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Physical, Chemical, and Morphological Characteristics of Bovine Hide Crackers in Acid Immersion

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ABSTRACT

This study aimed to identify the effects of soaking time and acid type on the production of bovine hide cracker. The materials used were 6 kg bovine belly hide, 3% citric acid, and 3% acetic acid. The research employed a Completely Randomized Design (CRD) with a 2 × 3 factorial arrangement, consisting of two acid treatments (acetic and citric acids) and three soaking durations (0, 2, and 4 h). Data were analyzed using analysis of variance (ANOVA), followed by Duncan's Multiple Range Test when significant differences were observed. The results showed that the acid type significantly affected ($P<0.05$) the protein content, pH, swelling power, and color of bovine hide crackers but had no significant effect on the yield, taste, aroma, or crispiness. Soaking time significantly affected the yield, protein content, pH, swelling power, color, and taste, but did not significantly affect the aroma or crispiness. The yield values ranged from 21.20 to 30.32%, protein content from 60.33 to 78.30%, pH from 5.50 to 6.85, and swelling power from 632.30 to 2,838.46%. Based on organoleptic evaluation, the hide crackers exhibited a slightly brown color, slightly sour to non-sour taste, non-fishy aroma, and a crispy texture. Morphological observations revealed that soaking in an acidic solution produced thinner cell walls and more air cavities than the non-soaked treatment, thereby supporting an increase in the swelling power of the crackers. Soaking bovine hides with citric and acetic acids influenced the chemical, physical, and morphological characteristics of bovine hide crackers. The selection of acid type and soaking duration should be adjusted according to the desired product characteristics.

Keywords:
Bovine hide crackers; physical and chemical properties; soaking time; type of acid.

1. Introduction

Leather is a fundamental by-product derived from livestock or waste generated by slaughterhouses and is a primary raw material for the leather industry (Rapika et al., 2016). An initiative aimed at enhancing its utilization involves processing it into cracker hides.

Bovine hide crackers are a popular livestock by-product because they are tasty, savory, and have a crunchy texture (Hendrikayanti et al., 2022). Bovine hide crackers are made through several stages: soaking in lime, removing hair, boiling, cutting, soaking in spices, drying, and frying (Lilir et al., 2021). The tangible characteristics of crackers are

influenced by their collagen content. It is established that around 95% of skin is comprised of collagen protein. When exposed to elevated temperatures for extended periods, collagen will undergo denaturation and transforms into a gel (Sabtu et al., 2021). It was also clarified that skin rich in collagen necessitates a longer cooking duration, whereas skin with minimal collagen cooks more quickly. The explanation states that the acid utilized during the extraction process can alter the collagen structure, enhancing its solubility (Al et al., 2024).

In the production of hide crackers, acetic acid (CH_3COOH) and citric acid ($C_6H_8O_7$) are utilized to relax the connective tissue of the hide, which results in the detachment of collagen fibers, permitting the hide to expand and facilitating the opening of its pores in the concluding phase. The opening of these pores is intended to impart a crispy texture to the hide crackers. From a scientific perspective, acids and bases help loosen the connective tissue of the hide, thus reducing the duration of the boiling process.

Currently, the demand for hide crackers has increased. However, there are issues concerning the quality of these products, including their texture, scent, and flavor. The consistency of the skin crackers is often hard, with a flavor and aroma. Overall, the texture of the hide crackers is affected by the amount of swelling of the hide; as the hide expands more, the crispiness of the texture increases. Furthermore, the unpleasant smell and flavor of hide crackers may result from trimethylamine (TMA). The features of hide crackers, particularly their texture, are associated with collagen, a type of connective tissue protein found in hides (Arumugam et al., 2018). Mammalian skin has relatively high amounts of the amino acids proline and hydroxyproline (Pang et al., 2017). Studies have indicated that natural acids can break down collagen present in the skin (Al et al., 2024). Organic acids play a role in improving the quality of skin crackers by modifying the collagen structure (increasing solubility, texture, and physical properties) and functioning as antimicrobials by lowering the pH and inhibiting the growth of microorganisms (Harianto, 2024). Both inorganic and organic acids can efficiently dismantle collagen connections to facilitate the extraction of fibrils (Sasmitaloka et al., 2017). This study aimed to investigate the impact of immersion time of bovine hides in citric and acetic acids on the properties of bovine hide crackers.

2. Materials and Methods

2.1 Place and time

Cracker research was conducted at the Microbiology Laboratory of ATK Yogyakarta Polytechnic from May to August 2025. Chemical testing of the skin crackers was carried out in the Chemix Pratama laboratory, while SEM testing was carried out at the LPPT of Gadjah Mada University.

2.2 Materials

The materials used in this study were 6 kg of bovine skin belly obtained from a slaughterhouse (Segoroyoso, Indonesia), citric acid (local chemical store, Indonesia), acetic acid (Merck, Germany), cooking oil (Tropical, Indonesia), and spices such as garlic, salt, and flavoring obtained from the market (Bantul, Indonesia). Digital scales (Ohaus EXP 125/AD Type, Shanghai, China) were used to make the skin crackers. Stoves (Rinnai Ceffon RI-522 C type, Nagoya, Japan), an oven (Memmert UN 110, Germany), and a pressure cooker (Airlux, Japan). The equipment used for analysis was a scanning electron microscope (SEM; 6510 LV Low Vacuum SEM, JEOL, Japan).

2.3 Methods

This study employed a completely randomized design (CRD) with a factorial layout. The first level consisted of soaking solutions containing 3% acetic acid and 3% citric acid, while the second level involved soaking durations of 0, 2, and 4 h. Each treatment was replicated thrice, resulting in 18 treatments.

2.4 The process of making bovine hide crackers

This process starts by obtaining fresh bovine hides from the belly area, and they choose skin that does not have any bruises, lice, or scars. The hide is washed and boiled at 50 °C for 10 min, then the hide is taken out and cut into small pieces measuring 20 × 20 cm. The next step was soaking in a solution of acetic acid and 3% citric acid for either 2 or 4 h, or no soaking at all. After washing to balance the pH, the next step was to boil the item in a pressure cooker at a temperature between 100 and 120 °C for 30 min. The pressure-cooked skin was cut into pieces that were 1 cm × 3 cm. The meat is then soaked in a spice mixture for 15 min. Subsequently, it was placed in an oven and dried at a temperature of 60 °C for 2–3 days. After drying, the samples were fried. The first time you fry, you use a temperature of 80 °C, and the second time, you use a temperature of 160 °C

2.5 Research Variables

The chemical (pH and protein content), physical (yield and expansion volume), and organoleptic (color, aroma, taste, and crispiness) qualities and morphology of the crackers were evaluated as research factors.

2.6 Variable testing

The pH and protein content of the hide crackers were tested, and the yield was calculated by multiplying the final product weight by the initial skin weight before treatment (AOAC, 2012). The expansion volume was calculated using the following formula (Hadiwiyoto, 1983):

$$\text{Volume Expansion Percentage (\%)} = \frac{(Vb-Va)}{Va} \text{ x } 100\% \quad \text{.....(1)}$$

Va = Volume of crackers before frying

Vb = Volume of crackers after frying

Organoleptic testing was performed according to Sukarto (2002), including color, aroma, taste, and crispiness, on a scale of 1-4. Twenty semi-trained panelists were previously trained to determine the properties of the skin crackers. The morphology of the crackers was observed using a Scanning Electron Microscope (SEM) 6510 LV Low Vacuum SEM (JEOL, Japan) at 20 kV. Ion sputtering was used to apply a gold coating on the dry cracker samples placed on metal pieces. SEM was used to view and record each sample.

2.7 Data analysis

An analysis of variance (ANOVA) based on a fully randomized design with a factorial pattern and three replicates for each treatment was used to examine the results of the chemical, physical, and organoleptic tests. If there was a significant difference, the Duncan multiple area test was used (Steel & Torrie, 1995.) A descriptive analysis was used to explain the morphological test results.

3. Results and Discussion

3.1 Hide cracker yield

The statistical calculations of the research results are presented in Table 1. Variance analysis revealed that the type of acid did not significantly influence (P>0.05) the production of bovine hide crackers. The average yield obtained with acetic acid treatment (26.34%) was higher than that obtained with citric acid treatment (25.19%). This indicates that citric acid has a greater ability to alter the collagen structure than acetic acid. As a tricarboxylic acid with three carboxyl groups, citric acid has a higher dissociation capacity, making it more effective in lowering the pH and increasing the swelling of skin tissue. This condition causes a greater loss of material components during soaking compared to acetic acid (Salsabila and Meylani, 2024). The collagen fibril network is extensively compromised when soaked in acid, leading to the denaturation of numerous proteins. According to Ergion et al. (2023), the amount of acid used to break down collagen influences the yield. Increasing the acid concentration causes the polypeptide cross-links to break more, making them easily dissolved (Mulyani et al., 2017). Protein denaturation occurs due to acid when soaking the skin; the acid harms the collagen framework, leading to skin stretching, thinning, and ultimately becoming see-through. When the skin is thin, it facilitates the evaporation of water, resulting in a reduction in moisture content. Reduced moisture content leads to a decrease in yield. The drying process diminishes the water content within the skin, which can result in varying yields, both high and low. According to Che Sulaiman et al. (2017), the use of elevated temperatures during the drying process may increase the oxidation and degradation of chemicals. Heat-sensitive bioactive chemicals result in a significant decrease in yield.

Table 1. Duncan's test results on the chemical and physical parameters of bovine hide crackers during the soaking time of acetic acid and citric acid

Parameter	Soaking Time (Hour)	Type of Acid		Average
		Acetic Acid	Citric Acid	
Yield (%)	0	30.32 ± 1.05^{c}	30.32 ± 1.05^{c}	30.30 ± 0.00
	2	24.76 ± 0.99^{b}	24.06 ± 1.05^{b}	24.41 ± 0.45
	4	23.93 ± 0.08^{b}	21.20 ± 0.30^{a}	22.57 ± 1.93
Average		26.34 ± 0.54	25.19 ± 4.67	25.76 ± 0.81
Protein Content (%)	0	78.30 ± 0.15^{e}	78.30 ± 0.15^{e}	78.30 ± 0.00
	2	73.22 ± 0.09^{d}	66.35 ± 0.08^{c}	69.79 ± 4.86
	4	64.62 ± 0.12^{a}	60.33 ± 0.07^{b}	62.48 ± 3.03
Average		72.05 ± 6.92	68.33 ± 9.15	70.19 ± 2.60
pH	0	6.85 ± 0.12^{d}	6.85 ± 0.12^{d}	6.85 ± 0.00
	2	6.56 ± 0.02^{c}	5.87 ± 0.04^{b}	6.22 ± 0.49
	4	6.05 ± 0.19^{b}	5.50 ± 0.15^{a}	5.78 ± 0.39
Average		6.49 ± 0.41	6.07 ± 0.70	6.28 ± 0.30
Swelling Power (%)	0	632.30 ± 4.94^{a}	632.30 ± 4.94^{a}	632.30 ± 0.00
	2	940.25 ± 6.72^{b}	1445.21 ± 7.13^{d}	1192.73 ± 357.06
	4	1048.37 ± 5.54^{c}	2838.46 ± 7.09^{e}	1943.42 ± 265.79
Average		873.64 ± 215.88	1638.66 ±1115.73	1256.15 ± 540.95

Note: Values followed by different letters in the same row and column indicate a difference P<0.05).

Table 1 shows that the yield of bovine hide crackers varied significantly (P<0.05) depending on the duration of soaking. The treatment that was not submerged in an acidic solution yielded the maximum amount (30.32%). The amount of time spent soaking in acid affects the yield of bovine hide crackers because the amount of acid

absorbed increases and the percentage of protein in the crackers decreases. Extending the duration of exposure to acidic solutions may lead to a heightened breakdown of collagen proteins, as indicated by a reduction in collagen output. This situation leads to a decline in the mass of leather products (Makgobole et al., 2024).

3.2 Bovine hide crackers' protein content

The type of acid and soaking time treatments had a substantial ($P<0.05$) impact on the protein content of bovine hide crackers, according to an analysis of variance (Table 1). The average protein content in the acetic acid treatment (72.05%) was higher than that in the citric acid treatment (68.33%). Immersion in an acidic solution causes protons (H^+) to interact with the charged groups in protein molecules, thereby altering the collagen structure. Under more acidic conditions, some protein molecules dissolved in the soaking medium. Consequently, the amount of protein remaining in the material decreases, and the protein content decreases (Ramadani et al. 2024).

The collagen fibers and protein structure of the hide become weaker the longer it is soaked in the acidic solution. Collagen dissolves as a result of collagen fiber shrinkage during soaking and uneven breakdown of the collagen structure. Long-term soaking in acidic solutions degrades proteins. Large voids emerge in the collagen fiber network as a result of the breakdown process. Amino acids dissolve or undergo solubilization as a result of continuous degradation (Makgobole et al., 2024). As stated by Safitri et al. (2019), proteins are amphoteric and easily react with acids and bases. Therefore, proteins are easily denatured by pH changes. The lower the pH of the acid solution, the more easily the protein dissolves.

The study found that the average protein content of bovine hide crackers was 70.19% ± 2.6. This value was higher than those reported by Susanti et al. (2022), who found 51.45% for buffalo hide crackers and 56.79% for bovine hide crackers. Similarly, the protein content reported by Sabtu et al. (2021) for pig hide crackers ranged from 15.72% to 17.79%, whereas Safitri et al. (2019) reported a value of 55.77% for tilapia hide crackers. Susanti et al. (2022) further explained that the protein composition of the product is influenced by differences in the protein content of the animal hide used as the raw material.

Lessu et al. (2019), state that variations in protein content can be caused by various feed types, processing methods, and the water concentration of each dietary ingredient. The type of organic acid can indirectly affect the protein content of a food product. However, it can affect solubility, denaturation, hydrolysis, and protein loss during processing, which can change the measured protein content in the final product (Soeparno, 2015). Additionally, the methods used to make skin crackers, such as drying and frying, have a significant impact on the final protein content of the crackers. According to Zhou et al. (2020), frying at high temperatures has both positive and negative effects, one of which is protein denaturation. During frying, the water in the tissue evaporates, increasing the amount of dissolved protein. Hardoko and Utami (2020) stated that a material's high or low protein content can be influenced by its density and degree of protein denaturation.

3.3 pH of hides crackers

The pH of the hide crackers was significantly affected ($P<0.05$) by the type of acid and soaking duration, as shown in Table 1. After soaking for 0, 2, and 4 h, the average pH values were 6.85, 6.22, and 5.78, respectively. The pH of bovine hide crackers soaked in HCl solution ranged from 5.71 to 5.8, which is nearly identical to the findings of Ponto

et al. (2023), who reported that the pH of bovine hide crackers soaked in HCl solution ranged from 5.71 to 5.8. Meanwhile, the soaking process in acid lowers the pH of the hide crackers (Sompie et al., 2019). Nonetheless, the pH of the study's hide crackers remained within the 4.5–6.5 range of the (SNI 01-4308-1996).

Table 1 displays the maximum pH value at a soaking duration of zero hours, while the lowest pH value is observed at a soaking duration of four hours because the acetic and citric acids have been absorbed into the skin tissue. The skin absorbs more acid the longer it is soaked, which lowers the pH. According to Sompie et al. (2019), soaking skin crackers in acid reduces their pH. Soaking the skin in citric and acetic acid solutions decreases the pH of the skin crackers because both acids release H^+ ions that diffuse into the skin tissue. Citric acid tends to produce a lower pH because it has a lower pKa value and three carboxylic groups that increase its acidification capacity. This decrease in pH plays a role in inhibiting the growth of microorganisms and affects the physical and chemical properties of the material during processing (Damodaran et al., 2017).

The notable variation in pH ($P<0.05$) may result from acid soaking, which leads to the hydrolysis of connective tissue proteins into various constituent amino acids, resulting in multiple amino acid residues that are water-loving or hydrophilic. This is due to the presence of hydrogen groups in peptides, which are polar organic molecules that can form water. The binding of water by amino acid residues can increase the pH of skin crackers (Siregar et al., 2022)

The longer the immersion in an acidic solution, the more H+ ions accumulate, leading to a decreased skin pH.. According to Bak et al. (2018), the decrease in pH during immersion occurs due to the diffusion and absorption of acid into the collagen network. Under acidic conditions, collagen swells, causing cross-links between molecules to open. This allows the acid, particularly acetic acid, to penetrate the interfibrillar spaces and interact directly with the collagen structure, trapping the acid within the fibril network.

3.4 Swelling power of Hide cracker

The swelling power of the crackers refers to the volume ratio of the crackers after frying to their volume before frying. The higher the swelling volume, the better the quality of the crackers (Hendrikayanti et al., 2022). It is also clarified that throughout the frying process, the size of the crackers expands as the heat activates the air pockets, resulting in light and airy crackers. The crunchiness of the fried crackers increased as the quantity of fried crackers increased.

Table 1 displays the variance analysis, indicating that soaking duration significantly influenced the resulting swelling power ($P<0.05$). Immersion of the skin in citric acid ($C_6H_8O_7$) resulted in an average swelling volume of 1,638.66%, whereas that of acetic acid was 873.64%. Acid causes collagen fibers to swell, increasing the distance between them to become wider. This is because hydrogen ions (H^+) cause denaturation and coagulation of proteins in the epidermis and dermis, resulting in a more open structure, facilitating water penetration during boiling and drying (Safithri et al., 2020). Soaking for four hours in citric acid resulted in the highest swelling power of 2,838.46%, whereas no soaking resulted in the lowest swelling volume of 632.30%.

Bovine hide crackers immersed in citric acid for 4 h after frying showed the greatest swelling since the 4-hour acid soak achieved optimal gelatinization (conversion of collagen to gelatin), leading to maximum hide swelling.

The average swelling power measurements for soaking durations of 0, 2, and 4 h were 632.30%, 1,192.73%, and 1,943.42%, respectively. Fried rawhide crackers undergo volume expansion, which is affected by acid soaking and reduced moisture levels. The optimal concentration (pH) of the acid necessary for enhancing the blooming of bovine hide crackers can impact the above. A 3% solution of acetic acid has a pH of 3, whereas a 3% solution of citric acid has a pH of 2.8. Acid can effectively dissolve protein; however, excessive solubility is insufficient for creating blooms and the texture of skin crackers. Throughout the protein denaturation process, acid influences it, causing the skin to become thinner. Thin skin promotes water evaporation, decreasing the total amount of water. Low water content helps crackers expand when they are fried.

The average volume of cracker swelling ranges from 632.30-2,838.46%. This result is higher than that of a previous study (Lilir et al., 2021), which reported a value of 177.22-1,801.65% for bovine hide. This variation arises from the collagen levels in the skin, which influence its thickness, subsequently affecting the difference in swelling power. Proteins can easily dissolve in acids. High solubility does not enhance the expansion of skin crackers (Safitri et al., 2019). Kittiphattanabawon et al. (2016) stated that collagen undergoes denaturation in acidic or alkaline solutions by severing the peptide chain, which leads to the swelling of collagen molecules. The volume of expansion is closely linked to the protein content of the crackers (Akonor et al., 2017). The swelling power increased as the protein content decreased. Elevated protein levels hinder water penetration into the skin tissue, causing air pockets to seal during frying, as minimal water evaporates. Consequently, the crackers could not completely expand during frying.

3.5 Hedonic evaluation of hide crackers

The objective of the cracker sensory test was to assess the panelists' degree of preference for the hide crackers. The hedonic assessment in Table 2 encompasses tests for color, flavor, scent, and crunchiness, whereas Figure 1 displays the crackers produced in this study.

3.5.1. Hide cracker color

The results of the study on bovine hide crackers under various soaking treatments, namely immersion in acetic and citric acids for 2 and 4 h, as well as a control treatment without immersion in an acid solution (0 h), are shown in Figure 1.

Soaking time and frying process are two factors that affect the color of bovine hide crackers. The variance analysis indicated that a soaking duration of four hours significantly influenced ($P<0.05$) the color intensity of bovine hide crackers. The frying process leads to the development of a brown hue as a result of the Maillard reaction, and factors that diminish the oil quality, such as an increase in acidity, may accelerate the browning process (Muchtar et al., 2023).

The type of acid significantly affected the color level of the bovine hide crackers, as indicated by a value of ($P<0.05$). The color intensity of the bovine hide crackers treated with acetic acid was greater than that of those treated with citric acid. Various soaking methods used for preparing skin crackers can alter the skin tissue composition.

Muchtar et al. (2023) indicated that enhanced acidic characteristics can influence the look of brownish-skin crackers. Basic properties are not as potent as acidic properties in

relaxing the connective tissue. In contrast to bases, acids dissolve collagen bonds into mono-helix forms, whereas bases reduce only to the bi-helix level.

Table 2. Mean Value of Hedonic Evaluation of Bovine Hide Crackers Regarding Soaking Duration Acetic Acid and Citric Acid

Parameters	Soaking Time (Hour)	Type Acid		Average
		Acetic Acid	Citric acid	
Color	0	2.73 ± 0.65[a] Brown	2.73 ± 0.65[a] Brown	2.73 ± 0.00 Brown
	2	3.18 ± 0.60[b] Slightly brown	2.46 ± 0.82[a] Brown	2.82 ± 0.51 Slightly brown
	4	3.00 ± 0.63[a] Slightly brown	3.36 ± 0.67[c] Slightly brown	3.18 ± 0.26 Slightly brown
Average		2.97 ± 0.23 Slightly brown	2.85 ± 0.47 Slightly brown	2.91 ± 0.09 Slightly brown
Flavor	0	3.55 ± 0.52[c] Not acid	3.55 ± 0.52[c] Not acid	3.55 ± 0.00 Not acid
	2	3.09 ± 1.04[b] Slightly acid	3.00 ± 0.78[b] Slightly acid	3.05 ± 0.06 Slightly acid
	4	2.64 ± 0.67[a] Slightly acid	2.00 ± 1.00[a] Acid	2.32 ± 0.45 Acid
Average		3.09 ± 0.46 Slightly acid	2.85 ± 0.78 Slightly acid	2.97 ± 0.17 Slightly acid
Aroma	0	3.82 ± 0.41 Not fishy	3.82 ± 0.41 Not fishy	3.82 ± 0.00 Not fishy
	2	3.55 ± 0.52 Not fishy	3.64 ± 0.51 Not fishy	3.59 ± 0.06 Not fishy
	4	3.55 ± 0.52 Not fishy	3.46 ± 0.69 Not fishy	3.50 ± 0.06 Not fishy
Average		3.64 ± 0.16 Not fishy	3.64 ± 0.18 Not fishy	3.64 ± 0.00 Not fishy
Crispness	0	3.09 ± 0.83[a] Crispy	3.09 ± 0.83[a] Crispy	3.09 ± 0.00 Crispy
	2	3.27 ± 0.65[a] Crispy	2.91 ± 0.70[a] Crispy	3.09± 0.26 Crispy
	4	3.46 ± 0.69[a] Very crispy	3.73 ± 0.65[b] Very crispy	3.59 ± 0.19 Very crispy
Average		3.27 ± 0.18 Crispy	3.24 ± 0.43 Crispy	3.26 ± 0.02 Crispy

Note: Values followed by different letters in the same row and column indicate a significant difference ($P<0.05$).

Table 2 indicates that the maximum average value occurs with immersion in citric acid for 4 h, resulting in a light brown color, while the minimum is observed with soaking in citric acid for 2 h, which is brown. The frying process leads to color variation due to the Maillard reaction. The interaction between reducing sugars and primary amine groups. This reaction yields brown food (Bolade, 2018). The crackers in this study exhibited colors that varied from 2.46 (brown) to 3.36 (slightly brown). According to Syahrul et al. (2017), the elements influencing the color of fried food include the temperature and duration of frying. The greater the frying temperature and the extended frying duration, the darker the hue, indicating overcooking or the opposite.

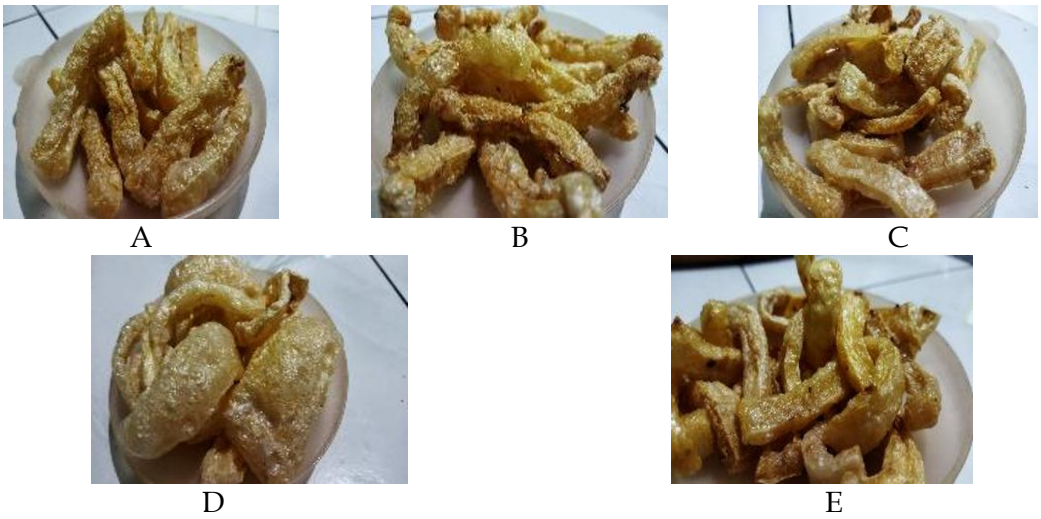

Figure 1. Research results on bovine hide cracker. A = Immersion in acetic acid for 2 h. B = Immersion in acetic acid for 4 h, C = immersion in citric acid for 2 h, D = immersion in citric acid for 4 h. E = Control (no immersion in acid solution (0 h).

3.5.2. Hide cracker taste

The analysis of variance results indicated that the acid type had no significant impact ($P>0.05$) on the flavor of bovine hide crackers, while the soaking duration significantly influenced ($P<0.05$) the flavor of the crackers at soak times of zero, 2, and 4 h. The spices and ingredients used can influence the taste of the resulting product. According to Korzeniowska et al. (2024), each food product is characterized by its own specific sensory qualities, which depend on many aspects, ranging from genetics and cultivation to finishing and technological processing. Heat treatment leads to the interaction of these elements, and the impact of the processing technique on them develops the flavor and aroma experienced by the senses.

Table 2 indicates that an extended soaking period resulted in a more acidic taste. The extended soaking time in acid allows it to penetrate deeper into the skin and collagen fibers, and during the neutralization process, residual acid remains in the collagen fibers, resulting in a tangier taste for the crackers. The flavor of the hide crackers subjected to various soaking methods in acetic and citric acids varied from 2 (acidic) to 3.55 (not acidic) owing to the equal concentration of both acids (3%), resulting in a mildly sour taste. Taste is also affected by the inclusion of spices. Petersen et al. (2024) described how the spices incorporated into the product influenced its flavor, whereas Iskandar et al. (2018) indicated that cooking oil contributed to the flavor of fried food components.

3.5.3. Hide cracker aroma

The aroma or scent information of cattle skin crackers used in this study is presented in Table 2. The variance analysis indicated no significant difference ($P>0.05$) in the crackers made, regardless of the acid treatment type or duration of soaking. The average aroma value of bovine hide crackers in Table 2 is 3.46-3.82 (not fishy). These results are in accordance with the Indonesian National Standard (SNI 01-4308-1996, 1996), which has a normal odor. The use of citric and acetic acid solutions can help reduce fishy odors. The higher the concentration of the acid solution, the more subtle the smell. The fishy odor disappears due to the tertiary amine compound trimethylamine (TMA), which reacts with citric acid and acetic acid

The typical scent of skin crackers immersed in citric and acetic acids resulted in an identical rating of 3. 82 (not fishy). This outcome is attributed to the immersion process in both citric and acetic acids at the same level of 3%. The properties of acids can enhance the flavor and smell of food items while inhibiting the growth of bacteria. According to Monirul et al. (2019), both acetic and ascorbic acids demonstrated significant antibacterial effects against various microbes. Additionally, acids can help preserve the texture, color, and flavor of fish during storage. The herbs or flavorings employed in creating skin crackers influence the scent of the crackers and contribute to a tasty and flavorful experience (Novia et al., 2024).

3.5.4. The crunchiness of hides cracker

A key factor in evaluating cracker food items is crunchiness. The average findings of the hedonic test regarding the crunchiness of bovine hide crackers are displayed in Table 2. The duration of soaking did not notably influence ($P>0.05$) the crunchiness of bovine hide crackers when they were immersed in acetic acid. This is due to the fact because, to achieve a particular crunchiness, crackers need to be fried (Guttiifera et al., 2020), and the frying temperature plays a key role. During the 4-hour citric acid soak, a significant difference was observed ($P < 0.05$), with the highest crispiness score of 3.73 (very crispy). The acid-soaking duration alters bovine hide proteins, which in turn produces a crispier texture in the crackers.

Immersion in different types of acids did not produce a significant difference ($P > 0.05$) in the crispiness of bovine hide crackers. However, the average crispiness of hides immersed in acetic acid was higher than that of those immersed in citric acid. Acid soaking helps to loosen the connective tissue of the hide. According to Bak et al. (2018), treatment with acidic solutions causes loosening of the connective tissue, which is indicated by the swelling of collagen fibers.

Table 2 shows that the average crispiness value ranged from 2.91 to 3.72, which falls within the crispy to very crispy category. The average crispiness of the crackers soaked in acid for 0 and 2 h was lower than that of the crackers soaked for 4 h because the crispiness of the fried crackers increased as their expansion volume increased. For both acetic and citric acid treatments, the crispiness values met the Indonesian standard (SNI 01-4308-1996, 1996), which requires a crispy texture.

3.6 Morphology of skin crackers

The morphology of the bovine hide crackers was obtained from the Scanning Electron Microscope cross-sectional image, as shown in Figure 2.

Ata et al. (2025) stated that, under restricted swelling circumstances, the arrangement of collagen usually stays as protein clusters, creating a compact, less permeable microstructure. The prevalence of these clusters restricts their enlargement when subjected to heat or frying, leading to a thicker texture. Foods lacking pores tend to feel hard when they are chewed. The soaking time further influences the internal structure of the cracker: longer soaking produces larger air cavities, whereas shorter soaking yields smaller air cavities.

The control treatment, which involved hides not soaked in any acid solution, showed a morphology characterized by thicker walls, minimal air cavities, and intact cell structures. Because the hide is only exposed to water, no collagen swelling occurs; it simply becomes wet. Consequently, the skin did not expand adequately during frying.

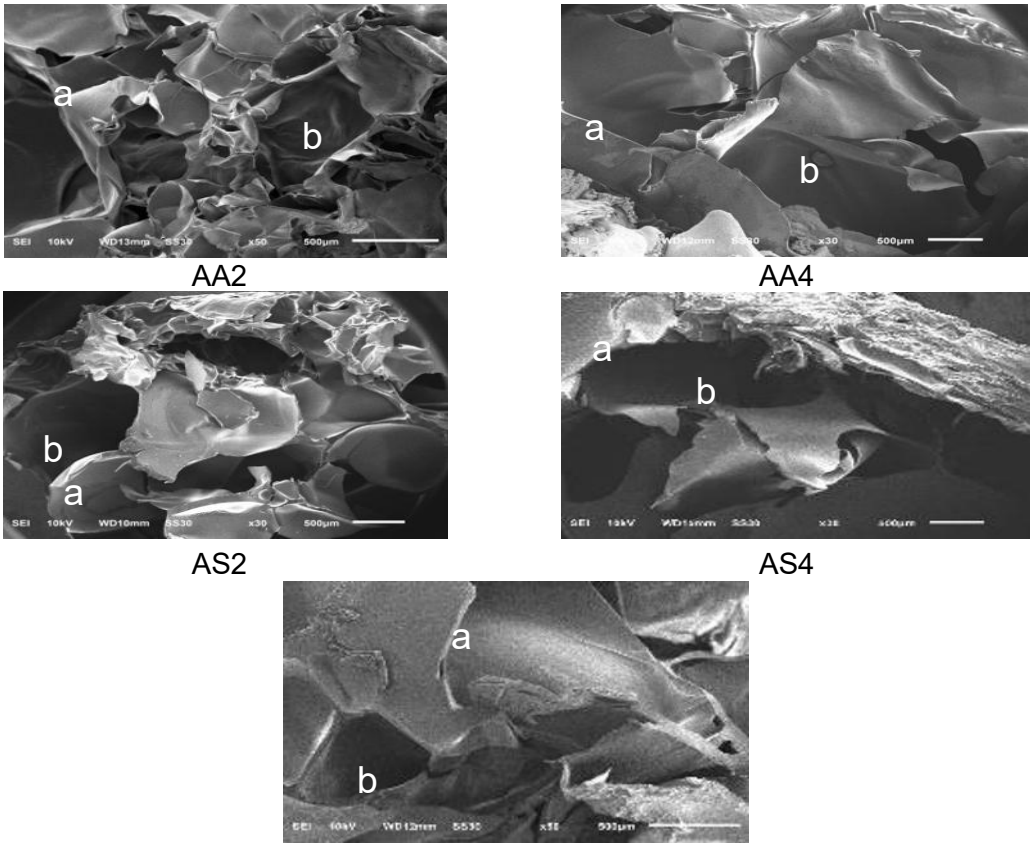

Figure 2. Microscopic photo (SEM) of the research hides crackers. a. Cell wall. b. Air cavity. Magnification 30X. Scale bar 500 µm. AA2 = Soaking in acetic acid for 2 h. AA4 = Soaked in acetic acid for 4 h. AS2 = Soaked in citric acid for 2 h. AS4 = Soaked in citric acid for 4 h. K = Control (no soaking in acid solution (0 h).

Figure 2 shows the morphological characteristics of bovine hide crackers soaked in acetic and citric acid solutions (AA2, AA4, AS2, and AS4). These treatments exhibited notable structural differences compared to the control, reflecting the effects of acid-induced collagen swelling. The microstructure of the hide crackers soaked in acid solutions, both acetic and citric acids, appeared to have more air cavities and thinner cell walls. The cell walls appeared more convoluted and fragile. Soaking bovine hides in an acid solution followed by frying induces structural changes in the hide proteins, which ultimately contribute to the formation of a cracker-like texture. During acid soaking, hide proteins undergo denaturation, resulting in reduced measurable protein content. Decreased collagen protein integrity leads to a reduction in cross-links, which play a role in maintaining tissue structure density. This reduction in cross-links results in looser tissue and increased porosity, allowing for greater swelling and the formation of air cavities during heating or frying (Tihauan et al., 2022).

Soaking the hide in acid for 4 h (AA4 and AS4) produced larger air cavities than soaking for 2 h (AA2 and AS2). Longer exposure to the acidic solution weakens the structure of hide proteins and collagen fibers, as more proteins become denatured. This denaturation causes the connective tissue to loosen, making the hide easier to expand during frying (Safitri et al., 2019). As the hides expand, air cavities develop within the

crackers. In contrast, the control treatment (hide not soaked in acid) displayed smaller air cavities and thicker cell walls. Because little to no protein denaturation occurs in the absence of acid, the connective tissue remains strong and less capable of expansion during frying, resulting in fewer and smaller air cavities in the product.

Prolonged acid soaking causes swelling and partial hydrolysis of collagen, which dissolves some proteins and reduces protein content. Conversely, loosening the collagen structure increases the capacity of the tissue to withstand and release water vapor pressure during frying. Consequently, the expansion capacity increased, as indicated by the formation of larger air cavities and slimmer cell walls in the SEM images. This hollower structure contributes to the crispiness of rambak crackers (Matinong et al., 2022).

4. Conclusion

The type of acid and the duration of soaking influence several characteristics of bovine hide crackers, including yield, protein content, pH, and expansion power. The resulting crackers have a slightly brown color, a taste ranging from mildly sour to not sour, a non-fishy aroma, and a crispy texture, all of which meet the requirements of SNI 01-4308-1996. Morphological differences were also evident: hides not soaked in an acid solution exhibited thick cell walls and few air cavities, whereas hides soaked in acetic or citric acid solutions developed thinner cell walls and numerous air cavities due to greater structural weakening and expansion during frying.

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References

Akonor, P.T., N.T. Dziedzoave, E.S. Buckman, M. Essel, F. Lavoe, & K.I. Tomlins. (2017). Sensory Optimization of Crackers Developed From High-Quality Cassava Flour, Starch, and Prawn Powder. *Food Science and Nutrition*, *5*(3): 564–569. https://doi.org/10.1002/fsn3.431.

Al, W., M. Salla, M. Krayem, & S. Khaled. (2024). Heliyon Hydrolyzed Collagen : Exploring Its Applications In The Food and Beverage Industries and Assessing Its Impact On Human Health – A comprehensive review. *Heliyon*, 10(16): e36433. https://doi.org/10.1016/j.heliyon.2024.e36433.

AOAC. (2012). Official Methods of Analysis of AOAC International. In Association of Official Analysis Chemists International. Arlington: Association of Official Analytical Chemists Inc.

Arumugam, G.K.S., D. Sharma, R.M. Balakrishnan, & J.B.P. Ettiyappan. (2018). Extraction, Optimization and Characterization of Collagen from Sole Fish Skin. Sus*tainable Chemistry and Pharmacy*, *9*:19–26. https://doi.org/10.1016/J.SCP.2018.04.003.

Ata, O., J.L. Kokini, S. Tavman, & G. Yazar. (2025). Advances in Collagen-/Gelatin-Based Hydrogels: Rheological Properties and Applications. *Macromol*, 5 (55): 1-34.

https://doi.org/10.3390/macromol5040055.

Bak, S.Y., S.W. Lee, C.H. Choi, & H.W. Kim. (2018). Assessment of the Influence of Acetic Acid Residue on Type I Collagen during Isolation. *Materials*, 11, 2518: 1-16. https://doi.org/10.3390/ma11122518.

Bolade, M.K. (2018). Physical & Organoleptic Characteristics of Non-Sour 'Kokoro' (A Nigerian Maize-Based Snack) As Influenced by Flour Particle Size Differential. *LWT*, *87*: 287–292. https://doi.org/10.1016/J.LWT.2017.09.001.

Che Sulaiman, I.S., M. Basri, H.R. Fard Masoumi, W.J. Chee, S.E. Ashari, & M. Ismail. (2017). Effects of Temperature, Time, And Solvent Ratio on The Extraction of Phenolic Compounds and The Anti-Radical Activity of *Clinacanthus Nutans* Lindau Leaves by Response Surface Methodology. *Chemistry Central Journal*, *11*(1): 1–11. https://doi.org/10.1186/s13065-017-0285-1.

Damodaran, S., & S.Y. Wang. (2017). Ice Crystal Growth Inhibition by Peptides from Fish Gelatin Hydrolysate. *Food Hydrocolloids*, *70*: 46–56. https://doi.org/10.1016/J.FOODHYD.2017.03.029.

Guttiifera, S.R. Sari, F. Pratama, T.W. Widowati, & D. Prariska. (2020). Karakteristik Sensoris Microwaveable Kemplang Palembang dengan Perbedaan Ketebalan dan Level Daya pada Proses Pematangan. *Jurnal Ilmu Perikanan Air Tawar (Clari*as*)*, 1(1): 13–18. https://doi.org/10.56869/clarias.v1i1.

Hadiwiyoto, S. (1983). Hasil-hasil Olahan Susu, Ikan, Daging dan Telur (Ed 2, cetak). Liberty.

Hardoko & S. Utami. (2020). Chemical-Physical Properties Characterization of White Snapper Fish Skin Rambak Crackers Based on Boiling and Drying Duration. *Jurnal Ilmiah Perikanan Dan Kelautan*, *12*(1): 122–130. https://doi.org/10.20473/jipk.v12i1.14842.

Harianto, D.F. (2024). Assessing the Organic Acids-solubilized Collagen Derived from the Skin of Unicornfish (*Naso reticulatus* Randall, 2011) on Physicochemical and Structural Characteristics : Toward Alternative Source for Industrial Applications. *ASEAN Journal on Science and Technology for Development*, *40*(2): 123-132. https://doi.org/10.61931/2224-9028.1535.

Hendrikayanti, R.H., A.S. Fahmi, & R.A. Kurniasih. (2022). Optimasi Waktu Pengukusan dan Suhu Penggorengan Kerupuk Ikan Patin Menggunakan Response Surface Methodology. *Journal of Fisheries and Marine Research*, 6(1): 78–90. https://doi.org/10.21776/ub.jfmr.2022.006.01.10.

Iskandar, H., Patang, & Kadirman. (2018). Processing Talas (*Colocasia esculenta* L., Schott) Become Flaky Use Appliance Vacuum Frying with Variation Time. *Jurnal Pendidikan Teknologi Pertanian*, *4*:29–42. https://doi.org/https://doi.org/10.26858/jptp.v1i1.6217.

Kittiphattanabawon, P., S. Benjakul, S. Sinthusamran, & H. Kishimur. (2016). Gelatin from Clown Featherback Skin: Extraction Conditions. *LWT - Food Science and Technology*, 66: 186–192. https://doi.org/10.1016/J.LWT.2015.10.029.

Korzeniowska, M.H., J.Łyczko, & M.C. Lamadrid. (2024). Processing Effects on Food Sensory Attributes. In *Sensory Science Applications for Food Production* (pp. 249–283).

IGI Global. https://doi.org/10.4018/979-8-3693-2121-8.ch012.

Lessu, R.J., M. Pattipeilohy, & S. Melay. (2019). Pengaruh Cara Pengolahan dan Waktu yang Berbeda Terhadap Kadar Protein Daging Bekicot (*Achatina Fulica*) Sebagai Sumber Protein Alternatif Masyarakat Negeri Lesluru Kecamatan Teon Nila Serua (TNS) Waipia. *Biopendix*, *5*(2): 72–81. https://doi.org/10.30598/biopendixvol5issue2page72 -81.

Lilir, F.B., C.K.M. Palar, & N.N. Lonta. (2021). Pengaruh Lama Pengeringan Terhadap Proses Pengolahan Kerupuk Kulit Sapi. *Zootec*, 41(1): 214–222.

Makgobole, M.U., S.C. Onwubu, A. Baruw, N. Mpofana, Z. Obiechefu, D. Naidoo, A. Khathi, & B. Mkhwanazi. (2024). Optimization of Collagen Extraction from Fish Scales Using Tris-Glycine Buffer : A Taguchi Methodological Approach. *Marine Drug*, 2 (256): 1-13. https://doi.org/10.3390/md22120562.

Matinong, A.M.E., Y. Chisti, K.L. Pickering, & R.G. Haverkamp. (2022). Collagen Extraction from Animal Skin. *Biology*, 11, 905: 1-15. https:// doi.org/10.3390/biology11060905.

Monirul, I., F. Yang, M. Niaz, J. Qixing, & X. Wenshui. (2019). Effectiveness of Eacombined Acetic Acid and Ascorbic Acid Spray on Fresh Silver Carp (*Hypophthalmichthys molitrix*) Fish to Increase Shelf-Life at Refrigerated Temperature. *Current Research in Nutrition and Food Science*, *7*(2): 415–426. https://doi.org/10.12944/CRNFSJ.7.2.11.

Muctar, F., Hastian, & Ruksanan. (2023). Analisis Kadar Air , Kadar Protein dan Karakteristik Organoleptik Kerupuk Stik Dengan Penambahan Konsentrasi Ikan Layang yang Berbeda. *Agritekh*. *3*(2): 94–105. http://doi.org/ 10.32627.

Mulyani, S., F. S.M. C.S. Setyabudi, Y. Pranoto, & U. Santoso. (2017). Physicochemical Properties of Gelatin Extracted from Buffalo Hide Pretreated with Different Acids. *Korean Journal Food Sci Anim Resour*, *37*(5): 708–715. https://doi.org/10.5851/kosfa.2017.37.5.708.

Novia, D., I. Juliyarsi, Yuherman, R.D. Setiawan, R. Afriyeni, & F. Nurhayani. (2024). Physicochemical and Sensory Properties of Cow Skin Crackers from Dry Salt-Preserved Skin Utilizing Sodium Meta-Bisulfite (SMB). *IOP Conference Series: Earth and Environmental Science*, *1341*(1): 1–9. https://doi.org/10.1088/1755-1315/1341/1/012043.

Pang, Z., H. Deeth, H. Yang, S. Prakash, & N. Bansal. (2017). Evaluation of Tilapia Skin Gelatin as A Mammalian Gelatin Replacer in Acid Milk Gels and Low-Fat Stirred Yogurt. *Journal of Dairy Science*, 100(5): 3436–3447. https://doi.org/10.3168/jds.2016-11881.

Ergion, A.R., L. Sulmartiwi, R.V.S. Manikam, D. Nirmala, Y. Waiprib, & S. Wijayanti. (2023). Effect of Acetic Acid Pre-treatment on Hydro-extraction of Water-Soluble Collagen from Skin of Alaska Pollock (*Theragra chalcogramma*). *Jurnal Ilmiah Perikanan Dan Kelautan*, 15(2): 468–477. https://doi.org/10.20473/jipk.v15i2.41274.

Petersen, K.S., V.L. Fulgoni, H. Hopfer, J.E. Hayes, R. Gooding, & P. Kris-Etherton. (2024). Using Herbs/Spices to Enhance The Flavor of Commonly Consumed Foods Reformulated to Be Lower In Overconsumed Dietary Components is An Acceptable Strategy and Has The Potential to Lower Intake Of Saturated Fat and

Sodium: A National Health and Nutrition Ex. *Journal of the Academy of Nutrition and Dietetics*, *124*(1): 15-27.e1. https://doi.org/10.1016/j.jand.2023.07.025.

Ponto, J.H.W., M. Sompie, & P.M. Mayore. (2023). Pengaruh Perendaman dalam Larutan Asam Klorida (Hcl) Terhadap Nilai Ph, Kekuatan Gel, Viskositas, dan Rendemen Gelatin Kulit Sapi. *Zootec*, 43(1) : 852–2626.

Ramadani, D.A., L. Hermalena, & R.A. Salihat. 2024. Pengaruh Konsentrasi Asam Asetat Terhadap Karakteristik Kolagen Dari Sisik Ikan Julung-Julung (*Hemiramphus* sp.). *Jurnal Research Ilmu Pertanian*, 4(2):173-182. https://doi.org/10.31933/b0ts7w60

Sabtu, B., I.H. Lobo Lay, & H. Armadianto. (2021). The Effect of Boiling Time on The Physical, Chemical and Organoleptic Properties of Pork Skin Crackers. *Journal of Tropical Animal Science and Technology*, 3(1): 10–20. https://doi.org/10.32938/jtast.v3i1.884.

Safitri, D., Sumardianto, & A.S. Fahmi. (2019). Effects of Immersion in Different Lime Water Concentration on Characteristics of Tilapia Skin Crackers. *Jurnal Ilmu Dan Teknologi Perikanan*, 1(1): 47–54. https://doi.org/https://core.ac.uk/download/pdf/234034519.pdf.

Safithri, M., K. Tarman, P. Suptijah, & S.N. Sagita. (2020). Karakteristik Kolagen Larut Asam Teripang Gama (*Stichopus variegatus*). *Jurnal Pengolahan Hasil Perikanan Indonesia*, 23(1): 166-177 . https://doi.org/10.17844/jphpi.v23i1.31063.

Salsabila, S.N.A., & C. Putri Meylani. (2024). Proses Produksi Asam Sitrat Melalui Fermentasi: Metode dan Strategi. *Journal of Integrative Natural Science*, 1(1): 10-18. https://ejournal.unsika.ac.id/index.php/JoINS/article/view/24.

Sasmitaloka, K.S., M. Miskiyah, & J. Juniawati. (2017). Kajian Potensi Kulit Sapi sebagai Bahan Dasar Produksi Gelatin Halal. *Buletin Peternakan*, 41(3): 328. https://doi.org/10.21059/buletinpeternak.v41i3.17872.

Siregar, W., A. Amhar, & Dzarnisa. (2022). Effect of Soaking Using Bromelain Enzyme on Quality and Organoleptic Test of Cowhide Crackers. *Jurnal Ilmiah Mahasiswa Pertanian*, 7(2): 270–278.

SNI 01-4308-1996. (1996). Mutu dan Cara Uji Kerupuk Kulit. Badan Standardisasi Nasional. pp. 1–9. http://lib.atk.ac.id/index.php?p=fstream&fid=365&bid=7526.

Soeparno. (2015). Ilmu dan Teknologi Daging. Gadjah Mada University Press. Yogyakarta. pp 516.

Sompie, M., S.E. Siswosubroto, G.D. Rembet, & J.W. Ponto. (2019). Effect of Different Types of Acid Solvent on Functional and Microbiological Properties of Chicken Leg Skin Gelatin. *IOP Conference Series: Earth and Environmental Science*, 387(1): 1–4. https://doi.org/10.1088/1755-1315/387/1/012128.

Steel, R.G.D., & J.H. Torrie. (1995). Prinsip dan Prosedur Statistika : suatu pendekatan biometrik (ed 2, ceta). Gramedia Pustaka Utama. Jakarta

Sukarto, S.T. (2002). Penilaian Organoleptik untuk Industri Pangan dan Hasil Pertanian (3rd ed.). Bhatara Karya Aksara.

Susanti, S., A. Hintono, S. Mulyani, F.A. Ardi, & F. Arifan. (2022). Comparison of Chemical Characteristics of Various Commercial Animal Skin Crackers. *American Journal of Animal and Veterinary Sciences*, 17(4): 314–321.

https://doi.org/10.3844/ajavsp.2022.314.321.

Syahrul, S.R., J. Hermanianto, & B. Nurtama. (2017). Optimasi Proses Penggorengan Tumpi-Tumpi Dari Ikan Bandeng Menggunakan Response Surface methodology. *JPHPI*, 20(3): 432–445. https://doi.org/10.17844/JPHPI.V20I3.19762

Tihauan, B.M., G.G. Pircalabioru, M. Axinie (Bucos), I.C. Marinas, A. C. Nicoarˇa, L. Mˇarutescu, O. Oprea, E. Matei, & S.S. Maier. (2022). Crosslinked Collagenic Scaffold Behavior Evaluation by Physico-Chemical, Mechanical and Biological Assessments in An In Vitro Microenvironment. *Polymers*. 14, 2430. https://doi.org/10.3390/ polym14122430.

Zhou, R., J. Sun, H. Qian, Y. Li, H. Zhang, X. Qi, & L. Wang. (2020). Effect of The Frying Process on The Properties of Gluten Protein of You-Tiao. *Food Chemistry*, 310, 125973. https://doi.org/10.1016/J.FOODCHEM.2019.12597.

Rapika, R., Z. Zulfikar, & Z. Zumarni. (2016). Kualitas Fisik Gelatin Hasil Ekstraksi Kulit Sapi dengan Lama Perendaman dan Konsentrasi Asam Klorida (HCl) yang Berbeda. *Jurnal Peternak*, 13(1): 26–32. DOI: 10.24014/jupet.v13i1.2386.