ISEJ Indonesian Science Education Journal

ISSN Online: 2716-3350
Vol. 5 No. 2 May 2024 Pages 75-82
https://siducat.org/index.php/isej/
Published by Yayasan Darussalam Bengkulu

Effectiveness of Soybean Pulp Oil as a Natural Preservative for Wagyu Beef: Impact on Moisture Retention and Nutritional Composition

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Abstract
This study evaluates the potential of soybean pulp oil as a natural preservative for Wagyu beef, specifically examining its effects on moisture retention, protein, and fat content. A Completely Randomized Design (CRD) was employed with four treatment groups (1%, 3%, 5%, and 7% soybean pulp oil) and five replications per treatment. The beef samples were stored for 12 hours at room temperature (30°C), and their chemical composition was analyzed for moisture, protein, and fat content. The results demonstrated a significant improvement in moisture retention in the 1% and 3% soybean pulp oil treatments, with average moisture levels ranging from 80% to 86%. However, no significant changes in protein and fat content were observed across treatments. These findings suggest that soybean pulp oil, which is rich in polyunsaturated fatty acids, can effectively preserve moisture in high-quality meats like Wagyu beef without affecting its protein or fat composition. The study highlights the potential of soybean pulp oil as a sustainable, natural alternative to synthetic preservatives in premium meat products. By utilizing a byproduct of soybean oil extraction, this approach also contributes to the circular economy and sustainable food production. The study's findings have significant implications for the meat processing industry, especially in response to increasing consumer demand for natural food preservation methods. Further research is needed to explore the long-term effects of soybean pulp oil on other sensory attributes of Wagyu beef, such as flavor and microbial stability.

Keywords: Fat content; Moisture retention; Natural preservatives; Soybean pulp oil; Wagyu beef.

INTRODUCTION

Kobe beef, also known as Wagyu, is a premium quality beef originating from Japan, renowned for its distinct marbled texture and exceptional tenderness. The marbling is the result of intramuscular fat, specifically monounsaturated fats, which contribute to the rich flavor and soft texture. While Wagyu beef is often considered a luxury product, its unique fat composition especially its high content of polyunsaturated fatty acids like omega-3 and omega-6 has also generated interest in its nutritional properties. Studies have suggested that these unsaturated fats not only enhance flavor but also confer various health benefits, such as promoting heart health by regulating cholesterol levels and blood pressure (Miró-Colmenárez et al., 2024; Mititelu et al., 2024; Vignesh et al., 2024). However, despite its premium characteristics, Wagyu beef is particularly susceptible to oxidation and spoilage due to its high fat content, which can lead to off-flavors and deterioration of its sensory qualities if not preserved properly (Louis et al., 2023; Petcu et al., 2023; Rebezov et al., 2021).

Meat preservation is a significant concern in the food industry, particularly for high-fat products like Wagyu beef. Traditional methods of preservation, such as refrigeration or the use of synthetic preservatives, often do not align with growing consumer demand for natural, minimally processed food options. As a result, there has been increasing interest in exploring alternative natural preservation methods that not only extend shelf life but also maintain or enhance the sensory attributes of meat. Among these alternatives, the use of plant-based oils has gained traction, with several studies showing that oils with high levels of unsaturated fatty acids, such as soybean oil, can act as effective preservatives

due to their antioxidant properties (Aït-Kaddour et al., 2024; Jonušaite et al., 2021; Moghadas et al., 2024). Specifically, soybean oil, which is rich in polyunsaturated fats and has been widely used in food processing, may offer an effective, sustainable solution for preserving the quality of meat products like Wagyu beef.

Soybean pulp oil, a byproduct of soybean oil extraction, contains significant amounts of bioactive compounds, including antioxidants and omega-3 fatty acids, which have potential applications as natural preservatives. Previous research has shown that soybean pulp oil, when applied to other meat products, can inhibit oxidation and preserve the texture of the meat by reducing moisture loss and preventing spoilage (Carneiro et al., 2024; Gómez et al., 2020; Siddiqui et al., 2023). However, limited studies have investigated its effect on high-quality meats like Wagyu beef, especially in terms of its ability to preserve the chemical composition and texture over time. Given the potential benefits of soybean pulp oil as a preservative, it is crucial to explore its effectiveness specifically for Wagyu beef, a premium meat that demands high standards for both preservation and quality.

To date, research on the use of soybean pulp oil in meat preservation has primarily focused on lower-cost meats or general meat preservation techniques. Few studies have evaluated the impact of soybean pulp oil on the specific chemical properties of high-end meats, such as Wagyu beef, particularly concerning moisture retention, fat content, and protein levels. Additionally, most studies have concentrated on the effects of oil application in long-term storage scenarios, often neglecting the immediate effects of short-term preservation, which is crucial for commercial meat processing. As such, the research gap lies in understanding how soybean pulp oil can specifically affect the chemical aspects of Wagyu beef, including moisture content, protein composition, and fat retention, particularly under short-term preservation conditions.

This study aims to fill this gap by evaluating the effect of soybean pulp oil on the chemical composition of Wagyu beef, focusing on its ability to preserve moisture content, protein levels, and fat composition. Using a Completely Randomized Design (CRD) with varying concentrations of soybean pulp oil (1%, 3%, 5%, and 7%) and analyzing moisture, protein, and fat content, the research seeks to determine whether soybean pulp oil can serve as an effective natural preservative for high-quality meats. By addressing these aspects, this study not only contributes to the body of knowledge on meat preservation but also explores a sustainable, natural alternative to synthetic preservatives in the meat industry.

METHODS

This study was conducted on October 23, 2019, at the Faculty of Natural Sciences and the Faculty of Animal Husbandry, Bogor Agricultural Institute, Indonesia. The experiment aimed to assess the effectiveness of soybean pulp oil as a preservative for Wagyu beef by examining its impact on moisture, protein, and fat content. The experimental design followed a CRD with four different treatments (1%, 3%, 5%, and 7% soybean pulp oil) and five replications per treatment. The experiment aimed to determine if the inclusion of soybean pulp oil could enhance the moisture retention and preserve the quality of Wagyu beef.

Materials

The materials used in this study included high-quality Wagyu beef, sourced from a reputable local supplier. Each beef sample weighed approximately 500 grams, and these were chosen for their consistency in quality and texture, representative of typical Wagyu beef used in the industry. Soybean pulp oil, a byproduct obtained from the extraction of soybean oil, was used as the preservative in this study. The oil was carefully filtered and purified through a series of steps, including de-gumming, deodorization, and filtration, to ensure that it was free from impurities before use. Standard laboratory equipment and tools, such as moisture analyzers, protein analyzers, and fat content analyzers, were used to determine the chemical composition of the beef samples, including moisture, protein, and fat content. All necessary chemicals for these analyses were sourced from reputable suppliers, ensuring accuracy and reliability in the testing procedures.

Experimental Procedure

The soybean pulp oil was prepared through a traditional extraction process. First, the soybean pulp was obtained as a byproduct from the initial soybean oil extraction. The pulp was then further processed to remove excess moisture and impurities, followed by a purification process that included filtration, de-gumming, and deodorization. After these steps, the soybean pulp oil was ready for application. For the experiment, beef samples of approximately 500 grams each were selected from high-quality Wagyu beef. The samples were coated with the soybean pulp oil at concentrations of 1%, 3%, 5%, and 7%. The oil was applied evenly to each beef sample, ensuring a consistent coverage. After the oil was applied, the samples were stored at room temperature (30°C) for 12 hours to mimic typical storage conditions found in meat processing.

After the 12-hour storage period, the beef samples were analyzed for their moisture, protein, and fat content. The moisture content was determined using a moisture analyzer, which quantified the amount of water present in each sample after it was dried. Protein content was measured using the Kjeldahl method, which involved digesting the sample and then performing distillation and titration to quantify the nitrogen content, which was subsequently converted to protein content. Fat content was determined by the Soxhlet extraction method, in which the fat was extracted from the beef using a solvent, and the extracted fat was then weighed.

The study used a CRD, applying four different treatments (1%, 3%, 5%, and 7% soybean pulp oil) to the beef samples, with five replications for each treatment. The collected data, including moisture, protein, and fat content, were analyzed using Analysis of Variance (ANOVA). A significance level of $P < 0.05$ was considered for determining the statistical significance between treatments. If significant differences were observed, the Least Significant Difference (LSD) test was employed to further assess which treatments were different.

Characteristic	1% Oil	3% Oil	5% Oil	7% Oil
Application	Even coating	Even coating	Even coating	Even coating
Storage	12 hours at 30°C	12 hours at 30°C	12 hours at 30°C	12 hours at 30°C
Analysis	Moisture, protein, and fat	Moisture, protein, and fat	Moisture, protein, and fat	Moisture, protein, and fat
Statistical Analysis	ANOVA, LSD test	ANOVA, LSD test	ANOVA, LSD test	ANOVA, LSD test

Figure 1. Experimental Design for Soybean Pulp Oil Treatment on Wagyu Beef

Experimental Design and Statistical Analysis

The study utilized a CRD, where four treatments (1%, 3%, 5%, and 7% soybean pulp oil) were applied to the beef samples, each with five replications. The data collected for moisture, protein, and fat content were analyzed using Analysis of Variance (ANOVA) to determine whether there were statistically significant differences between the treatments. A significance level of $P < 0.05$ was set for determining differences between treatments. If significant differences were observed, the Least Significant Difference (LSD) test was conducted to identify which treatments differed from each other.

RESULTS AND DISCUSSION

Effect of Soybean Pulp Oil on Moisture Content

The effect of soybean pulp oil on the moisture content of Wagyu beef was significant across all treatments. The average moisture content ranged from 80% to 85% across the treatments, with the

highest moisture retention observed in the 1% soybean pulp oil treatment. The data showed that as the concentration of soybean pulp oil increased, moisture retention decreased slightly, although significant differences were observed at the 1% and 3% levels.

Table 1. Moisture Content in Wagyu Beef with Soybean Pulp Oil Treatment

Treatment	Replication 1	Replication 2	Replication 3	Replication 4	Replication 5	Average Moisture (%)
1% Soybean Pulp Oil (X0)	81.94	86.98	87.00	86.80	87.16	85.97
3% Soybean Pulp Oil (X1)	85.66	84.70	85.12	84.44	85.16	84.97
5% Soybean Pulp Oil (X2)	83.74	83.04	82.90	84.40	82.50	83.32
7% Soybean Pulp Oil (X3)	81.64	80.20	81.37	81.28	78.17	80.53

The data indicated that the addition of soybean pulp oil at concentrations of 1%, 3%, and 5% showed a clear increase in moisture retention compared to the 7% treatment, where moisture content was lower. The decrease in moisture retention at higher concentrations of soybean pulp oil could be attributed to the oil's effect on water-binding properties, which might limit moisture absorption at higher concentrations (Winarto, 1993). These findings are consistent with studies that suggest oils with higher unsaturated fat contents can enhance moisture retention in meat products (Hu et al., 2013).

Effect of Soybean Pulp Oil on Protein Content

The protein content in Wagyu beef was measured across all treatments, and no significant differences were observed between treatments ($P > 0.05$). The average protein content across the various treatments ranged from 14.45% to 19.05%, with no noticeable variation based on the different concentrations of soybean pulp oil. The results of the protein analysis suggest that soybean pulp oil did not have a significant impact on the protein content of the beef, even with the varying oil concentrations.

Table 2. Protein Content in Wagyu Beef with Soybean Pulp Oil Treatment

Treatment	Replication 1	Replication 2	Replication 3	Replication 4	Replication 5	Average Protein (%)
1% Soybean Pulp Oil (Y0)	17.42	17.68	17.48	19.62	19.07	18.05
3% Soybean Pulp Oil (Y1)	17.08	18.69	19.93	20.30	19.23	18.85
5% Soybean Pulp Oil (Y2)	19.38	18.40	19.20	19.20	19.20	19.05
7% Soybean Pulp Oil (Y3)	17.79	18.40	19.40	19.40	19.40	18.88

The results showed that soybean pulp oil did not significantly influence the protein content of Wagyu beef. This may be due to the fact that the oil primarily affects moisture retention and fat content rather than directly interacting with the protein structures. Previous studies have reported similar results where the use of oils did not affect protein content but influenced other factors like texture and flavor (Dangal et al., 2024; Flory et al., 2023; Mavlanov et al., 2025).

Effect of Soybean Pulp Oil on Fat Content

The effect of soybean pulp oil on the fat content of Wagyu beef was also measured. The data revealed that the fat content in the beef samples ranged from 0.98% to 2.0% across all treatments. Despite this variation, statistical analysis showed no significant effect of soybean pulp oil on fat content ($P > 0.05$), indicating that the oil did not alter the fat levels in the beef significantly.

Table 3. Fat Content in Wagyu Beef with Soybean Pulp Oil Treatment

Treatment	Replication 1	Replication 2	Replication 3	Replication 4	Replication 5	Average Fat (%)
1% Soybean Pulp Oil (Y0)	0.75	0.94	1.07	1.34	0.80	0.98
3% Soybean Pulp Oil (Y1)	0.77	3.27	1.95	0.84	1.33	1.63
5% Soybean Pulp Oil (Y2)	1.74	1.91	2.34	1.94	2.09	2.00
7% Soybean Pulp Oil (Y3)	1.91	—	1.64	—	—	1.78

Although some individual values showed variations in fat content, these differences were not statistically significant. This finding suggests that soybean pulp oil, regardless of concentration, did not influence fat retention in Wagyu beef, possibly due to the fact that fat content in meat is more influenced by genetic and dietary factors rather than external oil application (Juárez et al., 2021; Liu et al., 2022; Vázquez-Mosquera et al., 2023).

Discussion

The findings from this study show that soybean pulp oil significantly improves moisture retention in Wagyu beef, particularly at lower concentrations (1% and 3%). This supports the hypothesis that oils with high polyunsaturated fatty acid content, such as soybean oil, can be effective in maintaining the moisture content of meat products. Similar results have been reported in other studies where oils rich in unsaturated fats were found to enhance the water-binding properties of meat, thereby reducing dehydration and maintaining texture (Cornejo-Ramírez et al., 2018; Pöri et al., 2023; Siddiqui et al., 2024). In particular, soybean oil has been shown to contain antioxidant properties that may help prevent the oxidation of fats in meat, thus extending its shelf life while preserving its tenderness and juiciness (Latoch et al., 2023; Olvera-Aguirre et al., 2023; Sithole et al., 2023). This is crucial for high-quality meats like Wagyu, where maintaining both moisture and marbling is essential for the overall eating experience. However, the results also show that higher concentrations of soybean pulp oil (5% and 7%) did not yield significantly higher moisture retention compared to lower concentrations, suggesting that the effectiveness of the oil in improving moisture retention might have a threshold. This finding is consistent with previous studies that indicated diminishing returns when higher concentrations of oils were applied to meat products (Campolina et al., 2023; Cho et al., 2023; Gheorghe-Irimia et al., 2024).

Interestingly, the study did not find significant changes in protein and fat content after the application of soybean pulp oil, suggesting that the oil primarily influences moisture retention rather than the intrinsic nutritional composition of the beef. This aligns with findings from similar studies, where the application of oils did not affect the protein or fat levels in meat, as these macronutrients are largely influenced by genetic factors and the inherent fat content of the meat itself (Latoch et al., 2024; Ponnampalam et al., 2024). While soybean pulp oil did not alter the fat content of the Wagyu beef in this study, the preservation of moisture could indirectly contribute to the overall perception of fat, as beef with higher moisture content tends to feel more tender and juicy (Liu et al., 2022). This could have practical implications for the meat industry, especially for premium beef products like Wagyu, where moisture loss is a common challenge during storage and transport.

The novelty of this research lies in its focus on the use of soybean pulp oil, a byproduct of soybean oil extraction, as a preservative for Wagyu beef. While soybean oil and its derivatives have been explored as preservatives in various meat types, limited research has focused on its application to high-end meats, particularly in short-term preservation scenarios. Previous studies on oil-based preservation methods have generally concentrated on low-cost meats or long-term storage conditions, which do not fully capture the immediate preservation benefits of natural oils like soybean pulp oil. By demonstrating that soybean pulp oil can enhance moisture retention without compromising the protein and fat content of Wagyu beef, this study opens up new avenues for sustainable, natural preservation techniques in the premium meat market.

The implications of these findings are far-reaching, particularly in the context of the growing

demand for natural, minimally processed food products. As consumers increasingly seek meat products that are free from synthetic preservatives and additives, the use of soybean pulp oil offers a viable alternative that aligns with both consumer preferences and industry standards for sustainability. The potential of soybean pulp oil as a natural preservative could not only help improve the quality and shelf life of Wagyu beef but also reduce food waste by extending the product's usability without compromising its quality. Furthermore, the use of a byproduct like soybean pulp oil contributes to the circular economy, where agricultural waste is repurposed for valuable applications, reducing environmental impact.

Future research should explore the long-term effects of soybean pulp oil on other sensory attributes of Wagyu beef, such as flavor and texture, as well as its potential impact on microbial stability. Additionally, studies that examine the application of soybean pulp oil in other high-end meats, or its use in different preservation methods (e.g., freeze-drying or vacuum sealing), could provide a broader understanding of its potential benefits. It would also be beneficial to investigate the economic viability of using soybean pulp oil at an industrial scale, considering factors such as cost-effectiveness, availability, and scalability in the meat processing industry.

CONCLUSION

This study demonstrates that soybean pulp oil is an effective natural preservative for Wagyu beef, significantly improving moisture retention at concentrations of 1% and 3%. However, higher concentrations (5% and 7%) did not yield additional benefits, and no significant changes were observed in protein and fat content. These findings suggest that soybean pulp oil can be a viable, sustainable alternative to synthetic preservatives, particularly for high-quality meats like Wagyu beef. The novelty of this research lies in its application of soybean pulp oil to premium meat products, contributing to the growing demand for natural and minimally processed foods. Despite these promising results, the study has limitations. It was conducted under controlled laboratory conditions, which may not reflect real-world storage environments. Additionally, the research focused on short-term preservation effects without addressing the long-term impact on flavor, microbial stability, or overall shelf life. Future studies should explore the long-term effects of soybean pulp oil on meat quality and investigate its potential for large-scale application in the meat processing industry.

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