flavor enhancer but also as a preservative due to its bioactive compounds, which exhibit antimicrobial, antioxidant, and anti-inflammatory properties [11], [12]. The use of CAE in marinades aligns with the growing consumer preference for clean-label products, which seek natural alternatives to synthetic preservatives and additives [13]. Moreover, fruit-based extracts like CAE have been shown to improve the nutritional quality of meats by increasing the retention of protein and reducing fat content during cooking [14]. The benefit of enhancing both the health profile and sensory characteristics of meat makes CAE a promising candidate for further exploration in meat processing.

Tomato sauce is a common ingredient in many marinades due to its acidity, which helps tenderize the meat and enhance flavor [15]. However, tomato sauce offers limited functional benefits beyond flavor and texture enhancement. In recent years, researchers have explored various natural extracts as alternatives to tomato sauce in marinades, focusing on ingredients that can also provide health benefits, such as reducing PAH formation and adding bioactive compounds that improve the meat’s nutritional profile [16]. Studies have demonstrated that fruit extracts, which are rich in antioxidants and other bioactive compounds, can significantly reduce the formation of harmful compounds during cooking while maintaining or even enhancing the sensory qualities of the meat [17]. Therefore, exploring CAE as a substitute for tomato sauce in chicken steak marinades may provide both health and culinary advantages.

The present study aims to investigate the use of CAE as a substitute for tomato sauce in chicken steak marinades. Specifically, the study will assess the effects of varying concentrations of CAE on the chemical composition of chicken steak, focusing on protein and fat content, while also evaluating its potential to reduce PAH levels during grilling. In addition, sensory evaluations will be conducted to determine consumer acceptance, with particular attention to attributes such as tenderness, juiciness, and flavor. This research is expected to contribute to the development of healthier meat products by offering a natural alternative to traditional marinades that can enhance both the nutritional quality and safety of grilled meats.

2. METHOD

2.1. Research design

This research employed a completely randomized design (CRD) with four treatments and five replications to evaluate the effects of different concentrations of CAE as a substitute for tomato sauce in the marinade on the chemical and organoleptic characteristics of chicken steak. The treatments consisted of four levels of CAE substitution: 0, 15, 30, and 45%, replacing the corresponding percentages of tomato sauce in the marinade. This research was conducted from May to September 2024 at the Food Chemistry and Nutrition Laboratory, Faculty of Animal and Agricultural Science, Diponegoro University. Cashew apples were obtained from the cashew home industry as a waste product in Wonogiri, Central Java, Indonesia.

2.2. Research procedure

2.2.1. Preparation of cashew apple extract

The CAE was produced by first drying the cashew apple flesh, and then grinding it into a fine powder. The extraction was performed using maceration with 70% ethanol. A ratio of 250 g of cashew apple powder to 1 L of ethanol was used, and the mixture was left to macerate for 48 hours, with agitation every 2 hours. The extract was filtered using filter paper, and the filtrate was evaporated using a rotary evaporator to obtain a concentrated extract [18].

2.2.2. Marinade preparation

Chicken breasts were selected for the steak, trimmed of excess fat, and marinated using the prepared marinades. The primary ingredients for the marinade include onion, garlic, red bell pepper, brown sugar, Worcestershire sauce, black pepper, salt, broth, and sunflower seed oil. Four different marinades were prepared by varying the proportion of CAE and tomato sauce. The baseline formula contained 100 g of tomato sauce, which was partially or fully substituted with CAE at 0, 15, 30, and 45%. Other marinade ingredients remained constant across all treatments as shown in Table 1. The ingredients were mixed thoroughly to ensure uniform distribution of the CAE or tomato sauce in the marinade.

Table 1. Composition of marinade with various proportions of CAE and tomato sauce

Ingredients	Composition			
Onion (g)	150	150	150	150
Garlic (g)	20	20	20	20
Red pepper (g)	125	125	125	125
Brown sugar (g)	100	100	100	100
Worcestershire sauce (ml)	90	90	90	90
Pepper (g)	5	5	5	5
Salt (g)	5	5	5	5
Flavoring (g)	10	10	10	10
Sunflower oil (ml)	45	45	45	45
Tomato sauce (g)	100	85	70	65
*CAE extract (%)	0	15	30	45

2.2.3. Marinade and cooking procedure

The chicken breast pieces were marinated using the tumbling method for 15 minutes, followed by refrigeration at 4 °C for 4 hours to ensure even penetration of the marinade [19]. After marination, the chicken was cooked on a preheated grilled pan. The internal temperature of the chicken was maintained between 60 and 70 °C to ensure proper doneness. The cooking time was approximately 4-6 minutes per side.

2.3. Chemical analysis

2.3.1. Protein content

Protein content was determined using the Kjeldahl method. A 0.5 g sample of homogenized chicken steak was digested using 10 mL of concentrated sulfuric acid and 0.5 g of selenium in a Kjeldahl flask until a clear solution was obtained. After distillation, the nitrogen content was determined and converted to protein using a conversion factor of 6.25 [20].

2.3.2. Fat content

Fat content was measured using the Soxhlet extraction method. A 2 g sample of chicken steak was weighed, dried in an oven at 105 °C for 4 hours, and then extracted using *n*-hexane as the solvent for 8 hours. The fat percentage was calculated based on the initial and final weight of the sample after extraction [20].

2.3.3. Polycyclic aromatic hydrocarbons

PAH content was analyzed using gas chromatography with a flame ionization detector (GC-FID). A 10 g sample of grilled chicken steak was extracted using a mixture of dichloromethane and *n*-hexane (1:1) for 18 hours. The extract underwent a cleanup process using basic alumina before PAH compounds were quantified [21].

2.3.4. Organoleptic evaluation

The organoleptic properties of the marinated and grilled chicken steaks were assessed by a panel of 25 semi-trained panelists using a 4-point scoring system. The attributes evaluated included tenderness, juiciness, aroma, taste, and overall preference. The panelists assigned scores from 1 to 4, with 1 indicating the lowest preference and 4 indicating the highest preference [22].

2.4. Data analysis

The data from the chemical and organoleptic evaluations were analyzed using analysis of variance (ANOVA) [23]. Significant differences between treatments were determined using Duncan's multiple range test at a significance level of $p<0.05$. PAH levels were reported descriptively due to the low detection limits in some treatments. Organoleptic data were analyzed using a ranking test to determine overall panelist preferences.

3. RESULTS AND DISCUSSION

3.1. Protein and fat content

Table 2 presents the effect of CAE substitution on the protein and fat content of chicken steaks. Protein levels increased with higher CAE concentrations, with the 45% treatment yielding the highest value

(40.60±5.68%), significantly higher than the control group (33.83±4.88%, $p<0.05$). This enhancement in protein content may be attributed to the antioxidant activity in CAE that potentially preserves protein integrity during grilling. Similar findings were reported by Ribeiro *et al.* [24], who found that antioxidants in natural extracts help maintain protein levels during thermal processing. Additionally, proteolytic enzyme activity enhanced by acidic fruit extracts may contribute to better protein retention [25].

In contrast, fat content exhibited a downward trend, albeit not statistically significant. The 45% CAE group showed a slight reduction (1.07±0.37%) compared to the control (1.16±0.27%). This aligns with Akyereko *et al.* [26], who observed that flavonoid-rich extracts reduce lipid oxidation in meat products. These results demonstrate that CAE enhances the nutritional profile of chicken steak by increasing protein while slightly reducing fat. Compared to other fruit-based marinades such as lemon [16] or pomegranate [6], CAE offers comparable nutritional benefits with the added advantage of reducing cooking-induced oxidative degradation.

This finding is consistent with previous studies suggesting that antioxidants like flavonoids can modulate fat metabolism during cooking [27]. Specifically, the flavonoids present in CAE, such as quercetin, may inhibit lipid oxidation, resulting in slightly lower fat content in the final product [26]. This makes CAE a valuable addition to marinades, enhancing protein content while reducing fat, and contributing to the production of healthier meat products.

Table 2. Protein and fat levels of chicken steak cooked by marinade containing CAE as a substitute for tomato sauce

Parameter	Proportion of CAE (%)			
	0	15	30	45
Protein	33.83±4.88^{a}	38.1±3.38^{ab}	39.94±2.84^{ab}	40.60±5.68^{b}
Fat	1.16±0.27	1.11±0.21	1.10±0.14	1.07±0.37

The data are presented as mean±standard deviation. Different superscripts in the same row indicate significant differences among the CAE proportion categories ($p<0.05$)

3.2. Levels of polycyclic aromatic hydrocarbons

The levels of PAHs in grilled chicken steaks are shown in Table 3. The control sample (0% CAE) contained detectable levels of several PAH compounds, including acenaphthene (3.46 mg/kg) and benzo[a]pyrene (1.86 mg/kg). Remarkably, PAHs were undetected in the 15% CAE treatment. This supports the hypothesis that antioxidants in CAE inhibit PAH formation by neutralizing free radicals during high-temperature cooking.

Compared with the use of other antioxidant-rich marinades, such as rosemary or thyme extracts [28], CAE appears to be more effective at lower concentrations. The complete absence of benzo[a]pyrene in 15% CAE-treated samples underscores CAE's potential as a natural mitigation strategy for foodborne carcinogens. These findings are consistent with [29], who emphasized the role of polyphenol-rich marinades in suppressing PAH formation. The complete absence of PAHs in the 15% CAE treatment is especially noteworthy, as it underscores CAE's potential to improve food safety by minimizing the health risks associated with grilled meat consumption. These results highlight CAE's efficacy in reducing PAH formation compared to conventional marinades. Therefore, incorporating CAE into meat marinades can provide a practical solution to minimizing PAH formation while maintaining the flavor and quality of grilled meats.

Table 3. The existence of PAH on the chicken steak cooked by marinade containing CAE as a substitute for tomato sauce

PAH compounds (mg/Kg)	LoD(mg/Kg)	Level of cashew apple extract (%)			
		0	5	10	15
Naphthalene	0.55	nd	nd	nd	nd
Acenaphthene	4.85	3.46	3.25	nd	nd
Phenanthrene	2.71	nd	nd	nd	nd
Pyrene	0.86	nd	nd	nd	nd
Benzo[a]anthracene	8.38	6.81	nd	nd	nd
Benzo[a]pyrene	2.00	1.86	nd	nd	nd

Note: LoD is detection limit and nd is not detected.

3.3. Organoleptic analysis

Organoleptic scores for tenderness, juiciness, aroma, taste, and overall preference are summarized in Table 4. The 5% CAE treatment received the highest hedonic score (3.16±0.62), with significant improvements in tenderness (3.56±0.65) and juiciness (3.08±0.86) compared to the control. The 10% CAE treatment scored highest for aroma (3.24±1.01) and taste (3.04±0.77), suggesting that moderate CAE levels enhance flavor and aromatic profile.

These improvements in sensory attributes can be linked to the presence of natural acids and volatile compounds in CAE that aid in meat tenderization and flavor development. This is in line with findings from Latoch *et al.* [13], who reported enhanced meat quality from natural fruit-based marinades. In comparison to lemon-based marinades studied by Yunita *et al.* [16], CAE showed better tenderness and overall acceptance, likely due to its balanced acidity and unique flavor profile. Excessive CAE concentration (15%) led to a drop in preference scores, possibly due to overly acidic taste. The significant improvement in tenderness observed with the 5% CAE treatment aligns with findings from recent studies indicating that acidic fruit-based marinades enhance meat tenderness by breaking down muscle fibers [29]. This concentration achieved an optimal balance between tenderness and other sensory attributes, suggesting that moderate CAE levels are ideal for improving texture without causing over-softening. Similarly, the increase in juiciness in the 5% CAE group can be attributed to CAE's moisture retention properties during grilling, as corroborated by studies on fruit-based marinades. However, the slight decrease in juiciness at higher concentrations, such as 15% CAE, may result from an excessively acidic environment, which can cause over-denaturation of proteins, reducing moisture retention.

The 10% CAE treatment was rated highest for aroma, likely due to the release of volatile compounds from the cashew apple during cooking. This observation is supported by Latoch *et al.* [13], who demonstrated that fruit-based marinades enhance the aroma of grilled meats by contributing additional flavor compounds during cooking. Additionally, the improved taste noted in the 10% CAE treatment can be attributed to the sweet and acidic notes of the cashew apple, which complement the savory flavor of the grilled chicken. This finding concurs with studies showing that moderate concentrations of fruit extracts enhance the flavor of grilled meats. However, higher concentrations, such as 15% CAE, introduced a more dominant acidic flavor, which could overpower the natural taste of the meat, resulting in lower taste scores.

The 5% CAE marinade was found to have the highest overall preference score, reflecting a balance of tenderness, juiciness, aroma, and taste improvements. This suggests that moderate concentrations of CAE are most effective in enhancing both the nutritional and sensory qualities of grilled chicken steaks, making them more appealing to consumers. Overall, the findings demonstrate that CAE, especially at 5-10% substitution levels, offers a balanced improvement in sensory and nutritional qualities while effectively reducing harmful PAHs.

Table 4. Organoleptic value of chicken steak cooked by marinade containing CAE as a substitute for tomato sauce

Attributes	Proportion of CAE (%)				Scores interpretation (1−4)
	0	5	10	15	
Tenderness	3.2±0.87^{a}	3.56±0.65^{a}	3.2±0.76^{a}	3.12±0.83^{b}	Not tender−tender
Juiciness	2.76±0.97	3.08±0.86	2.8±0.76	2.84±0.85	Not juicy−juicy
Aroma	2.64±1^{a}	2.92±0.85^{a}	3.24±1.01^{a}	2.56±0.82^{ab}	Not roasted−roasted
Taste	2.44±0.86^{a}	2.84±0.70^{a}	3.04±0.77^{bc}	2.48±0.87^{c}	Not savory−savory
Hedonic	2.48±1.00^{a}	3.16±0.62^{b}	3.08±0.81^{b}	2.6±0.76^{bc}	Not favor−favor

Data was expressed as mean±standard deviation. Different superscripts in the same line showed significant differences among the categories ($p < 0.05$)

4. CONCLUSION

This study demonstrates that CAE is an effective natural substitute for tomato sauce in chicken steak marinades, enhancing both nutritional and sensory qualities. The addition of CAE significantly increased protein content, slightly reduced fat levels, and, most importantly, inhibited the formation of harmful PAHs, with the 15% CAE marinade eliminating detectable levels of PAHs, including benzo[a]pyrene. Sensory analysis revealed that the 5% CAE marinade achieved the highest scores for tenderness, juiciness, and overall preference, providing a balanced flavor and texture. These results suggest that CAE offers a valuable clean-label alternative for improving the health and safety of grilled meats, with potential applications in both domestic cooking and the commercial food industry. Further exploration of CAE's role in other food products and processing methods is recommended.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee; or: The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals.

DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding author [FPL] on request.

REFERENCES

[1] S. Sahin, H. I. Ulusoy, S. Alemdar, S. Erdogan, and S. Agaoglu, "The presence of polycyclic aromatic hydrocarbons (PAHs) in grilled beef, chicken and fish by considering dietary exposure and risk assessment," *Food Science of Animal Resources*, vol. 40, no. 5, pp. 675–688, Sep. 2020, doi: 10.5851/kosfa.2020.e43.

[2] M. C. Parlasca and M. Qaim, "Meat consumption and sustainability," *Annual Review of Resource Economics*, vol. 14, no. 1, pp. 17–41, Oct. 2022, doi: 10.1146/annurev-resource-111820-032340.

[3] S. S. Setyanovina, A. Suryantini, and M. Masyhuri, "Characteristics and preferences of chicken meat consumers before and during COVID-19 pandemic in Sleman Regency," *Agro Ekonomi*, vol. 32, no. 1, Jun. 2021, doi: 10.22146/ae.60713.

[4] C. O. R. Okpala, S. Juchniewicz, K. Leicht, M. Korzeniowska, and R. P. F. Guiné, "Antioxidant, organoleptic and physicochemical changes in different marinated oven-grilled chicken breast meat," *Foods*, vol. 11, no. 24, 2022, doi: 10.3390/foods11243951.

[5] G. Sumer and F. Oz, "The effect of direct and indirect barbecue cooking on polycyclic aromatic hydrocarbon formation and beef quality," *Foods*, vol. 12, no. 7, Mar. 2023, doi: 10.3390/foods12071374.

[6] A. Onopiuk *et al.*, "Influence of plant extract addition to marinades on polycyclic aromatic hydrocarbon formation in grilled pork meat," *Molecules*, vol. 27, no. 1, Dec. 2021, doi: 10.3390/molecules27010175.

[7] M. Ciecierska and U. Komorowska, "Effects of different marinades and types of grills on polycyclic aromatic hydrocarbon content in grilled chicken breast tenderloins," *Foods*, vol. 13, no. 21, 2024, doi: 10.3390/foods13213378.

[8] G. R. Sampaio *et al.*, "Polycyclic aromatic hydrocarbons in foods: biological effects, legislation, occurrence, analytical methods, and strategies to reduce their formation," *International Journal of Molecular Sciences*, vol. 22, no. 11, 2021, doi: 10.3390/ijms22116010.

[9] Dheeraj, A. Srivastava, and A. Mishra, "Mitigation of cashew apple fruits astringency," *Environmental Sustainability*, vol. 6, no. 3, pp. 319–329, May 2023, doi: 10.1007/s42398-023-00276-7.

[10] L. B. C. Sahie, D. Soro, K. Y. Kone, N. E. Assidjo, and K. B. Yao, "Some processing steps and uses of cashew apples: a review," *Food and Nutrition Sciences*, vol. 14, no. 01, pp. 38–57, 2023, doi: 10.4236/fns.2023.141004.

[11] B. Laxmanaswami and A. Urooj, "Phytochemical profile and antimicrobial activity of cashew apple (*Anacardium occidentale* L.) extract," *GSC Biological and Pharmaceutical Sciences*, vol. 5, no. 3, pp. 095–098, Dec. 2018, doi: 10.30574/gscbps.2018.5.3.0152.
[12] N. Aslam *et al.*, "Exploring the potential of cashew waste for food and health applications-a review," *Future Foods*, vol. 9, Jun. 2024, doi: 10.1016/j.fufo.2024.100319.
[13] A. Latoch, E. Czarniecka-Skubina, and M. Moczkowska-Wyrwisz, "Marinades based on natural ingredients as a way to improve the quality and shelf life of meat: a review," *Foods*, vol. 12, no. 19, Oct. 2023, doi: 10.3390/foods12193638.
[14] S. Susanti, V. P. Bintoro, A. Hintono, and K. Nisa, "Physical and chemical characteristics of beef marinated by cashew apple extract," *International Journal of Food Studies*, vol. 11, no. 1, pp. 98–105, Apr. 2022, doi: 10.7455/ijfs/11.1.2022.a9.
[15] K. Tkacz, M. Modzelewska-Kapitula, M. Petracci, and W. Zdunczyk, "Improving the quality of sous-vide beef from Holstein-Friesian," *Meat Science*, vol. 182, pp. 1–9, 2021.
[16] C. N. Yunita, L. E. Radiati, and D. Rosyidi, "Effect of lemon marination on polycyclic aromatic hydrocarbons (PAH) and quality of chicken satay," *Jurnal Penelitian Pendidikan IPA*, vol. 9, no. 6, pp. 4723–4730, Jun. 2023, doi: 10.29303/jppipa.v9i6.4269.
[17] A. C. Orădan, A. C. Tocai (Moțoc), C. A. Rosan, and S. I. Vicas, "Fruit extracts incorporated into meat products as natural antioxidants, preservatives, and colorants," *Processes*, vol. 12, no. 12, Dec. 2024, doi: 10.3390/pr12122756.
[18] S. Susanti, B. E. Setiani, H. Rizqiati, D. R. Febriandi, V. P. Bintoro, and B. E. Setiani, "Inhibitory activity of cashew apple (*Anacardium Occidentale*) extract marinade on the meat total bacteria," *Current Research in Nutrition and Food Science Journal*, vol. 6, no. 1, pp. 106–112, Apr. 2018, doi: 10.12944/CRNFSJ.6.1.11.
[19] S. Ardicli, O. Ardicli, and H. Ustuner, "Unraveling the complexities of beef marination: effect of marinating time, marination treatments, and breed," *Foods*, vol. 13, no. 18, Sep. 2024, doi: 10.3390/foods13182979.
[20] B. E. Setiani, B. Dwiloka, Y. B. Pramono, T. N. Arroyan, H. Mardhika, and A. D. Puspitoasih, "Physicochemical properties of steak made of post laying hen breast meat thawed using various methods," *IOP Conference Series: Earth and Environmental Science*, vol. 803, no. 1, Jul. 2021, doi: 10.1088/1755-1315/803/1/012033.
[21] E. N. Hamidi, P. Hajeb, J. Selamat, S. Y. Lee, and A. F. Abdull Razis, "Bioaccessibility of polycyclic aromatic hydrocarbons (PAHs) in grilled meat: the effects of meat doneness and fat content," *International Journal of Environmental Research and Public Health*, vol. 19, no. 2, Jan. 2022, doi: 10.3390/ijerph19020736.
[22] F. Swastawati *et al.*, "Physicochemical changes and sensory quality of liquid smoked milkfish nuggets," *African Journal of Food, Agriculture, Nutrition and Development*, vol. 21, no. 07, pp. 18261–18278, Sep. 2021, doi: 10.18697/ajfand.102.19440.
[23] W. N. L. Tanod, R. Murwani, S. Susanti, and E. Kusumanti, "Addition of cashew (*Anacardium occidentale*) apple powder into diet can increase body weight and intestinal relative weight in broiler," *Pakistan Journal of Nutrition*, vol. 14, no. 9, pp. 629–631, 2015, doi: 10.3923/pjn.2015.629.631.
[24] J. S. Ribeiro *et al.*, "Natural antioxidants used in meat products: a brief review," *Meat Science*, vol. 148, pp. 181–188, Feb. 2019, doi: 10.1016/j.meatsci.2018.10.016.
[25] M. Serdaroglu, Ö. Yüncü-Boyacı, and M. Karaman, "Enhancing meat quality through marination: principle, ingredients and effects," *Food Science and Applied Biotechnology*, vol. 7, no. 2, Oct. 2024, doi: 10.30721/fsab2024.v7.i2.369.
[26] Y. G. Akyereko, G. B. Yeboah, F. D. Wireko-Manu, F. Alemawor, F. C. Mills-Robertson, and W. Odoom, "Nutritional value and health benefits of cashew apple," *JSFA reports*, vol. 3, no. 3, pp. 110–118, Mar. 2023, doi: 10.1002/jsf2.107.
[27] W. Broto, V. P. Bintoro, G. A. Setiawan, S. R. Nuswantari, and S. Susanti, "The pH and hedonic of chicken steak cooked with seasoning contains cashew apple extract," *Journal of Applied Food Technology*, vol. 8, no. 2, pp. 44–47, 2021.
[28] Z. Wang, K. Ng, R. D. Warner, R. Stockmann, and Z. Fang, "Reduction strategies for polycyclic aromatic hydrocarbons in processed foods," *Comprehensive Reviews in Food Science and Food Safety*, vol. 21, no. 2, pp. 1598–1626, Mar. 2022, doi: 10.1111/1541-4337.12905.
[29] L. Duedahl-Olesen and A. C. Ionas, "Formation and mitigation of PAHs in barbecued meat–a review," *Critical Reviews in Food Science and Nutrition*, vol. 62, no. 13, pp. 3553–3568, 2022, doi: 10.1080/10408398.2020.1867056.

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