The Effects of Using Different Types of Liver on Sausage Products:A Review

ABSTRACT

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| Vitamin and mineral deficiencies—particularly in vitamin A, iron, and zinc—remain a significant global health issue, especially among preschool-aged children, pregnant women, and the elderly. The World Health Organization (WHO) estimates that around 50% of preschool children and 7% of women of reproductive age suffer from these micronutrient deficiencies, contributing to 19% of the approximately 10.8 million annual child deaths. One potential dietary source to address these deficiencies is liver, which is rich in protein, vitamins A, D, B2, B12, folic acid, iron, and zinc. Liver is a slaughterhouse by-product with high nutritional value and strong potential for development as a functional food. However, its distinctive aroma and strong flavor often reduce consumer preference. Processing liver into products such as sausages offers a promising solution. Sausage, one of the oldest processed foods, can improve liver acceptability through proper formulation and processing techniques. The addition of chicken, pork, and goat liver in sausage affects the physical and chemical qualities of the final product. Liver substitution up to a certain level can enhance nutritional value without compromising emulsion stability, texture, and flavor. Therefore, optimizing the liver substitution ratio is essential to produce sausages that are both nutritionally beneficial and sensorially acceptable. |

*Keywords: Sausage; liver; meat processing,* *folic acid,* *Sausage*

1. INTRODUCTION

Vitamin and mineral deficiencies remain a significant issue affecting various populations worldwide (WHO, 2023). Among the most common deficiencies are vitamin A and minerals such as iron and zinc, which are prevalent among the elderly, pregnant women, and children (Hofman, 2017). WHO reports estimate that deficiencies in vitamins and minerals particularly iron, vitamin A, and zinc affect approximately 50% of preschool-aged children and 7% of women of reproductive age globally. Each year, an estimated 10.8 million child deaths occur worldwide, with about 19% attributed to deficiencies in iron, zinc, and vitamin A (WHO, 2023).

A potential dietary source to help address these deficiencies is liver. Liver is a functional food rich in essential vitamins and minerals, such as iron, zinc, and vitamin A. Furthermore, liver is a by-product of slaughterhouses that can be consumed and processed into various nutritious food products. It explains that liver, as one of the by-products of the animal slaughtering process, often faces wastage issues due to suboptimal utilization. This liver waste can contribute to environmental pollution if not properly managed. The handling and utilization of liver as a functional food ingredient can reduce the amount of waste generated while simultaneously increasing the economic value of this by-product (Sadakuzzaman et al., 2021). It also provides a wide range of important macro- and micronutrients comparable to lean muscle tissue (Falowo et al., 2017). Liver contains protein and is an excellent source of minerals, vitamins A, D, B2, and B12, as well as folic acid. It is a raw material with high development potential and serves as a highly effective emulsifier in processing due to its unique flavor and technical functions (Kyung Ku, 2022). The nutrient content varies among different types of liver sources, such as chicken, pork, and goat liver.

Functional foods are products that provide health benefits beyond basic nutrition, containing biologically active components that can prevent diseases and enhance well-being (Aathithya, 2024). These foods may be whole, enhanced, fortified, or modified and consumed as part of a nutrient-rich diet (Barik et al., 2022). Examples include fruits, vegetables, and foods supplemented with nutrients, dietary fiber, phytochemicals, or probiotics (Anil et al., 2022). Liver is one example of a functional food; however, its distinctive aroma and strong flavor often reduce consumer preference, necessitating processing methods, such as incorporation into sausage products.

Sausage is one of the oldest forms of processed foods and was originally partly used as a means to preserve meat. The word "sausage" derives from the Latin word *salsus*, meaning salted or literally preserved. Sausages were made and consumed by the ancient Babylonians and Chinese around 1500 BCE. Salami was mentioned by the Greeks around 449 BCE, and Native Americans made a sausage-like product called pemmican (Lonergan et al., 2019). The study by Park and Kim (2020) shows that consumer acceptance of liver-based products is greatly influenced by the distinctive taste and aroma of liver, which is often disliked by some consumers. However, the use of appropriate processing techniques, such as removing the off-odor and adjusting seasonings, can significantly improve consumer preference. Additionally, educating consumers about the nutritional benefits of liver also plays an important role in increasing the acceptance of liver-based products. Sausage is a food product made from ground meat mixed with spices and can be prepared and cooked immediately for consumption (Rosida et al., 2015). There are several types of sausages, such as raw, cooked, and fermented (Carballo, 2021). The characteristics of high-quality sausages include a chewy texture, low cooking loss, high water binding capacity (WBC) to ensure good juiciness, as well as desirable flavor and sliceability (Ismanto et al., 2020). Aside from sausages, another processed product with liver addition is nuggets. This study compared the quality of chicken and beef liver nuggets using different cooking methods (raw and pre-steamed). The results showed that steamed beef liver nuggets had the best quality, with a protein content of 23.33%, fat, crude fiber, ash and dry matter (Amertaningtyas dkk.,2021).

2. NUTRITIONAL POTENTIAL OF LIVER

Edible internal organs obtained during animal slaughter are known as offal. Offal features prominently in many traditional regional cuisines worldwide, both for their nutritional value and organoleptic characteristics (Alsina and Saguer, 2023). Animal liver is one of the offal types rich in mineral sources, including iron (Fe), copper (Cu), zinc (Zn), and tin (Sn), which are readily absorbed by the body (Kabata-Pendias and Szteke, 2012). Additionally, liver contains high amounts of various vitamins such as vitamins A, B2, B12, C, folic acid, niacin, and pantothenic acid, with levels far exceeding those found in any plant-based food. Recommended liver consumption for humans varies by age and gender, generally ranging from 100 to 250 grams per week. However, to date, its utilization has been limited to liver pâté products and animal feed due to a lack of knowledge about its protein functions (Steen et al., 2016). Liver is a rich source of iron, zinc, copper, and manganese (Babicz et al., 2019). Moreover, liver is abundant in several macroelements such as calcium, sodium, and potassium (Alsina and Saguer, 2023). The texture of liver is influenced by a complex composition of muscle fibers, connective tissue, and intramuscular fat, which affect its technological and sensory properties (Listrat et al., 2016).

**2.1 Chicken Liver**

According to IndexBox data, global chicken liver production reached approximately 17 million tons in 2022. Chicken liver, a consumable by-product of poultry, accounts for about 2–2.5% of their live weight. It is recognized as a highly nutritious by-product rich in essential vitamins and minerals. Chicken liver contains higher amounts of iron, vitamin A, and B-complex vitamins compared to other poultry by-products. Furthermore, its fat content ranges from 0.81 to 6.5% (Wibisono et al., 2023). Chicken liver also contains protein at levels of 16–17 %/100 g (Wibisono et al., 2023). Representing approximately 1.6–2.3% of the chicken, it is one of the main poultry by-products (Nacak, 2023). Chicken liver is a nutrient-dense offal with high protein content and essential vitamins and minerals. It contains significant levels of vitamins A, B-complex, iron, zinc, and manganese compared to muscle tissue. Chicken liver also exhibits a favorable fatty acid profile, with a beneficial ratio of polyunsaturated to saturated fats (Seong et al., 2015). According to Seong et al. (2015), chicken liver can serve as a source of vitamins A, B12, and several minerals including iron. Therefore, incorporating chicken liver into meat formulations can be a promising strategy to develop new products with high nutritional quality. However, its use may affect certain quality characteristics such as emulsion stability, water-holding capacity (WHC), cooking loss, texture, and color. stated that the addition of chicken liver increased the lightness value (L\*) of nuggets, but did not affect the redness (a\*) and yellowness (b\*) values. The resulting color change was perceptible to the human eye, with a ΔE value ranging from 5 to 8, indicating a noticeable difference in color. Sensory evaluation showed that nuggets enriched with chicken liver were well accepted by consumers, despite the detectable changes in color (Mehmood et al., 2021)

**2.2 Pork Liver**

In pigs, offal constitutes about 17% of live weight, with liver being the most prominent part. Its nutritional value is comparable to meat, though it contains higher levels of vitamins and minerals, making liver considered a first-class meat by-product due to its richness in protein, vitamins, and mineral elements (Kakimov et al., 2018). Pork liver is a by-product of pig slaughter with high nutritional value and potential application in processed food products. It provides energy ranging from 123 to 131 kcal per 100 grams and contains protein, vitamin A, calcium, and iron at 19.3–19.8%, which is relatively higher than meat. These nutrients support growth and visual health (Choi et al., 2017). The favorable nutrient profile enables liver to possess important functional properties for food products. As a low-cost by-product from slaughterhouses, liver is rich in protein as well as essential nutrients such as amino acids, minerals, and fatty acids (Steen et al., 2016). Pork liver contains approximately 72.4% moisture, 20% protein, 4.75% fat, and 1.97% ash. The lightness (L\*), redness (a\*), and yellowness (b\*) values ranged from 59.1 to 76.1, 7.4 to 12.2, and 16.2 to 17.7, respectively. The addition did not show a significant difference in the b\* value. Based on the results of this study, the addition of pork liver decreased lightness and increased redness. Although there were changes in color, sensory evaluation results showed that sausages with added pork liver were still well accepted by consumers. The consumer liking level remained fairly high, especially when the proportion of liver used was not excessive, allowing the characteristic aroma and flavor of the liver to be acceptable (Peñuñuri-Pacheco et al., 2024)

**2.3 Goat Liver**

Goat liver can be considered an alternative ingredient for incorporation into goat meat sausages due to its high iron content. Goat liver contains approximately 7.78 mg of iron per 100 g (Tomoviÿ et al., 2017). Its use is expected to enhance the iron content of goat meat sausages. Physically, goat liver differs from goat meat, having a higher fat content of up to 6.27 g/100 g, which may influence the final texture of the produced sausage (Triyannanto et al., 2024). This aligns with findings by Daramola (2019), who stated that goat liver is an organ of ruminant animals with high nutritional value and is often utilized as a food ingredient. According to Oluwatosin Daramola (2019), goat liver contains very good nutritional content, particularly as a source of animal protein. In 100 grams of goat liver, there is approximately 47.68% protein, 30.26% fat, and 2.35% ash (minerals), while carbohydrates and fiber were undetectable. Additionally, goat liver is rich in essential minerals such as potassium (1007.2 mg/kg), sodium (456.3 mg/kg), calcium (167.3 mg/kg), iron (13 mg/kg), as well as copper and manganese in significant amounts. This nutrient profile indicates that goat liver is not only a source of high-quality protein but also contains various essential minerals beneficial for health. The addition of goat liver causes the sausage color to become darker and redder; however, this color change is still visually acceptable to consumers. In terms of acceptability, substitution of up to 50% goat liver does not decrease consumer acceptance of the sausage’s taste, aroma, or texture. Moreover, the addition of liver also increases the iron content, making the use of goat liver as a substitute ingredient in goat meat products an effective alternative to improve nutritional value without compromising sensory quality (Triyananto et al.,2024). The study conducted by Khalid et al. (2024) demonstrated that the addition of mutton and fish livers to chicken nuggets had a positive impact on nutritional value, functional quality, and consumer acceptance. In terms of nutritional content, the incorporation of liver increased the protein level of the nuggets by 1.5 to 2.0 percent. Furthermore, antioxidant activity also improved, with mutton liver exhibiting higher antioxidant potential compared to fish liver, indicated by a DPPH activity value of 25.9% and a total phenolic content (TPC) of 154 mg GAE per 100 grams. Physically, the texture quality of the nuggets also improved, particularly in parameters such as hardness and chewiness. Sensory evaluation results showed that nuggets with added mutton and fish liver were well accepted by consumers, especially in terms of taste and texture, which were perceived as more appealing and enjoyable.

**3. PHYSICAL QUALITY OF SAUSAGES WITH THE ADDITION OF VARIOUS TYPES OF LIVER**

**3.1 Chicken Liver**

A study by Nacak (2023) substituted chicken liver with different ratios: 100% chicken meat + 0% chicken liver, 75% chicken meat + 25% chicken liver, 50% chicken meat + 50% chicken liver, and 25% chicken meat + 75% chicken liver. The emulsion stability and water-holding capacity (WHC) of sausages with 75% substitution showed lower emulsion stability and WHC compared to other treatments. This is because proteins provide good emulsifying ability (Tanmak et al., 2016), and the lower protein content in the 75% chicken liver substitution led to decreased emulsion stability. Sausages with 75% chicken liver substitution experienced higher cooking loss compared to others. According to Afshari et al. (2017), the greater the amount of fat and water lost, the higher the cooking loss. Therefore, the smaller amount of retained fluid and fat in the 75% substitution resulted in greater loss during cooking.

Color is a major factor influencing consumer preference. The addition of non-meat ingredients can cause undesirable color changes (Serdaroğlu et al., 2018). Increasing the proportion of chicken liver caused a decrease in L\* (lightness) and b\* (yellowness) values, while increasing the a\* (redness) value. Higher levels of chicken liver substitution produced darker color, partly due to the presence of minerals such as iron and zinc (Permatasri et al., 2020). Sausages with higher chicken liver proportions exhibited softer texture than others. Substitution of chicken liver at 50% ratio can produce sausages with good quality, especially in protein content and emulsion stability, but substitution beyond 50% may reduce emulsion quality. Zhang et al. (2019) found that higher fat content in meat emulsions reduces stability due to increased fat droplet coalescence. Protein acts as an emulsifier by stabilizing fat droplets; insufficient protein weakens the emulsion. Fat type also affects stability, with fats melting at higher temperatures forming more stable emulsions. Balancing protein and fat content is key to maintaining emulsion quality.

**3.2 Pork Liver**

Pork liver is a protein-rich by-product with potential for use in processed meat products (Feliu-Alsina & Saguer, 2023). Research by Pacheco et al. (2024) formulated frankfurter sausages with pork liver addition at 0% (control), 4%, 8%, and 12%. The addition of pork liver slightly reduced moisture content, with the highest pork liver formulations showing decreases from 70.3% (control) to 69.9% and 68.6% at 8% and 12%, respectively. This is attributed to pork liver proteins being water-soluble, particularly albumin and myofibrillar fragments (Steen et al., 2016). The high protein content, especially water-soluble proteins like albumin and myofibrillar fragments, contributes to its functional properties in food systems (Chen et al., 2017).

The addition of pork liver did not significantly affect sausage texture. However, it caused a decrease in L\* value (darker appearance) and an increase in a\* value (redder appearance). Lightness (L\*), redness (a\*), and yellowness (b\*) ranged from 59.1 to 76.1, 7.4 to 12.2, and 16.2 to 17.7, respectively. Pork liver contains high levels of iron and heme iron, influencing the red color of processed meat products. In these products, nitrite binds and stabilizes, while heme iron forms nitrosyl-myoglobin complexes. After cooking, nitrosylhemochrome forms, giving the characteristic pink color (Suman and Joseph, 2013).

Pork liver addition significantly affected firmness but did not influence springiness. Samples with 8% and 12% pork liver had the lowest firmness values, and firmness increased during storage. The addition of various proteins and additives can significantly affect sausage texture properties (Petrášová et al., 2018). Storage conditions also impact texture, with firmness and hardness increasing after storage (Zajác et al., 2015). Springiness is a key indicator to differentiate sausages stored for different durations (Feng et al., 2017). Storage conditions significantly affect the quality of sausages and processed meats. Temperature and duration influence the physicochemical properties as well as microbial growth in turkey meat and sausages (Kluth et al., 2021). Stated that the decrease in chewiness is associated with changes in protein microstructure and moisture loss during storage (Feng et al.,2017)

**3.3 Goat Liver**

A study by Triyannanto et al. (2024) substituted goat liver with goat meat at 100% goat meat, 75% goat meat + 25% goat liver, and 50% goat meat + 50% goat liver. The texture profile of sausages showed significant differences in hardness but not in springiness across substitution ratios. According to Aprianti et al. (2021), sausages that break easily during chewing have low springiness, often caused by low hardness. The springiness of goat meat sausages decreased with increasing proportions of goat liver. Aprianti et al. (2021) defined springiness as the chewing resilience of a sausage until it breaks down. Additionally, sausage elasticity is influenced by hardness and elasticity levels. Lower springiness indicates a less chewy and softer texture (Setiaboma et al., 2021).

Data indicated that goat meat sausages with 50:50 liver substitution had the highest softness. The highest softness is due to fat emulsions in goat liver. This occurs because protein compounds contain polar groups, causing the protein-water phase to form a strong matrix bond. This strong protein-water matrix bond increases the capacity of coated fat globules, enhancing the emulsification process. Sausage hardness decreased as the proportion of goat liver increased. Goat liver contains 6.27 g/100 g fat, while goat meat contains 2.6 g/100 g fat. The higher fat content in goat liver makes sausages with goat liver substitution softer.

Substitution of goat meat with goat liver at various ratios significantly affected water-holding capacity (WHC) of goat meat sausages, ranging from 41.87% to 45.20%. Increased substitution led to higher WHC. Soeparno (2015) stated WHC is also influenced by the product’s pH, especially when proteins reach their isoelectric point. The study showed that goat liver addition did not significantly affect moisture content, possibly due to a balanced combination of liver, added water, and starch. Liver has high moisture content, meaning liver tissue contains a considerable amount of water, but WHC depends on how well the water is retained under different conditions. Rompis and Londok (2022) noted water is a crucial component in sausage affecting appearance, texture, and flavor. The substitution of goat liver did not significantly affect color, aroma, taste, or sausage acceptability (p > 0.05). The lack of effect on color may be due to the relatively high amount of starch added compared to liver. Purwosari and Afifah (2016) stated that starch from tapioca and corn flour does not influence sausage color. Pork liver addition also did not affect aroma because the characteristic offal odor was masked by the spices used. Sausage aroma is influenced by the spices in the mixture. This is consistent with findings by Sofyan et al. (2018), who reported that the addition of spices like salt, pepper, nutmeg, shallots, and garlic affects the aroma of mushroom sausages, as these spices dissolve in water and during boiling produce the resulting sausage aroma.

**Table 1. Physical quality of sausages with the addition of various types of liver**

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| --- | --- | --- | --- | --- |
| Types of Liver Addition | Formulation of Liver Addition | Physical Quality of Sausages | Effect of Addition | Source |
| Chicken Liver | Substitution of chicken liver in chicken meat-based sausages at levels of 25%, 50%, and 75% | **WHC:** 74–83.19% **Cooking loss:** 3.89–7.03% **Hardness:** 557,077–4,605,000 g L \*: 56.78–73.79 a: 3.64–14.83 b: 10.95–13.84 | A 50% substitution maintains WHC and achieves good emulsion stability. Increasing chicken liver substitution lowers L\* values. A 75% substitution results in higher cooking loss and reduced emulsion stability. | Nacak (2023) |
| Pork Liver | Substitution of pork liver in pork-based sausages at levels of 4%, 8%, and 12%. | **Moisture content:** 68.6–69.9% **Humidity:** 68.6–70% **Hardness:** 56.3–58.6 **Cohesiveness:** 0.62–0.70 **Springiness:** 31.2–34.0 | Substitution at 8% and 12% slightly reduces moisture content, with 12% having the lowest. Hardness is highest at 4%, while 12% substitution results in the lowest hardness and springiness. | (Pacheco, et al., 2024) |
| Goat Liver | Substitution of goat liver in goat meat-based sausages at ratios of 25% and 50%. | Hardness: 11.57–14.85 g Gumminess: 9.28–11.24 Chewiness: 8.40–10.05 Springiness: 89.83–90.69% Water Holding Capacity (WHC): 43.14–45.20% Warmth: 3.14–3.23 Aroma: 2.97–3.06 Tenderness: 3.14–3.80 Taste: 3.26–3.40 | At 50% substitution, hardness, gummines, chewiness, springiness decreased.  WHC increased at 50% addition, while color, aroma, softness, taste also increased at 50% substitution. | (Triyanto, et al., 2024) |

### **4. CHEMICAL QUALITY OF SAUSAGES WITH THE ADDITION OF VARIOUS TYPES OF LIVER**

#### **4.1 Chicken Liver**

The study by Nacak et al. (2023) showed that sausages with 75% chicken liver substitution had lower protein content. At a 25% substitution level, the protein content was approximately 17.29%; at 50%, it was 17.01%; and at 75%, it decreased to 16.84%. Research by Seo et al. (2015) explored various substitutions in sausage production to enhance nutritional value and quality. Replacing pork with corn starch, chicken breast, and surimi was found to increase protein content. Sausages with higher water content compared to other substitution levels also showed higher pH values, both in raw and cooked conditions. According to Dourou et al. (2021), the pH of fresh chicken liver is 6.60; therefore, an increase in the ratio of liver inclusion tends to raise the overall pH.

#### **4.2 Pork Liver**

In a study by Pacheco et al. (2024), the addition of pork liver to frankfurter sausages significantly increased key micronutrient levels, especially iron. The iron content increased progressively with liver addition: from 2.8 mg in the control group to 3.5 mg with 4% liver, 5 mg with 8% liver, and up to 20% with 12% pork liver. This is attributed to the high iron content of pork liver, which contains about 96 µg/100 g of iron and significant amounts of zinc (Alsina & Saguer, 2023). Srebernich et al. (2017) also reported an increase in iron and zinc content from 1.65 to 4.17 mg/100 g and from 1.92 to 3.80 mg/100 g, respectively.

The addition of pork liver also increased vitamin A levels in frankfurter sausages. The control group had 60 µg of vitamin A, which rose to 300 µg with 4% liver, 600 µg with 8%, and 1,188 µg with 12%. Organs like the liver are known to have far higher vitamin A content than muscle tissues, with pork liver containing approximately 57,406.68 μg RE/100 g. Pork liver also has higher vitamin A content than beef and lamb liver. Zinc content also increased with pork liver addition: from 1.6 mg in the control to 3.0 mg at 4%, 6.0 mg at 8%, and 11.1 mg at 12% substitution.

#### **4.3 Goat Liver**

According to Triyannanto et al. (2024), the iron content in goat meat sausages substituted with goat liver showed a significant increase. Goat liver contains a high level of minerals, particularly iron (Srebernich et al., 2015). The iron content in goat liver (7.78 mg/g; Tomović et al., 2017) is substantially higher than in goat meat (3.2 mg/300 g; Srebernich et al., 2015). The high iron level in the liver contributes directly to the elevated iron levels in the final sausage product.

Substitution of goat meat with goat liver at different ratios also led to significant changes in pH. A higher substitution level resulted in increased pH values of the sausages. According to Soeparno (2015), the pH of sausage ingredients significantly affects the final product. Goat liver has a pH of 6.5–6.6, which is higher than the pH of goat meat (5.3–5.8), leading to an increase in the pH of sausages as liver content rises. Laksmi (2012) also stated that the pH of raw materials influences the final sausage pH. In a study by Massingue et al. (2018), the pH of goat sausages ranged from 6.30 to 6.46.

**Table 2. Chemical quality of sausages with the addition of various types of liver**

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| --- | --- | --- | --- | --- |
| Types of Liver Addition | Formulation of Liver Addition | Physical Quality of Sausages | Effect of Addition | Source |
| Chicken Liver | Substitution of chicken liver in chicken-based sausages at levels of 25%, 50%, and 75%. | Protein ranges from 16.48 to 17.29% pH ranges from 6.24 to 6.61 Fat content ranges from 19.82 to 20.80% Ash content ranges from 2.61 to 2.80% | A 75% substitution resulted in a lower protein content of 16.48%. The ash content at this substitution level was 2.80%. The fat content for the 75% substitution was 20.80%. | Nacak (2023) |
| Pork Liver | Substitution of pork liver in pork-based sausages at levels of 4%, 8%, and 12%. | Protein: 16.6–17.8% Ash content: 2.0–2.5% Fat: 2.5–2.7% Iron: 20–130.4 μg per 100 g | The 12% substitution had the highest protein content. Fat and ash contents were lowest at the 8% substitution level. | (Pacheco, et al., 2024) |
| Goat Liver | Substitution of goat liver in goat meat sausages at ratios of 25% and 50%. | Protein 20.89–20.9% Fat 4.59–4.79% Collagen 2.35–2.48% Iron content 30.51–32.89 mg/100g | 25% substitution increases fat and protein. 50% substitution increases collagen and iron content. | (Triyananto, et al., 2024) |

5. Conclusion

The incorporation of chicken, pork, and goat liver significantly influences the physical and chemical properties of sausages. Substituting chicken liver up to 50% maintains emulsion stability and water-holding capacity, whereas a 75% substitution reduces emulsion quality and protein content. In pork-based sausages, increasing the proportion of pork liver enhances the levels of iron, vitamin A, and zinc, though it may negatively affect texture and color. Goat liver substitution improves protein, fat, collagen, iron content, and water-holding capacity, resulting in a softer texture. Therefore, optimizing the liver substitution ratio is essential to balance nutritional enhancement with acceptable physical quality. Moderate liver inclusion levels (≤50% for chicken/goat liver, ≤8% for pork liver) can improve the nutritional profile without compromising texture, flavor, or overall consumer acceptance.

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**REFERENCES**

Word Health Organization (WHO). 2023. Micronutrents. Retrivied from WHO Website <https://www.who.int/helath-topics/micronutrient>.

Hoffman, R. 2017. Micronutrient deficiencies in the elderly–could ready meals be part of the solution? *Journal of Nutritional Science* 6: e2

## Sadakuzzaman, M., Hossain, M. A., Rahman, M. M., Azad, M.A.K., Hossain, M. M, Ali, M. S. *et al*. (2021). Combined effect of irridiation and butylated hydroxyanisol on shelf life and quality of beef ata ambient temperature. *Meat Reseach*, 1(3).

## Falowo, A. B., Muchenje, V., & Hugo, A. (2017). Effect of sous-vide technique on fatty acid and mineral compositions of beef and liver from Bonsmara and non-descript cattle. *Annals of Animal Science*, *17*(2), 565.

Ku, S. K., Kim, J., Kim, S. M., Yong, H. I., Kim, B. K., & Choi, Y. S. (2022). Combined effects of pressure cooking and enzyme treatment to enhance the digestibility and physicochemical properties of spreadable liver sausage. *Food Science of Animal Resources*, 42(3), 441.

## Aathithya. 2024. Functional Foods and its Role in Human Health- A Riview. *Comfin Research,*12(2), 29-34

Barik, M., Chowdhury, S., & Tewari, S. (2022). Preventive and therapeutic role of functional foods: A review. *International Journal of Food and Nutrition Science*, *11*(7), 361-371

Anil, P., Nitin, K., Kumar, S., Kumari, A., & Chhikara, N. (2022). Food function and health benefits of functional foods. *Functional foods*, 419-441. <https://doi.org/10.1002/9781119776345.ch12>.

Lonergan, S. M., Topel, D. G., & Marple, D. N. 2019. Sausage processing and production. The science of animal growth and meat technology, 14(229), 229-53.

Park, J. W., & Kim, H. Y. (2020). Consumer acceptance and sensory evaluation of liver-based meat products: A review. Food Quality and Preference, 83, 103910.

Rosida D. F., Sarofa, U., & Dewi, R. C. (2015). Karakteristik Fisiko Kimia Sosis Ayam dengan Penggunaan Konsentrat Protein Biji Lamtoro Gung (Leucaena leucocephala) sebagai Emulsifier. Jurnal Teknologi Pangan, 9 (1). <https://doi.org/10.33005/jtp.v9i1.465>

Carballo, J. (2021). Sausage: Nutrition, safety, Processing and Quality improvement. Foods. 10(4). 890, <https://doi.org/10.3390/foods10040890>

Ismanto, A., Lestyanto, D. P., Haris, M. I., & Erwanto, Y. (2020). Komposisi kimia, karakteristik fisik, dan organoleptik sosis ayam dengan penambahan karagenan dan enzim transglutaminase. Sains Peternakan: Jurnal Penelitian Ilmu Peternakan, 18(1), 73-80. <https://doi.org/10.20961/sainspet.v18il.27974>

Amertaningtyas, D., Evanuarini, H., & Apriliyani, M. W. (2021). Kualitas nugget hati dengan perbedaan jenis hati dan cara pemasakan. Prosiding Seminar Nasional Teknologi Agribisnis Peternakan (STAP), 8, 454–459.

Alsina, N. F. and Saguer, E. 2023. Microbial Quality and Physicochemical Characteristic of Pork Livers Supllied by an Industrial Slaughterhouse. *Polish Journal of Food and Nutrition Science*, 73(2), 130-138. <https://doi.org/10.31883/pjfns/12874>

Kabata-Pendias, A., & Szteke, B. (2012). Trace elements in geoand biosphere. Pulawy: IUNG-PIB [In Polish].

Steen, L., Glorieux, S., Goemaere, O., Brijs, K., Paelinck, *et al.* (2016). Functional properties of pork liver protein fractions. Food and Bioprocess Technology, *9*, 970-980.

Babicz, M., Kasprzyk, A., & Kropiwiec-Domańska, K. (2019). Influence of the sex and type of tissue on the basic chemical composition and the content of minerals in the sirloin and offal of fattener pigs. Canadian Journal of Animal Science, 99(2), 343–348. <https://doi.org/10.1139/cjas-2018-0085>

Listrat, A., Lebret, B., Louveau, I., Astruc, T., Bonnet, M., Lefaucheur, *et al.* (2016). How muscle structure and composition influence meat and flesh quality. *The Scientific World Journal*, *2016*(1), 3182746

**IndexBox.** (2023). Frozen poultry liver market: Global analysis and forecast to 2030.

## Wibisono, H. H., Aries, M., & Nasution, Z. (2023). Formulation of Chicken Nuggets with the Addition of Chicken Liver as a Product Rich in Iron and Vitamin A for Adolescent Females. Jurnal Gizi dan Pangan, 18 (1), 52-54. [https://doi.org/10.25182/jgp.2023.18](https://doi.org/10.25182/jgp.2023.18.)

**Wibisono, D. A., Subroto, M. A., & Nugroho, Y.** (2023). Kandungan gizi dan potensi hati ayam sebagai sumber protein hewani. Jurnal Gizi dan Pangan, 30(2), 120-126

Nacak, B. (2023). Effects of replacing chicken meat with chicken liver on some quality characteristics of model system chicken meat emulsions. Meat Technology, 64(2), 438–442. <https://doi.org/10.18485/meattech.2023.64.2.84>

Seong, P. N., Cho, S. H., Park, K. M., Kang, G. H., Park, B. Y., *et al*. (2015). Characterization of chicken by-products by mean of proximate and nutritional compositions. Korean journal for food science of animal resources, *35*(2), 179.

Mehmood, L., Mujahid, S. A., Asghar, S., Rahman, H. U., & Khalid, N. (2024). Formulation and Quality Evaluation of Chicken Nuggets Supplemented with Beef and Chicken Livers. Food Science of Animal Resources, 44(3), 620–634.

Kakimov, A., Suychinov, A., Tsoy, A., Mustambayev, N., Ibragimov, N., Kuderinova, N., *et al.* (2018). Nutritive and biological value of liver and blood of various slaughtered animals. Journal of Pharmaceutical Research International, 22(3), 1–5. <https://doi.org/10.9734/JPRI/2018/41448>

## Choi, Y. S., Ku, S. K., Lee, H. J., Park, J. D., Sung, J. M. *et al*. (2017). Effects of Pork Liver Levels on The Quality Characteristics on Hamburger Patties. Korean journal of food and cookery science, *33*(1), 20-27.

Tomović, V. M., Jokanović, M. R., Pihler, I. I., Švarc-Gajić, J. V., Vasiljević, I. M. *et al*. (2017). Ultimate pH, colour characteristics and proximate and mineral composition of edible organs, glands and kidney fat from Saanen goat male kids. *Journal of Applied Animal Research*, *45*(1), 430-436.

Triyannanto, E. Physicochemical and Sensory Properties of Goat Meat Sausages Prepared with Different Levels of Goat Liver. *Buletin Peternakan*, *48*(4), 278-283.

Khalid, N., Mehmood, L., Asghar, S., Ubaid Ur Rahman, H., & Mujahid, S. A. (2024). Formulation of chicken nuggets supplemented with mutton and fish livers: Insights from antioxidant and textural studies. Preventive Nutrition and Food Science, 29(1), 70–77. <https://doi.org/10.3746/pnf.2024.29.1.70>.

Busari, Y. O., Bello, L. A., Daramola, O. E. and Lajide, L. 2019. Proximate Composition and Mineral Analysis of Goat’s Liver, Cow’s Pancreas and Their Meat Stock. *International Journal of Recent Innovation in Food Science & Nutrition*. 2(1). 12-20

Tamnak, S., Mirshosseini, H., Tan, C. P., Ghazali, H. M., & Muhammmad, K. (2016). Physicochemical Properties, Rheological Behavior and Morphology of Pectin-Pea Protein Isolate Mixture and Conjugates in Aqueous System and Oil in Water Emulsion. *Food Hydocolloid*, 56, 405-41. <https://doi.org/10.1016/j.foodhyb.2015.12.033>.

Afshari, R., Hosseini, H., Mousavi, K, A., & Khaksar, R. (2017). Physico-chemical Properties of Functional Low-fat Beef Burgers: Fatty Acid Profile Modification. LWT-*Food Science and Technology*, 78, 325-331, <https://doi.org/10.1016/j.lwt.2016.12.064>

Serdaroğlu, M., Kavuşan, H. S., İpek, G. & Öztürk, B. (2018). Evaluation of the quality of beef patties formulat‑ed with dried pumpkin pulp and seed. Korean Journal for Food Science of Animal Resources, 38(1), 3–13, <https://doi.org/10.5851/kosfa.2018.38.1.001>

Permatasari, N., Angkasa, D., Dhyani, P., Melani, V. & Purwara, L. (2020). Pengembangan Biskuit MPASI Tinggi Besi dan Seng dari tepung Kacang Tunggak (*Vignia unguiculata L.)* dan Hati Ayam. *Jurnal Pangan dan Gizi*, 10(02), 33-38

Zhang, W., Zhang, Y., He, Y., Xu, X. & Zhao, X. 2024. Oil Density and Viscosity Affect Emulsion Stability and Destabilization Mechanism. Jurnal of Food Enginering*,* 366,1-11. <https://doi.org/10.1016/j.jfoodeng.2023.111864>.

Alsina, N. F., &Saguer, E. (2023). Microbial Quality and Physicochemical Characteristic of Pork Livers Supllied by an Industrial Slaughterhouse. *Polish Journal of Food and Nutrition Science*, 73(2), 130-138. <https://doi.org/10.31883/pjfns/12874>

Peñuñuri-Pacheco, N., González-Ríos, H., Jara-Marini, M. E., Astiazarán-García, H., Tortoledo-Ortiz, O., *et al*. 2024. Quality of frankfurter-type sausage with added pork liver as source of retinol and minerals.International Food Research Journal, 31(6), 149-1662.

Chen, X., Tume, R. K., Xu, X., & Zhou, G. (2017). Solubilization of myofibrillar proteins in water or low ionic strength media: Classical techniques, basic principles, and novel functionalities. Critical Reviews in Food Science and Nutrition, *57*(15), 3260-3280. <https://doi.org/10.1080/10408398.2015.1110111>

Suman, S. P. and Joseph, P. 2013. Myoglobin chemistry and meat color. Annual Review of Food Science and Technology 4: 79-99.

Petrášová, M., Král, M., Pospiech, M., Halamová, P., Tremlová, B., & Walczycka, M. (2019). Pork protein addition effect on structural and qualitative parameters of frankfurter‐type sausage. *Journal of the Science of Food and Agriculture*, *99*(4), 1888-1897. <https://doi.org/10.1002/jsfa.9348>.

Zajác, P., Čurlej, J., Barnová, M., & Čapla, J. (2015). Analysis of Texturometric Properties of Selected Traditional and Commercial Sausages. *Slovak Journal of Food Science s/Potravinarstvo*, *9*(1). 485-467. <https://doi.org/10.5219/473>

Feng, C. H., Li, C., García‐Martín, J. F., Malakar, P. K., Yan, Y., Liu, Y. W., et al. 2017. Physical Properties and Volatile Composition Changes of Cooked Sausages Stuffed in a New Casing Formulation Based in Surfactants and Lactic Acid During Long‐Term Storage. *Journal of Food Science*, *82*(3), 594-604. <https://doi.org/10.1111/1750-3841.1341>

Kluth, I. K., Teuteberg, V., Ploetz, M., & Krischek, C. (2021). Effects of freezing temperatures and storage times on the quality and safety of raw turkey meat and sausage products. *Poultry science*, *100*(9), 101305.

Triyannanto, E. (2024). Physicochemical and Sensory Properties of Goat Meat Sausages Prepared with Different Levels of Goat Liver. *Buletin Peternakan*, *48*(4), 278-283. <https://doi.org/10.21059/buletinpeternak.v48i4.97221>

Apriantini, A., Afriadi, D., Febriyani, N., & Arief I. I. (2021). Fisikokimia, Mikrobiologi dan Organoleptik Sosis Daging Sapi dengan Penambahan Tepung Biji Durian (*Durio zibethinusMurr*). Jurnal Ilmu Produksi dan Teknologi Hasil Peternakan. 9(2): 79 -88.

Setiaboma, W., Irawansyha, A. C., Desnilasari, D., Putri, D. P., Agustina, W., Sholichah, E. *et al.* (2021. Karakterisasi Kimia dan Uji Organoleptik Bakso Ikan Manyung (*Arius thalassinuss, Ruppell*) dengan Penambahan Daun Kelor (*Moringa oleifereaLam*) Segar dan Kukus. *JBI BIOPROPAL Industri*. 12(1): 9-18

Soeparno. 2015. Ilmu dan Teknologi Daging Edisi Kedua. Gadjah Mada University Press. Yogyakarta

Rompis, J. E. G., & Londok, J. J. M. R. (2022). Bahan Pengikat dan Bahan Pengisi Sosis Daging Sapi. CV Patra Media Grafindo Bandung: Bandung

Purwosari, A. G., Afifah, C. A. N. 2016. Pengaruh Penggunaan Jenis dan Jumlah Bahan Pengisi terhadap Hasil Jadi Sosis Ikan Gabus (*Channa striata*). *E-journal Boga*. 5(1): 211-228

Sofyan, R., Mulyani, S., & Yulifianti, R. (2018). Effect of filler concentration and sodium tripolyphosphate (Na₅P₃O₁₀) on the characteristics of white oyster mushroom (Pleurotus ostreatus) sausage. Jurnal Teknologi dan Industri Pertanian Indonesia, 10(1), 22–28. <https://doi.org/10.23969/pftj.v5i1.807>

Seo, H. W., Kang, G. H., Cho, S. H., Van Ba, H., & Seong, P. N. (2015). Quality properties of sausages made with replacement of pork with corn starch, chicken breast and surimi during refrigerated storage. *Korean Journal for Food Science of Animal Resources*, *35*(5), 638. <https://doi.org/10.5851/kosfa.2015.35.5.638>.

Dourou, D., Grounta, A., Argyri, A. A., Froutis, G., Tsakanikas, *et al.* (2021). Rapid Micro‑bial Quality Assessment of Chicken Liver Inoculated or Not with *Salmonella* Using FTIR Spectroscopy and Machine Learning*. Frontiers in Microbiology*, 11, <https://doi.org/10.3389/fmicb.2020.623788>

Srebernich, S. M., Silveira, E. T. F., Goncalves, R. D. C., Ormenese, S. C., &Morgano, M. A. 2015. Development and Evaluation of Iron-Rich Meatloaves Containing Pork Liver for Schoolchildren. *Food Science and Technology (Brazil),* 35(3): 460-467.

Laksmi, R. T. 2012. Daya Ikat Air, pH, dan Sifat Organoleptik Chicken Nugget yang Disubstitusi dengan Telur Rebus. *Indonesia Jurnal of Food Technology*. 1(1): 69-77

Massingue, A. A., Torres Filho, R. D. A., Fontes, P. R., Ramos, A. D. L. S., Fontes, E. A. F., Olalquiaga Perez, J. R., & Ramos, E. M. (2018). Effect of mechanically deboned poultry meat content on technological properties and sensory characteristics of lamb and mutton sausages. Asian-Australasian Journal of Animal Sciences, 31(4), 576–584. <https://doi.org/10.5713/ajas.17.0471>