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The effect of marinating on the quality of deer meat

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ABSTRACT

Deer meat differs from common livestock meat by its distinctive odour and toughness. Hexanal, the primary odour-causing substance, can be reduced through casein adsorption or metal ion chelation. To improve texture, increasing water retention and utilising proteolytic enzymes may be effective. However, while these approaches show promise in isolated studies, their comprehensive efficacy and optimal application in deer meat processing, particularly in a practical culinary context, remain largely unverified and underexplored. Therefore, the aim of this study was to investigate the effects of marinating deer meat using lemon juice, honey, banana, and yoghurt, all of which have potential deodorising and tenderising properties. Deer meat was marinated for 12 h in each substance and then heated by baking. After cooking, the pH, moisture content, firmness, odour, and taste components of the meat were measured. The results showed that pH was higher in all groups of marinated deer meat after baking, water retention was highest in lemon- and honey-marinated meat, while lemon-, yoghurt-, and banana-marinated deer meat was less firm than the control meat. Yoghurt was the most effective food ingredient in reducing the deer meat's odour, while lemon and yoghurt induced higher inosinic acid and alanine levels than in the control. Overall, the findings indicate that lemon juice is the most effective food ingredient for improving deer meat quality.

1. Introduction

Deer meat has a distinctive odour (*Kogiso and Kaneko*, 2015) and is characterised by its toughness (*Yoshimura et al.*, 2011). Therefore, cooking methods that can improve both its aroma and tenderness are necessary. The primary odour-causing substance in deer meat is hexanal, which can be reduced by adsorption onto casein, a protein found in milk (*Kogiso and Kanego*, 2015). Additionally, hexanal formation is promoted by copper and iron ions during lipid oxidation (*Koyanagi*, 2013). Adding iron chelators to pork, beef, and chicken meat has been shown to reduce hexanal production by more than 90% (*Todokoro et al.*, 2021). This suggests that food items containing chelating agents may help mitigate hexanal levels in deer meat. One such ingredient with chelating properties is citric acid, which is abundant in lemons.

Regarding firmness, immersing chicken meat in a honey concentration of 0–50% increased water retention proportionally, with a honey concentration of up to 40% leading to increased retention. In a sensory test, many respondents reported that the meat became softer as water retention increased (*Shimizu and Nakamura*, 2001). Moreover, soaking chicken meat in a solution containing the proteolytic enzyme ficin decreased its shear strength value (*Güven et al.*, 2021). Based on these findings, casein adsorption, citric acid chelation, improving water retention using honey, and adding proteolytic enzymes to enhance softness appear to be effective cooking methods for improving the odour and tenderness of deer meat.

Milk, yoghurt, cheese, and other dairy products contain casein, with yoghurt having a protein composition similar to that of milk (*Naito et al.*, 2019). Yoghurt is fermented with lactic acid bacteria

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(*Tsuchihashi*, 2022), which is expected to have a greater tenderising effect than unfermented cow's milk owing to its lactic acid content. Bananas also contain high levels of ficin, which may contribute to softening.

Amino acids and nucleotides influence flavour development in meat. After an animal's death, proteases in the muscle break down proteins, generating amino acids, such as glutamic acid. Simultaneously, inosinic acid is produced when ATP degrades to ADP, AMP, and IMP via ATP-degrading enzymes. In common livestock, meat is typically aged for a certain period after slaughter, which causes rapid degradation of nucleic acid-based taste components and an increase in amino acid-based taste components. Conversely, deer meat differs from other meats in that inosinic acid remains stable while amino acid accumulation is low (*Yamazaki et al.*, 2024), leading to lower concentrations of amino acid-based taste components. The glutamic acid content in deer meat is relatively low, whereas alanine and glutamine, which contribute to sweetness, are found in abundance (*Fujiwara et al.*, 2018).

However, despite these promising theoretical approaches and insights from other meat types, there are no comprehensive reports verifying the physical and chemical quality of deer meat using these specific, naturally derived ingredients in practical processing methods. While individual components such as citric acid or ficin have shown promise, their combined effects and overall efficacy in a real-world culinary context for deer meat remain largely unverified and underexplored. This highlights a significant gap in understanding how accessible ingredients can effectively address the distinctive challenges of deer meat quality.

Given this unexplored area, this study aimed to evaluate the effects of honey, lemon, yoghurt, and banana marinades on the pH, moisture content, firmness, odour, and taste of deer meat. Based on the results, the optimal seasoning conditions that improve the quality and palatability of deer meat were identified.

2. Materials and Methods

2.1. Ethical approval

Ethical approval for animal use was not required for this study as commercially sourced deer meat was purchased, and no animals were directly involved in the research.

2.2. Sample and marinade preparation

Frozen deer meat, sourced from Kyushu, Japan, was thawed overnight at 4 °C. It was then cut into small pieces (approximately 2 cm long × 2 cm wide × 1 cm high). Lemon juice, multifloral honey, yoghurt, and finely chopped un-peeled bananas were each mixed in a 1:1 ratio with water to prepare pickling solutions. These four pickling solutions defined the experimental groups, with each group comprising three replicates, containing one deer meat sample per replicate. The meat samples were marinated in their respective solutions for 12 h. Following marination, meat samples were baked using an induction cooker (IRIS OHYAMA Inc., Miyagi, Japan) set at 1000 W. The meat was heated to 75 °C for 1 min and maintained at this temperature until its core temperature reached 75 °C.

2.3. Physical properties of deer meat after marination

2.3.1. pH

A pH meter (Sato Shoji Co., Ltd., Kanagawa, Japan) was used to measure the pH levels of the marinated deer meat both before and after heating. The samples were allowed to cool for 5 min before pH measurement.

2.3.2. Water holding capacity

After cooking, 0.5 g of accurately weighed deer meat was wrapped in filter paper (QL-C, particle retention capacity: 10 μm, diameter: 70 mm, SANSYO Co., Ltd., Tokyo, Japan). The wrapped samples were then centrifuged (2200 *g*, 30 min, 4 °C), and the samples were weighed once more.

2.3.3. Breaking strength

Deer meat was cooled for 5 min after heating, after which breaking stress was measured using a creep meter (YAMADEN Co., Ltd., Tokyo, Japan). The cylindrical plunger had a 3-mm diameter, and breaking strength was measured at a strain rate of 70% and a velocity of 1.00 mm/s.

2.3.4. Moisture content

After preheating to 105 °C, 1.0 g of chopped and cooked deer meat samples were accurately weighed into a weighing jar and then dried at 105 °C for 170 min. After cooling, the samples were weighed again, and the moisture content was calculated.

2.4. Chemical composition of deer meat after marination

2.4.1. Hexanal

The hexanal measurement method was modified based on the methods used by *Fujino et al.* (1991). Deer meat samples (2 g) were accurately weighed, and hexanal was extracted using 99% ethanol (Tokyo Chemical Industry Co., Ltd., Tokyo, Japan). The extract was centrifuged (20321 *g*, 5 min, 5 °C) and diluted to 5 mL.

Next, 500 µL of this solution were mixed with 500 µL 2,4-dinitrophenylhydrazine (DNPH) solution. The DNPH solution was prepared by dissolving 50 mg DNPH (FUJIFILM Wako Pure Chemical Corporation, Osaka, Japan) in 40 mL ethanol (FUJIFILM Wako Pure Chemical Corporation), 1 mL hydrochloric acid (FUJIFILM Wako Pure Chemical Corporation), and 4 mL pure water.

The resulting mixture was heated in a heat block at 45 °C for 45 min, cooled in cold water, and filtered through a 0.22 µm membrane filter (Hangzhou Cobetter Filtration Equipment Co., Ltd., Hangzhou, China). The filtered solution was then analysed using high-performance liquid chromatography (HPLC, SHIMADZU CORPORATION, Kyoto, Japan).

The HPLC system utilised a Luster C18 column (150 × 4.6 mm, LCScience Co., Ltd., Nara, Japan) with a mobile phase of acetonitrile (FUJIFILM Wako Pure Chemical Corporation) and water (8:2). The flow rate was 1.0 mL/min, the column temperature was 40 °C, and detection was performed using a UV detector at a wavelength of 360 nm. The injection volume was 20 µL.

2.4.2. Inosinic acid

Inosinic acid was measured according to the methods used in *Seki* (2024). Accurately weighed deer meat (2.5 g) was placed in a 15 mL centrifuge tube and homogenised in 4 mL 10% perchloric acid (KANTO CHEMICAL Co., Inc., Tokyo, Japan) to extract amino acids and inosinic acid. After centrifugation (17075 *g*, 10 min, 5 °C), the supernatant was transferred to a new 15 mL centrifuge tube. This extraction and centrifugation procedure was repeated once more. The final volume was then adjusted to 10 mL.

Next, 1 mL of the extract was neutralised to pH 7 using 10 M potassium hydroxide solution (FUJIFILM Wako Pure Chemical Corporation) and centrifuged (20321 *g*, 5 min, 5 °C). The supernatant was then collected and transferred to a new 15 mL centrifuge tube. The remaining precipitate was resuspended in 1 mL deionised water. This precipitation and supernatant collection procedure was repeated two times, and the combined supernatants were then diluted to 5 mL with water. The final solution was filtered through a 0.22 µm membrane filter and analysed using HPLC.

HPLC analysis was performed using a SHIMADZU CORPORATION system equipped with a COSMOSIL 5C18-PAQ column (150 × 4.6 mm, NACALAI TESQUE, INC., Kyoto, Japan). The mobile phase consisted of 20 mM NaH_2PO_4 adjusted to pH 2.8. A constant flow rate of 0.50 mL/min was maintained, and the column temperature was set at 40 °C. Detection was carried out using a UV detector at a wavelength of 260 nm, with an injection volume of 20 µL.

2.4.3. Alanine and glutamine

The measurement method for alanine and glutamine was modified based on the methods in *Seki* (2021). For this assay, 20 µL of the sample from the inosinic acid assay were combined with 70 µL ethanol (FUJIFILM Wako Pure Chemical Corporation), 20 µL triethylamine (FUJIFILM Wako Pure Chemical Corporation), and 20 µL phenyl isothiocyanate (KANTO CHEMICAL Co., Inc.). This combination was thoroughly mixed and then incubated at 25 °C for 30 min.

Following incubation, a 500 µL solution of 250 mM acetic acid buffer (pH 6.6) and acetonitrile (97:3) were added and mixed. The resulting solution was then filtered through a 0.22 µm membrane filter before HPLC analysis.

HPLC analysis was performed using a SHIMADZU CORPORATION system equipped with a COSMOSIL 5C18-MS-II column (150 × 4.6 mm, COSMOSIL; NACALAI TESQUE, Inc.). The mobile phase comprised two components: mobile phase A, which consisted of 250 mM acetic acid buffer (pH 6.6) with acetonitrile (97:3), and mobile phase B, which was a mixture of acetonitrile (FUJIFILM Wako Pure Chemical Corporation) and water (6:4).

A constant flow rate of 1.0 mL/min was maintained with the following gradient program: 0 min (B 5%) → 16 min (B 100%) → 20 min (B 5%) → 25 min (B 5%). The column temperature was set at 40 °C. Detection was performed using a UV detector at a wavelength of 254 nm, and the injection volume was 20 µL.

2.5. Statistical analysis

Statistical analysis was performed according to Fisher's three principles of experimental design. Comparisons between two groups were conducted using *t*-tests, while one-way analysis of variance (ANOVA) was applied for comparisons involving three or more groups. All analyses were performed using Microsoft Excel, with a significance level set at 5%.

3. Results

3.1. Physical properties of deer meat after marination

3.1.1. pH

Table 1 shows the pH, water holding capacity, breaking strength, and moisture content of deer meat marinated in different pickling solutions. The initial pH of the deer meat in the control (water-only marinade) was 6.11, significantly higher than that of deer meat marinated in honey (5.23), lemon (3.53), yoghurt (5.29), and banana (5.63) ($p<0.001$ for all comparisons). Post heating, the pH levels were significantly higher in all deer meat groups than in corresponding groups prior to heating ($p<0.001$). The pH of the deer meat in the control sample (water only) was 6.49, which remained significantly higher than that of meat marinated in honey (5.74), lemon (3.96), yoghurt (5.72), and banana (6.05) ($p<0.001$ for all comparisons).

3.1.2. Water holding capacity

In terms of water retention, lemon-marinated (85.6%) and honey-marinated (78.7%) deer meat showed significantly higher levels ($p=0.0019$ and $p=0.014$, respectively) than did the control deer meat (68.5%). Conversely, yoghurt-marinated (63.3%) and banana-marinated (66.5%) deer meat produced slightly lower water retention levels than did the control (deer meat marinated in water; 68.5%), although these differences were not statistically significant ($p=0.15$ and $p=0.39$, respectively).

3.1.3. Breaking strength

Regarding breaking strength, the control and honey-marinated deer meat exhibited similar values (13.6 N and 13.4 N, respectively, $p=0.87$). In contrast, lemon-, yoghurt-, and banana-marinated deer meat showed significantly lower breaking strength than did the control ($p=0.015$, $p=0.018$, and $p=0.032$, respectively). No significant difference in breaking strength was observed among the lemon, yoghurt, and banana treatments ($p=0.88$; ANOVA).

Table 1. Physical properties of deer meat after marination

	pH		**Water holding capacity (%)**	**Breaking strength (N)**	**Moisture (%)**
	Before heating	**After heating**			
Control (water-only)	6.11±0.010	6.49±0.04	68.5±3.2	13.6±1.2	60.8±0.91
Honey	5.23±0.057^{a}	5.74±0.048^{b}	78.7±1.3^{c}	13.4±1.3	72.0±1.1^{e}
Lemon	3.53±0.06^{a}	3.96±0.05^{b}	85.6±2.6^{c}	9.57±1.2^{d}	66.3±1.2^{e}
Yoghurt	5.29±0.04^{a}	5.72±0.069^{b}	63.3±4.0	9.59±1.3^{d}	56.0±0.46^{e}
Banana	5.63±0.02^{a}	6.05±0.039^{b}	66.5±1.2	9.91±1.5^{d}	57.5±0.31^{e}
p	p<0.001^{a}	p<0.001^{b}	p<0.05^{c}	p<0.05^{d}	p<0.05^{e}

Legend: Mean values for pH and breaking strength are reported for each marinade (n=9), based on three technical and three biological replicates. For water holding capacity and moisture content, mean values are given for each solution (n=3), derived from three technical and one biological replicate. In all cases ± denotes the standard deviation. Significance levels are as follows: $p<0.001^{a}$: Significant difference compared to the control pH. $p<0.001^{b}$: Significant difference compared to the control pH and the pH before heating. $p<0.05^{c}$: Significant difference compared to the control water holding capacity. $p<0.05^{d}$: Significant difference compared to the control breaking strength. $p<0.05^{e}$: Significant difference compared to the control moisture content.

3.1.4. Moisture content

The moisture content of honey-marinated (72.0%) and lemon-marinated (66.3%) deer meat was significantly higher than that of the control (60.8%) ($p=0.00018$ and $p=0.0033$, respectively). In contrast, yoghurt-marinated (56.0%) and banana-marinated (57.5%) deer meat showed significantly lower moisture content than that did the control ($p=0.0038$ and $p=0.028$, respectively).

3.2. Chemical composition of deer meat after marination

3.2.1. Hexanal

Table 2 summarises the amounts of hexanal, alanine, glutamine, and inosinate in the marinated deer meat. The honey-marinated deer meat exhibited a significantly higher mean hexanal level (1.74 µg g^{-1}) than the control (1.56 µg g^{-1}) ($p=0.0027$). The banana-marinated deer meat showed an elevated hexanal content (1.72 µg g^{-1}) relative to the control ($p=0.17$). Conversely, the yoghurt-marinated deer meat had the lowest hexanal content (0.859 µg g^{-1}) ($p=0.017$) among the groups. The lemon-marinated meat had a slightly lower hexanal content (1.54 µg g^{-1}) than did the control, although this difference was not statistically significant ($p=0.46$).

3.2.2. Inosinic acid

Inosinic acid, a key taste compound, was significantly higher in lemon-marinated (1.31 mg g^{-1}) and honey-marinated (1.19 mg g^{-1}) deer meat ($p=0.0065$ and $p=0.026$, respectively) than in the control (0.966 mg g^{-1}). However, there was little change in the inosinic acid concentration of the yoghurt-marinated deer meat (0.957 mg g^{-1}) when compared with the control ($p=0.85$). Conversely, the banana-marinated deer meat exhibited the lowest inosinic acid concentration (0.725 mg g^{-1}) ($p=0.0179$) among the groups.

3.2.3. Alanine and glutamine

The alanine level in the yoghurt-marinated deer meat (0.918 mg g^{-1}) was significantly higher than that in the control (0.854 mg g^{-1}) ($p=0.0072$). The honey-marinated deer meat (0.884 mg g^{-1}) had a slightly higher alanine content than did the control ($p=0.15$). In contrast, lemon-marinated (0.742 mg g^{-1}) and banana-marinated (0.720 mg g^{-1}) deer meat contained significantly lower alanine levels than did the control ($p=0.0044$ and $p=0.0071$, respectively). Glutamine levels varied across treatments. The lemon-marinated deer meat (0.205 mg g^{-1}) exhibited slightly higher glutamine content than the control (0.187 mg g^{-1}) ($p=0.36$). Conversely, the glutamine content in the

Table 2. Chemical composition of deer meat after marination

	Hexanal (µg g^{-1})	**Inosinic acid (mg g^{-1})**	**Alanine (mg g^{-1})**	**Glutamine (mg g^{-1})**
Control (water-only)	1.56±0.026	0.966±0.016	0.854±0.014	0.187±0.021
Honey	1.74±0.038^{a}	1.19±0.064^{b}	0.884±0.023	0.156±0.023
Lemon	1.54±0.040	1.31±0.046^{b}	0.742±0.021^{c}	0.205±0.020
Yoghurt	0.859±0.16^{a}	0.957±0.070	0.918±0.017^{c}	0.0871±0.0074^{d}
Banana	1.72±0.13	0.725±0.054^{b}	0.720±0.032^{c}	0.116±0.00054^{d}
P	$p<0.05^{a}$	$p<0.0^{5b}$	$p<0.05^{c}$	$p<0.05^{d}$

Legend: Mean values for each solution are reported (n=3 technical replicates, n=1 biological replicate), with ± denoting the standard deviation. Significance levels are as follows: $p<0.05^{a}$: Significant difference compared to the control hexanal content. $p<0.05^{b}$: Significant difference compared to the control inosinic acid content. $p<0.05^{c}$: Significant difference compared to the control alanine content. $p<0.05^{d}$: Significant difference compared to the control glutamine content.

honey-marinated deer meat (0.156 mg g^{-1}) was slightly lower than that in the control (p=0.16). Yoghurt-marinated (0.0871 mg g^{-1}) and banana-marinated (0.0116 mg g^{-1}) deer meat contained significantly lower glutamine levels than did the control (p=0.016, p=0.028, respectively).

4. Discussion

This study examined the effects of different marinating solutions on the physicochemical properties of deer meat, specifically focusing on pH, water retention, texture, and biochemical composition.

4.1. Physical properties of deer meat after marination

4.1.1. pH

The pH of deer meat marinated in the different food ingredient solutions was highest in the control (water-only). The initial pH of the marinating solutions were 4.78 for honey, 2.44 for lemon, 5.57 for banana, and 4.22 for yoghurt. Therefore, the pH of the marinated deer meat was lower than that of the control, as it was influenced by the pH of the marinating solution. In addition, the pH of the deer meat immersed in each marinade was higher than that of the marinating solution. The pH of raw deer meat has been reported to be between 5.6 and 5.8 (Shimada et al., 2022), and in this study it was 6.11, which is close to this value. Since the pH of the meat itself was higher than that of the marinating solution, the pH of the marinating meat was higher than that of the marinating solution, particularly in the case of honey, lemon, and yogurt.

Furthermore, the pH was consistently higher after heating than before heating across all groups of marinated deer meat. In cheese, heating has been reported to decompose amino acids to produce ammonia (*Buňka et al.*, 2004). Ammonia production increases pH, and in this study, an increase in pH was observed after heating in all experimental groups. This suggests that thermal denaturation contributed to the pH increase, regardless of the marinating solution. The pH increases due to heating were approximately 0.4 for the control, lemon-, banana-, and yoghurt-marinated meat, while honey induced a slightly higher pH increase of approximately 0.5. As the pH of acacia honey has been reported to increase by 0.1 after heat treatment at 90 °C (*Sulaiman and Sarbon*, 2022), the use of honey in the marinade could have contributed intrinsically to the more pronounced rise in pH after heating compared to the other treatments.

4.1.2. Water holding capacity

The water retention properties of deer meat marinated in honey and lemon were higher than those of the control. Immersing pork meat in a solution of honey and water was also shown to improve its water-holding capacity, with increasing honey concentrations leading to nearly 75% water retention at 50% honey concentration (*Shimizu and Nakamura*, 2001). A similar trend was observed in the current study, where deer meat marinated in 50% honey retained 78.7% water. *Hu et al.* (2016) further demonstrated that adding glucose to chicken meat improved its water retention. Additionally, in kefiran gel, the addition of 50% fructose increased water retention from approximately 45% to up to 100% (*Zavala et al.*, 2015). This suggests that the sugar component of honey influenced the water retention capacity in the current study.

Similarly, improved water retention in chicken meat marinated in lemon juice has been reported (*Unal et al.*, 2022), which aligns with the current findings. The lowest water retention in meat is typically observed at pH 5.5, near the isoelectric point of meat proteins (*Abe et al.*, 2018). The pH of the lemon-treated meat was 3.53, sufficiently distant from the isoelectric point, which may have contributed to its enhanced water retention.

Conversely, both yoghurt- and banana-marinated deer meat exhibited slightly lower water retention levels than that of the control. *Masoumi et al.* (2022) showed that yoghurt lowers pH, thereby enhancing water retention in chicken. However, in the current study, the pH of deer meat marinated in yoghurt (5.29) and banana (5.63) remained close to the isoelectric point of meat, which likely played a role in the lower water retention of these two groups compared to the control.

4.1.3. Breaking strength

The breaking strength of deer meat marinated in honey was not significantly different to that of the control. In chicken meat, the addition of 10, 20, and 30% honey solution has been reported to increase water retention and tenderness, with a corresponding increase in honey concentration (*Hashim et al.*, 1999). In contrast, more respondents answered that pork marinated in a 50% honey mixture was tougher than that in 30–40% honey (*Shimizu and Nakamura*, 2001), possibly because honey caused caramelisation, which toughened the meat surface after heating. Honey caramelisation also occurred in the current study.

Meat marinated in lemon, yoghurt, and banana exhibited lower breaking strength than that of the control. Similar results have been reported in beef, where the meat softened as water retention improved (*Mega et al.*, 1979). In the current study, the low pH measured after lemon marination could have improved water retention, thereby resulting in lower rupture strength. Lactic acid in marinades has been associated with the softening of pork, sheep, and rabbit meat (*Simitzis et al.*, 2021). As lactic acid is present in yoghurt, a similar effect was anticipated in this study.

Treatment of chicken meat with ficin, one of the proteolytic enzymes found in banana peels, has demonstrated a softening effect (*Güven et al.*, 2021). Our findings align with these results, suggesting that ficin contained in banana peels reduced the breaking strength of the deer meat.

4.1.4. Moisture content

Moisture content was higher in deer meat marinated in honey and lemon than that in the control. As fructose and glucose are major components of honey, and lemon shifts the pH away from the isoelectric point of deer meat, both these factors likely contributed to higher water retention and subsequent moisture holding. Higher water retention has been linked to higher moisture content in pork (*Jankowiak et al.*, 2021). Although lemon-marinated deer meat exhibited higher water retention than the honey-marinated in this study, the moisture content after heating was lower in lemon-marinated deer meat than that in honey-marinated meat (66.3 vs. 72.0%, respectively). In honey, water retention is primarily enhanced by sugar, whereas in lemon juice, it is predominantly influenced by pH-induced changes in the isoelectric point. *Terazawa et al.* (2014) compared the moisture content of ground beef marinated in unglazed soy sauce, mirin, and soy sauce, then cooked in teriyaki sauce, finding that the teriyaki group retained more moisture due to the caramelisation of sugar. In the current study, the caramelisation of sugar contained in the honey is thought to have contributed to the higher moisture content observed in the honey-marinated deer meat than in the lemon-marinated meat.

Conversely, the moisture content of deer meat marinated in yoghurt and banana was lower than that of the control. This reduction can be attributed to water loss due to heating, which decreased the water retention properties as the pH remained close to the meat's isoelectric point (approximately 5.5). Similarly, banana marination produced a lower moisture content than did the control, a phenomenon also observed with yoghurt-marinated meat, both of which are attributable to the lower water content after heating.

4.2. Chemical composition of deer meat after marination

4.2.1. Hexanal

The hexanal content in deer meat marinated in honey and banana was higher than that in the control. Honey has been reported to contain hexanal as a volatile component, although its content varies depending on the nectar source (*Zhu et al.*, 2022). Similarly, as bananas have been reported to contain hexanal as a major volatile component (*Mukherjee et al.*, 2022), the higher hexanal levels observed in the meats marinated in honey and banana compared to the control can be attributed to the presence of hexanal in these marinating solutions.

Deer meat marinated in lemon showed no significant change in hexanal content compared to the control. Hexanal is produced by lipid oxidation, a process that involves metal ions (*Koyanagi*, 2013). Lipid oxidation can be inhibited by mitigating the action of metal ions via chelation (*Todokoro et al.*, 2021). As citric acid in lemons possesses chelating properties (*Akatsuka et al.*, 2015), it likely inhibits hexanal formation. However, chelation does not remove pre-existing hexanal, which explains why no change was observed in the lemon-marinated meat.

The amount of hexanal in deer meat marinated in yoghurt was lower than that in the control. Yoghurt contains casein, a protein that has been reported to adsorb hexanal in deer meat (*Kogiso and Kanego*, 2015). Thus, casein in yoghurt may have contributed to the removal of hexanal in this study.

4.2.2. Inosinic acid

The inosinic acid content in banana-marinated deer meat was lower than that in the control meat. Previous studies have reported a decrease in inosinic acid levels with increasing bacterial counts. For instance, when beef was stored at 5 °C for 8 days, the number of total viable bacteria increased from approximately 4 log CFU g^{-1} to 8 log CFU g^{-1}, while the amount of inosinic acid decreased from 0.3 μmol g^{-1} to 0.02 μmol g^{-1} (*Parris et al.*, 1983). Similarly, when sterilised chicken meat was inoculated with *Staphylococcus* spp. and Enterobacteriaceae isolated from raw chicken meat and incubated at 35 °C for 48 h, the *Staphylococcus* count increased. While the amount of inosinic acid in chicken without bacterial inoculation decreased slightly, inosinic acid levels were reported to disappear within 48 h in inoculated meat (*Hayashi and Nakata*, 2003). Given that Enterobacteriaceae have been detected in bananas (*Issouffou et al.*, 2018) and that *Staphylococcus* spp. is commonly found on human skin and other surfaces, these bacteria may have been present in the bananas. Moreover, bacterial growth has been observed in the epidermis and pulp of bananas after being cut, with an increase from 0 $\log_{10}$ CFU g^{-1} to 7 $\log_{10}$ CFU g^{-1} in the pulp within two days (*Abe et al.*, 2012). This evidence suggests that inosinic acid may have been degraded by the bacteria present in bananas.

Conversely, honey- and lemon-marinated deer meat contained higher levels of inosinic acid than that in the control meat. Inosinic acid-degrading enzymes degrade inosinic acid over time, and its levels can be maintained by suppressing enzyme activity. *Seki and Kikuchi* (2022) reported that honey inhibits inosinic acid-degrading enzymes in chub mackerel, suggesting that honey in the current study similarly inhibited these enzymes. In addition, inosinic acid-degrading enzymes in various fish species have different optimum pH values (*Tomioka and Endo*, 1984). As honey and lemon create an acidic environment, enzyme activity in deer meat could have been suppressed, thereby preserving inosinic acid. This collectively suggests that honey and lemon may have supported the retention of inosinic acid in the marinated deer meat.

4.2.3. Alanine and glutamine

Honey contains gluconic acid, which has been reported to inhibit myosin degradation in squid (*Kuwahara et al.*, 2004). As myosin is a protein, inhibiting its degradation would prevent the production of amino acids. However, honey itself contains 3.43–27.0 mg/100 g alanine (*Quintas et al.*, 2021). Thus, while gluconic acid-induced proteolysis inhibition may have prevented the formation of amino acids, the alanine naturally present in honey may have offset this effect, resulting in the honey-marinated meat having a similar amount of alanine as the control.

The alanine content in deer meat marinated in lemon and banana was lower than that in the control. The addition of citric acid to squid inhibits the activity of metalloproteinase, an endogenous protease, and suppresses alanine production (*Geng et al.*, 2018). Similarly, the citric acid in lemons could have inhibited deer meat protease activity in this study, thereby inhibiting alanine production. Moreover, bananas contain starch, and amino acids are involved in starch gelatinisation. Alanine is reported to bind to starch, albeit relatively weakly (*Ito et al.*, 2006), suggesting that heating could have facilitated the binding of alanine to starch, thereby resulting in less free alanine in the banana-marinated meat than in the control.

In contrast, the amount of alanine in deer meat marinated in yoghurt was higher than that in the control. In fermented sausages, the addition of lactic acid bacteria resulted in protein degradation and higher alanine content (*Kato*, 1991). Various proteolytic enzymes are present in meat, each requiring different conditions for their activation and inhibition. In this study, yoghurt likely promoted the activity of proteolytic enzymes that produce alanine, which may have caused the higher alanine content of yoghurt-marinated meat. The glutamine content in deer meat marinated with honey and banana was lower than that of the control. The addition of gluconic acid to squid inhibits degradation (*Kuwahara et al.*, 2004). Given the high gluconic acid levels in honey, this compound could have inhibited protein degradation in the current study. Similarly to alanine, the starch in bananas likely interacted with amino acids in deer meat during banana marination, which likely reduced glutamine content. Although the amount of glutamine in lemon-marinated deer meat was higher than that in the control, the difference was not significant, suggesting that lemon had no substantial effect on glutamine levels. However, deer meat marinated in yoghurt had significantly lower glutamine levels than that did the control. Yoghurt contains a type of lactic acid bacteria that produce high levels of gamma-aminobutyric acid (GABA). *Ohmori et al.* (2018) reported that when yoghurt containing these bacteria was mixed with sake, the L-glutamic acid in the sake was broken down by the lactic acid bacteria, leading to increased GABA levels. As glutamine serves as a precursor for glutamic acid, a similar phenomenon may have occurred in this study, resulting in the depletion of glutamine in the yoghurt-marinated deer meat.

4.3. Limitations

This study has some limitations that warrant discussion. A primary concern is the lack of precise information regarding sample storage conditions; specifically, details on the duration and temperature that deer meat samples were frozen at was not available from the supplier.

Additionally, specific data on the deer species, exact hunting location, or the hunting season could not be obtained. While these details would significantly enrich the study's ecological context and reproducibility, they simply were not provided by the third-party supplier. Despite these gaps regarding the meat's origin, this study's conclusions remain solid given the available information.

Finally, many of the proposed mechanistic explanations in this study rely on findings from studies involving other types of meat, such as chicken, pork, beef, squid, and fish. While they offer plausible hypotheses, the specific physiological and biochemical responses of deer meat might differ. As these mechanisms could not be confirmed directly with individual deer meat samples, the direct applicability of these external findings to deer meat should be viewed with caution.

5. Conclusion

This study examined the effects of honey, lemon juice, yoghurt, and banana marination on deer meat quality. Regardless of the marinating solution used, the pH increased with heat. Both honey and lemon treatments resulted in high water retention, while lemon-marinated deer meat exhibited the lowest breaking strength compared with the other groups. Marination in yoghurt resulted in the lowest odour intensity, whereas lemon marination yielded the highest inosinic acid levels. Glutamine and alanine levels were the highest in yoghurt-marinated meat. Overall, the results indicate that among the marinating solutions tested, lemon marination offers the most significant improvements to the quality of deer meat.

With the growing population, food shortages are a significant concern. Consequently, in addition to major livestock meats, the utilisation of meat from wild deer and boar is expected to increase in the future. This study investigated methods to enhance the palatability of deer meat. Future research will focus on assessing quality changes and conducting sensory evaluations of processed deer meat to further expand its culinary applications.

Uticaj rastvora marinade na kvalitet mesa divljači jelena

Hiroko Seki

INFORMACIJE O RADU

Ključne reči:
Meso jelenske divljači
Kvalitet mesa
Mariniranje limunom
Sposobnost zadržavanja vode
Jogurt
Smanjenje mirisa.

APSTRAKT

Meso divljači jelena se izdvaja od mesa domaćih životinja zbog svog karakterističnog mirisa i žilavosti. Heksanal, primarno supstanca koja uzrokuje neprijatan miris, može se smanjiti adsorpcijom kazeina ili helacijom metalnih jona. Poboljšanje teksture može se postići povećanjem sposobnosti zadržavanja vode i korišćenjem proteolitičkih enzima. U ovom radu istraživan je uticaj mariniranja na kvalitet mesa divljači jelena korišćenjem limuna, meda, banane i jogurta, koji imaju potencijalna svojstva dezodoracije i omekšavanja. Meso divljači jelena je marinirano 12 sati u svakom rastvoru marinade, a zatim zagrejano. Nakon kuvanja, mereni su pH, sadržaj vlage, čvrstoća, miris i komponente ukusa mesa. Rezultati su pokazali da se pH povećao u svim uzorcima nakon pečenja, sposobnost zadržavanja vode je bila najveća u mesu mariniranom limunom i medom, a čvrstoća se smanjila u uzorcima tretiranim limunom, jogurtom i bananom. Jogurt je bio najefikasniji u smanjenju mirisa, dok se upotrebom limuna i jogurta povećao sadržaj inozinske kiseline i alanina. Na kraju, ovi rezultati ukazuju da je limun najefikasniji sastojak hrane za poboljšanje kvaliteta mesa jelenske divljači.

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