DOI: https://doi.org/10.21323/2414-438X-2024-9-3-268-276
Received 02.04.2024
Accepted in revised 23.09.2024
Accepted for publication 26.09.2024

Available online at https://www.meatjournal.ru/jour
Original scientific article
Open Access

SENSORY TESTING AND QUALITY MAINTENANCE OF HAMBURGERS CONTAINING SOYBEAN MEAT

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Keywords: *consumer preference, food quality, meat substitute, soya protein, color and pH, viable bacteria count, peroxide content*

Abstract
In the past few years, lifestyle-related diseases have been increasing, and meat intake has been linked to this increase. Therefore, in recent years, there have been attempts to use soybeans as a substitute for meat. Soybeans exhibit antioxidant and antimicrobial effects. Therefore, processing foods using soybeans may preserve food quality because the main factors causing food deterioration are oxidation and microbial growth. To verify the quality-retention effect of soybeans, we conducted a sensory test on hamburgers, the quality of which readily deteriorates over time. We investigated the percentage of soybean meat that would be acceptable in a hamburger and quality retention with the addition of different amounts of soybean meat. We found that hamburgers with soybean meat were accepted by more than half of the participants when the soybean meat content was ≤50%. In terms of changes over time in quality-related factors, the L- and b-values (lightness/brightness and yellowness/blueness, respectively) were higher, a-value (redness/greenness) was lower, and pH was higher in hamburgers that contained soybean meat than in those without added soybean meat. Furthermore, an increase in the bacteria count and peroxide content was suppressed in hamburgers containing soybean meat. The results indicate that hamburgers containing soybean meat are of higher quality than those made with 100% animal meat. The use of soybeans as a meat substitute in hamburgers can help mitigate the rise of lifestyle-related diseases linked to high meat consumption.

For citation: Fujisawa, F., Seki, H. (2024). Sensory testing and quality maintenance of hamburgers containing soybean meat. *Theory and Practice of Meat Processing*, 9(2), 268-276. https://doi.org/10.21323/2414-438X-2024-9-3-268-276

Funding:
This research was funded by the Tokyo University of Technology Graduate Research Fund.

Acknowledgements:
We would like to thank the members of the Food Processing Laboratory in the School of Bioscience and Biotechnology, Tokyo University of Technology, for their support.

Introduction

Over the last few years, the number of cases of lifestyle-related diseases, such as obesity, cancer, and diabetes, has increased rapidly [1], becoming a social problem worldwide. According to the World Health Organization and 2012 World Health Statistics, lifestyle-related diseases accounted for 63% of global deaths or 36 million deaths in 2008, with a higher proportion of middle-aged and elderly people. By 2030, the number of deaths from lifestyle-related diseases is projected to increase to 55 million, including 13 million from cancer [2]. In addition, in the 2023 WHO report, the total number of global deaths from NCDs (non-communicable diseases, which include lifestyle-related diseases plus chronic obstructive pulmonary disease and mental health) is projected to reach 90 million by 2048 [3]. In 2024, the WHO reports that while many health risks due to smoking and poor sanitation have decreased in recent years, health risks associated with activities such as alcohol consumption and hypertension are very high, and the obesity epidemic shows no signs of recovery [4].

The increase in cancer incidence is closely related to dietary changes, and a strong association between increased animal protein intake and cancer risk has been reported [5]. In men, the relative risk of colon and colorectal cancer considerably increases with high meat intake [5], and the overall risk of developing colorectal cancer increased in those consuming red meat and processed meat [6]. Furthermore, the incidence of colorectal cancer has been reported to be higher in Hawaii and Los Angeles than in Miyazaki, Japan, where meat consumption is high [7].

In recent years, soybean, a vegetable with high protein content, has been attracting attention as an alternative to animal protein sources. Soybeans have approximately 0.41and 2.9 times higher fat and protein content, respectively, than beef [8], offering the advantage of efficient protein intake. Soybeans can be consumed as boiled beans, but they are often processed into various foods, with many being sold as processed products. Processed soybean-based products include natto (fermented soybeans), okara (bean curd), soymilk, and soybean meat. Among them, tofu and okara are widely consumed as processed soybean products, and they can be mixed with ground meat to prepare hamburgers with reduced animal protein content.

Okara tempeh (OT), a soybean product, has been shown to have high water retention, oil absorption, and antioxidant capacities, making it an excellent processed food material [9]. A previous study measured the peroxide content in cupcakes with and without OT stored at 40 °C. The absorbance value at 550 nm reflecting the peroxide content of cupcakes without the additive increased from 0.30 at week 0 to 1.0 at week 3, whereas that of cupcakes with OT increased from 0.30 at week 0 to 0.75 at week 3, indicating that OT inhibits fat and oil oxidation [9]. Given that ground meat has a high lipid content, food processing using soy products is expected to prevent lipid oxidation owing to the antioxidant effects of soy. Furthermore, a study investigated the minimum inhibitory concentration of ethanol extracts of different soybean powders for various bacteria. The inhibition zones of *Escherichia coli* were 3.16 and 9.33 mm upon treatment with extracts of black and yellow soybeans, respectively, whereas those of *Bacillus subtilis* were 7.16 and 10.0 mm, respectively [10], showing that the ethanol extract of yellow soybeans exerts a stronger antibacterial effect than that of black soybeans. In addition, when the antibacterial effects of soybean-derived saponin and chloramphenicol, an antibiotic, were measured on *E. coli*, the bacterial inhibition zone was 13.2 and 12.0 mm, respectively [11]. This finding demonstrated that for *E. coli*, the antibacterial effect of saponin extracted from soybeans is stronger than that of chloramphenicol and confirmed the antimicrobial property of soybeans. However, it has been reported that tofu and okara have a disadvantage as hamburger additives because hamburgers with these soybean products are whiter and smoother than those without them, resulting in the loss of the unique texture of meat [12]. Among processed soybean products, soybean meat, which has meat-like color and texture, can be added to hamburgers without changing their color or texture. Soybean meat is made of dried, processed soy protein [13] and can be used in a variety of dishes by tempering with water. The consumption of soybean meat in Japan has considerably increased from 23,560 tons in 2010 to 33,297 tons in 2019 [14], indicating a growing demand.

Soybeans contain several bioactive components, such as soy saponins, soy proteins, lecithin, and soy isoflavones; the latter, in particular, has many health-promoting effects [15]. Furthermore, as isoflavones are a type of polyphenol with antioxidant and antimicrobial effects [16], the production of hamburgers using soybean meat may preserve their quality without sacrificing flavor or texture.

Generally, food quality is evaluated based on physical, chemical, and biological factors, as well as sensory factors determined over time. However, the parameters that substantially affect food quality vary depending on the food type. Hamburgers are made by kneading, preparing, and baking ground meat. Although hamburgers are cooked, ground meat has a larger surface area exposed to air and is more likely to lose quality than steaks and grilled meat [17]. Parameters related to changes in meat quality include pH, oxidation, and microorganism count. Previous studies have reported that in raw beef slices, the pH increased from 5.91 on day 1 to 7.14 on day 18 [18], whereas in uncooked hamburger meat, it increased from 5.51 on day 1 to 7.11 on day 7 [19], demonstrating a faster pH increase in minced meat. It has also been reported that the disruption of muscle cell membranes during meat mincing accelerates the interaction between unsaturated fatty acids and oxidative substances, accelerating lipid oxidation and acidification [19]. Additionally, the content of 2-thiobarbituric acid reactive substances in beef steak reportedly increased from 0.130 mgMDA/kg on day 1 to 3.41 mgMDA/kg on day 16, whereas that in ground beef increased from 2.02 mgMDA/kg on day 1 to 6.91 mgMDA/kg on day 16 [17], indicating that lipid oxidation proceeds at a faster rate in ground beef than in steak meat. Furthermore, the microbial load in raw beef slices was found to be 3.60 logCFU (colony-forming unit)/g on day 1 and 9.50 logCFU/g on day 18 [18], whereas that in ground beef was found to be approximately 3.00 logCFU/g on day 1 and 10.0 logCFU/g on day 12 [20], showing a faster increase in the latter.

In the present study, the meat parameters that affect quality considerably, namely, color, pH, microbial count, and lipid oxidation [18], were analyzed. The effect of soybean meat on quality retention in the production of hamburgers was examined. In addition, a questionnaire survey was conducted to determine the percentage of soybean meat that is acceptable in hamburgers. Moreover, the quality change in hamburgers achieved with the acceptable soybean meat-to-meat ratio was investigated, and the quality retention of soybean meat was verified. The findings of the present study could facilitate a reduction in the intake of animal proteins, which, in turn, could decrease the risk of development of lifestyle-related diseases, while maintaining the overall quality of hamburgers by using soybeans. Furthermore, the results of this research could contribute to the reduction of food loss and human health, in addition to contributing to the popularization of soybeans globally.

Objects and methods

Hamburger and soybean meat preparation

A mixture of ground beef (thigh; domestic, Australia, and USA) and pork (shoulder; domestic, USA, and Canada) (7:3 ratio) purchased as an off-the-shelf product at a retail store in Hachioji City, Japan, was used to prepare hamburger patties. Dried soybean meat (100 g; Nichie Corporation, Nagoya, Japan) was placed in a frying pan with approximately 500 mL of water and brought to a boil to produce soybean meat. Subsequently, the soybean meat was allowed to simmer over low heat for 5 min and drained. For the sensory test, approximately 1,000 g of ground meat was prepared, and hamburger patties containing 0%, 30%, 50%, 60%, and 70% soybean meat were made. The hamburgers were grilled at 190 °C until browned on both sides, and then steamed at 170 °C for 5 min with the lid on. For measuring the changes in quality, hamburger patties containing 0%, 30%, and 50% soybean meat were prepared, grilled at 190 °C until browned on both sides, and then steamed at 170 °C for 5 min with the lid on. The hamburgers were then placed on a tray, covered with Saran Wrap, and stored at 5 °C for 21 days.

Sensory test

Fifteen hamburger patties (three patties per group) were prepared for the sensory test. In this test, a score of 4 (very good), 3 (good), 2 (bad), or 1 (very bad) was assigned for the appearance, texture, firmness, and juiciness of the hamburger, as described by Shibata-Ishiwatari et al. [12]. A score was assigned for each parameter, and the patty was given an overall score. The percentage of respondents who thought the hamburger was acceptable was determined. The sensory test was conducted three times with 10 (male: 7; female: 3) participants aged between 21 and 22 years. The study was approved by the Ethics Committee of the Tokyo University of Technology (No. E22BS-011).

Quality assessment

For the assessment of the quality of hamburgers, 18 hamburger patties containing 0%, 30%, and 50% soybean meat (six hamburger patties per group weighing approximately 30 g each) were prepared and evaluated, as more than 50% of the sensory test respondents found them acceptable.

Color and pH

A colorimeter (Shenzhen ThreeNH Technology Co., Ltd., Guangzhou, China) and pH meter (Sato Shoji Co., Ltd., Kanagawa, Japan) were used to measure the surface characteristics and pH, respectively, on three different locations on the surface of the hamburgers 4, 7, 12, 18, and 21 days after they were cooked. The L- (lightness/brightness), a- (redness/greenness), and b- (yellowness/blueness) values were measured.

Viable bacteria count

Hamburger samples (2 g) were added to 20 mL of 0.9% sterile saline solution. Once the meat sank to the bottom, the supernatant was collected and diluted. Subsequently, 100 µL of the diluted supernatant was smeared on a standard agar medium using a bacteria spreader (SFC–1000; AS ONE CORPORATION, Osaka, Japan). The culture medium was then incubated at 35 °C for 48 h, and the bacteria count was determined on days 4, 7, 12, 18, and 21.

Peroxide content

Hamburger samples (5 g) were placed in a triangular flask and mixed with 30 mL of isooctane (Kanto Chemical Co., Ltd., Tokyo, Japan) and acetic acid (FUJIFILM Wako Pure Chemical Co., Ltd., Osaka, Japan) at a 2:3 ratio. Subsequently, a saturated solution of 0.01 mM potassium iodide (FUJIFILM Wako Pure Chemical Co., Ltd.) was added, and the mixture was shaken for 1 min and placed in the dark at 25 °C for 5 min. Thereafter, 30 mL of pure water was added, and the solution was shaken for 5 min, after which 0.5 mL of 1% starch solution (FUJIFILM Wako Pure Chemical Co., Ltd.) was added. The peroxide content was determined on days 4, 7, 12, 18, and 21 through titration using the following formula:

$$\textit{Peroxide content} = 10 \times (V - v) \times F/C;$$

where V is the titration volume; v is the blank; F is 1.0; and C is the sample volume (g).

Statistical analysis

The Wilcoxon signed rank test and *t*-test were used to determine differences in the means between the groups. The Wilcoxon signed rank test was performed using the R software (The R Foundation, Vienna, Austria); the *t*-test and analysis of variance were performed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Results with p-value < 0.05 were considered statistically significant.

Results and discussion

Sensory test

Table 1 shows the results of the questionnaire survey on the sensory quality of hamburger patties with different percentages of soybean meat. Eighty percent of the respondents found the hamburgers were acceptable when the percentage of soybean meat was 0%–50%, whereas < 40% found them acceptable when the percentage of soybean meat was 60%–70%. The appearance scores tended to decrease with an increase in the amount of soybean meat ($p > 0.05$). In terms of texture, the score of 34–31 for hamburgers containing 30%–50% soybean meat, respectively, was higher than the score of 24 for

Table 1. Sensory test results for hamburgers with different percentages of soybean meat

Soybean meat percentage (%)	Appearance score	Texture score	Hardness score	Juiciness score	Acceptable percentage (%)
0	35	30	30	34	100
30	34	34	32	31	90
50	34	31	32	26	80
60	31	28	30	23	40
70	27	24	26	21	30

hamburgers with 70% soybean meat ($p < 0.05$). The firmness score of 32 for hamburgers with 30% soybean meat was higher than the score of 26 for hamburgers with 70% soybean meat ($p < 0.05$). Additionally, the juiciness score of 34–31 for hamburgers containing 0%–30% soybean meat, respectively, was higher than the score of 23–21 for hamburgers containing 60%–70% soybean meat ($p < 0.05$), respectively.

Regarding the appearance of hamburgers, the evaluation scores tended to increase as the percentage of soybean meat in the hamburger patties decreased (Table 1). When the meat surface temperature reaches approximately 150 °C, a reaction (Maillard reaction) occurs between amino compounds, such as proteins, and carbonyl compounds of reducing sugars; this reaction causes a significant change in meat color from red/pink to grayish brown during the heating process [19]. The beef and pork used in this study each contained 26 g of amino acids, and 0.4 and 0.1 g of sugar, respectively, per 100 g (edible portions), whereas the soybeans contained 1.8 mg of amino acids and no sugar [20]. Therefore, as the amount of added soybean meat increased, the sugar content in hamburgers decreased, which could have inhibited the Maillard reaction, resulting in decreased appearance evaluation scores. Furthermore, the red color of raw meat is due to myoglobin, which changes to grayish-brown when heated, and then to pink during cooling [19]. Soybean meat does not contain myoglobin; thus, this color change does not occur, which may explain the lower appearance score of hamburgers with soybean meat than that of hamburgers without it.

In terms of hamburger texture and firmness, the evaluation scores tended to decrease as the percentage of soybean meat in the hamburgers increased. In a previous study, when minced OT was added to standard hamburgers (700 g minced ground beef, 5 g onion, 5 g breadcrumbs, 5 g salt, and 0.1 g nutmeg), the scores for texture and firmness increased with increasing OT quantity [5]. A difference in preference for meat firmness has been suggested based on gender, with female students reportedly regarding "softness" as a more important quality of beef [20]. Moreover, in a study by Shibata-Ishiwatari et al. [12], all participants were female individuals. In the present study, we enrolled seven male and three female individuals; the decreasing scores for texture and firmness with increasing soybean meat content in hamburgers may be explained by the small proportion of female individuals enrolled in this study.

In a previous study, hamburgers were prepared with yams and okara or tofu as substitutes for chicken eggs, breadcrumbs, and milk as the binder. The yams and okara were rated as "non-cohesive" and "dry," with significantly decreased juiciness compared to that of 100% animal meat hamburgers [12]. In the present study, the juiciness evaluation scores also decreased with increasing soybean meat content in hamburgers.

In a study by Matsuo [9], hamburgers containing up to 20% OT were acceptable. When hamburgers contained over 30% OT, the total score decreased. In the present study, we observed a similar trend, with decreasing overall evaluation scores for hamburgers with increasing soybean meat content.

Quality assessment

Color and pH

Figure 1 shows changes in the L-values of hamburgers containing various percentages of soybean meat when refrigerated for 21 days. For hamburgers containing 0% soybean meat, the L-values varied between 35.8 and 42.8 throughout this period, revealing no increasing or decreasing trend ($p > 0.05$). The L-values for hamburgers with 30% soybean meat varied between 36.8 and 44.0 on days 1–18 ($p > 0.05$) and slightly increased to 50.8 on day 21 ($p > 0.05$). Hamburgers with 50% soybean meat showed L-values varying between 39.0 and 45.7 on days 1–7 ($p > 0.05$) and slightly increasing to 51.2 on day 21 ($p > 0.05$). Additionally, a trend toward increasing L-values with increasing amount of soybean meat in hamburgers was observed.

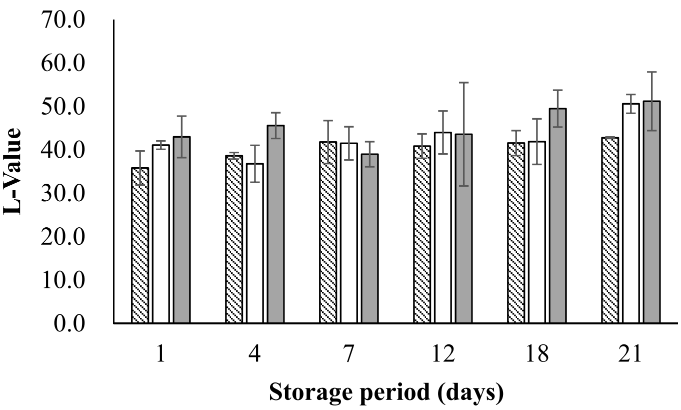

Figure 1. L–Values of hamburgers with different percentages of soybean meat during 21 days of refrigerated storage. Shaded, white, and gray bars represent hamburgers with 0%, 30%, and 50% soybean meat, respectively. Data are presented as mean ± standard deviation (n = 5)

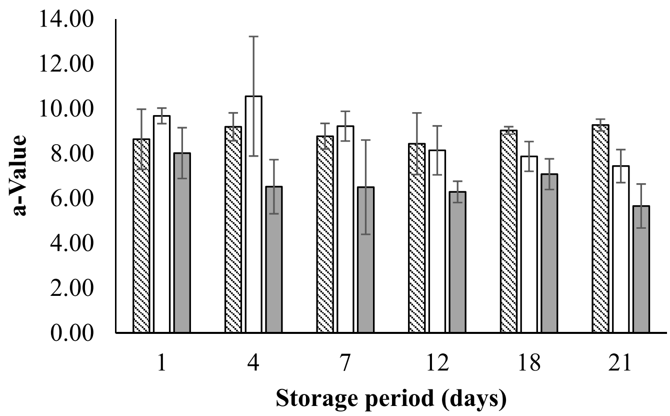

Figure 2. a-Values of hamburgers containing different percentages of soybean meat during 21 days of refrigerated storage. Shaded, white, and gray bars represent hamburgers with 0%, 30%, and 50% soybean meat, respectively. Data are presented as mean ± standard deviation (n = 5)

Figure 2 shows changes in the a-values of hamburgers containing various percentages of soybean meat when refrigerated for 21 days. For hamburgers containing 0% soybean meat, the a-value varied between 8.44 and 9.27 over the 21-day period, showing no increasing or decreasing trend ($p > 0.05$). For hamburgers with 30% soybean meat, the a-value was 9.68 on day 1, increasing slightly to 10.6 on day 4 ($p > 0.05$) and decreasing slightly to 7.44 on day 21 ($p > 0.05$). The a-values of hamburgers containing 50% soybean meat ranged from 5.66 to 8.02 on days 1–21, revealing no increasing or decreasing trend ($p > 0.05$). Additionally, a trend toward decreasing a-values with increasing amount of soybean meat in hamburgers was observed.

Figure 3 shows changes in the b-values of hamburgers with various percentages of soybean meat when refrigerated for 21 days. For hamburgers with 0% soybean meat, the b-value was 11.7 on day 1, increasing slightly to 19.9 on day 4 ($p > 0.05$) and varying between 18.5 and 19.9 on days 4 to 21; there was no increasing or decreasing trend ($p > 0.05$). For hamburgers with 30% soybean meat, the b-value range was 18.4–22.2 over the 21-day period, with no increasing or decreasing trend ($p > 0.05$). The b-values for hamburgers with 50% soybean meat varied between 16.8 and 20.8 over the 21 days, without an increasing or decreasing trend ($p > 0.05$).

Figure 4 shows changes in the pH of hamburgers containing different percentages of soybean meat when refrigerated for 21 days. Hamburgers with 0% soybean meat had a pH of 5.94 on day 1, increasing to 6.22 on day 12 ($p < 0.05$), decreasing to 5.95 on day 18 ($p < 0.05$), and increasing again to 6.12 on day 21 ($p < 0.05$). For hamburgers with 30% soybean meat, the pH was 6.26 on day 1, increasing slightly to 6.46 on day 12 ($p > 0.05$), and decreasing slightly to 6.36 on day 21 ($p > 0.05$). In hamburgers containing 50% soybean meat, the pH was 6.22 on day 1 and increased to 6.70 on day 21 ($p < 0.05$). The pH of hamburgers tended to increase as the amount of soybean meat increased.

Figures 1–3 show that when hamburgers without soybean meat were stored at 5 °C for 21 days, there was no trend of increase or decrease in the L-, a-, and b-values. For lamb cooked on the grill at 200 °C and refrigerated at 2 °C for 14 days, the L-, a-, and b-values reportedly vary between 50.5 and 51.2, 7.9 and 8.0, and 13.8 and 15.3, respectively, from day 1 to day 14 with no increasing or decreasing trend [21]. In the hamburger without soybean meat in this study, the L-, a-, and b-values fluctuated between 35.8 and 42.8, 8.62 and 9.27, and 15.0 and 18.5, respectively, over a 21-day period with no increasing or decreasing trend, and the same trend was observed, indicating that no color change occurs over time during storage. However, compared with those for lamb, the a and b values in this study were close, whereas the L value in this study was low. The L value, which indicates brightness, decreases as the aminocarbonyl reaction proceeds with heating in the case of direct grilling [22], and in this study, the hamburger was grilled at a heating temperature of 180 °C until the hamburger became charred. On the contrary, lamb was cooked on the grill at 200 °C. However, the internal temperature of the meat was about 72 °C because the grill cooking method heats the meat as a whole without concentrating the heat in one place. Therefore, the surface temperature was lower on the grill compared with that of direct heat, which may have resulted in lower L-values in this study.

Figures 1–3 show that the L-values increased and a-values decreased as the percentage of soybean meat added in the hamburger increased from 0% to 50%; the L-values reportedly decrease due to the aminocarbonyl reaction [22]. A comparison of the composition of meat and soybeans, per 100 g of edible portion, revealed that both beef and pork contained 0.4 and 0.1 g of sugar, respectively, and 26 g of amino acids, whereas soybeans contained 1.8 mg of

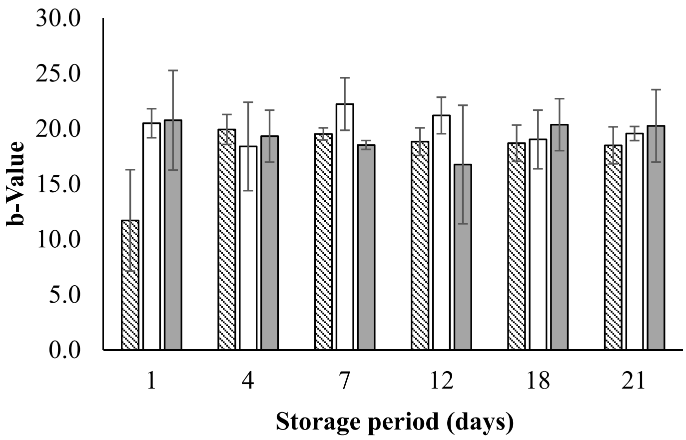

Figure 3. b-Values of hamburgers with different percentages of soybean meat during refrigerated storage for 21 days. Shaded, white, and gray bars represent hamburgers with 0%, 30%, and 50% soybean meat, respectively. Data are presented as mean ± standard deviation (n = 5)

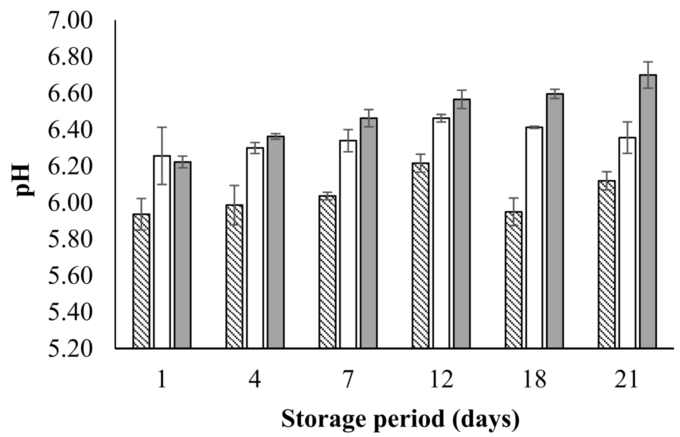

Figure 4. pH of hamburgers with various percentages of soybean meat during 21 days of refrigerated storage. Shaded, white, and gray bars represent hamburgers with 0%, 30%, and 50% soybean meat, respectively. Data are presented as mean ± standard deviation (n = 5)

amino acids and no sugar [8]; both amino acid and sugar contents in soybeans were lower than those in meat. Therefore, the addition of soybean meat is not a good option. We believe that the addition of more soybean meat increased the L-value because the Maillard reaction did not occur due to the lower amount of sugar. In addition, the color of the meat became lighter with the addition of soybeans, which may have resulted in a tendency for the a-value to decrease with increased soybean addition.

Figure 4 shows that the pH of all the hamburgers examined tended to increase with time when stored at 5 °C for 21 days. The pH also increased as the percentage of soybean meat increased. The pH of ground beef stored at 4 °C for 12 days reportedly varies between 5.68 and 6.16 [23], and that of ground pork stored at 4 °C for 14 days varies between 5.88 and 6.00 [24]. In the present study, the pH of the hamburger with 0% soybean meat refrigerated for 21 days ranged from 5.94 to 6.22 from day 1 to day 21, respectively.

Figure 4 shows that as the amount of soybean meat in the hamburger increased, the pH also increased; the pH of soybeans (kouji-irasu, ayamidori, green and black soybeans) is in the range of 6.29–6.62, whereas the pH of cooked ground meat is 6.16 [23]. The pH of the soybeans reflected the pH of the hamburgers with soybeans; therefore, it can be considered that the pH increased as the percentage of soybean meat increased.

Viable bacteria count

Figure 5 shows changes in the viable bacteria count in hamburgers containing different percentages of soybean meat and refrigerated for 21 days. In hamburgers with 0% soybean meat, the bacteria count was 5.83 logCFU g^{-1} on day 1, increasing to 11.9 logCFU g^{-1} on day 21 ($p < 0.05$). In hamburgers with 30% soybean meat, this count was 6.30 logCFU g^{-1} on day 1 and 11.8 logCFU g^{-1} on day 21 ($p < 0.05$). In hamburgers with 50% soybean meat, the bacteria count was 6.05 logCFU g^{-1} on day 1, increasing to 6.54 logCFU g^{-1} on day 4 ($p < 0.05$), decreasing to 5.43 logCFU g^{-1} on day 7 ($p < 0.05$), and increasing again to 9.99 logCFU g^{-1} on day 21 ($p < 0.05$). Moreover, the bacteria counts increased over time. After day 4, the bacteria counts were lower in hamburgers with 50% soybean meat than in those with 0% and 30% soybean meat.

In UV-irradiated raw beef, the microbial count was reportedly around 3.70 logCFU g^{-1} on day 1, increasing to approximately 9.50 logCFU g^{-1} on day 18 [18], which is consistent with the results of the present study. Additionally, in our study, the bacteria counts in hamburgers with 30% and 50% soybean meat were lower than those in hamburgers without soybean meat. It has been reported that soybeans contain the isoflavones 2′-hydroxyerythrin A and isoerythrinin A, which have antimicrobial properties [25]. The presence of these isoflavones could be a reason for the decreasing bacteria counts with increasing soybean meat content in hamburgers observed in our study.

Peroxide content

Figure 6 shows changes in the peroxide content in hamburgers containing different percentages of soybean meat during refrigerated storage for 21 days. In hamburgers with 0% soybean meat, the peroxide content was 10.1 meq/kg^{-1} on day 1, increasing to 18.7 meq/kg^{-1} on day 12 ($p < 0.05$), and decreasing to 12.8 meq/kg^{-1} on day 21 ($p < 0.05$). In hamburgers with 30% soybean meat, the peroxide content was 7.10 meq/kg^{-1} on day 1, decreasing to 4.07 meq/kg^{-1} on day 12 ($p < 0.05$), and increasing to 6.21 meq/kg^{-1} on day 21 ($p < 0.05$). In hamburgers with 50% soybean meat, this value ranged between 2.84 and 4.89 meq/kg^{-1} on days 1–21, with no increasing or decreasing trend ($p > 0.05$). Additionally, the peroxide content decreased with increasing soybean meat content in hamburgers.

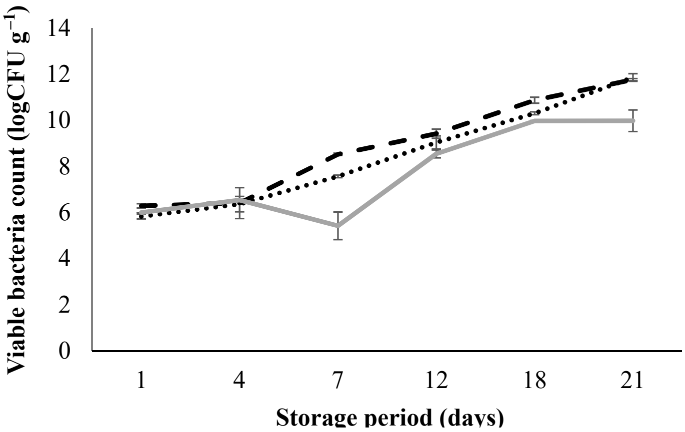

Figure 5. Viable bacteria counts in hamburgers with different percentages of soybean meat during refrigerated storage for 21 days. Dotted, dashed, and gray lines represent hamburgers with 0%, 30%, and 50% soybean meat, respectively. Data are presented as mean ± standard deviation (n = 5)

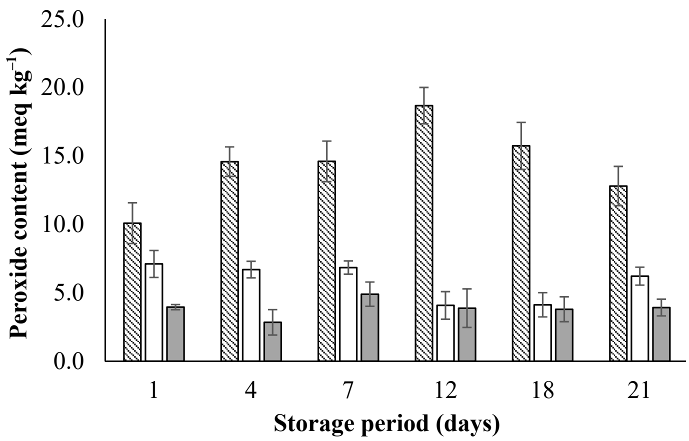

Figure 6. Peroxide content in hamburgers with different percentages of soybean meat during 21 days of refrigerated storage. Shaded, white, and gray bars represent hamburgers with 0%, 30%, and 50% soybean meat, respectively. Data are presented as mean ± standard deviation (n = 5)

In our study, the peroxide content increased slowly over time. Additionally, this parameter tended to increase and then decrease over time in hamburgers containing soybean meat. In a previous study on dry fermented sausages, the addition of soy flakes decreased the peroxide content to below 4.0 meq/kg^{-1} [26]. It has also been reported that OT suppressed fat and oil oxidation in ground hamburger meat and cupcakes [12]. Therefore, adding soybean meat to hamburgers may have reduced the peroxide content and suppressed its increase over time. Moreover, in the present study, the peroxide content in hamburgers without soybean meat reached the maximum on day 12 and then decreased. Ghimire et al. [27] reported that the peroxide content in beef meatballs was 0.25 meq/kg^{-1} on day 1, reached its maximum of 1.27 meq/kg^{-1} on day 6, and then decreased. This change happens because the degradation of unstable hydroperoxides leads to the formation of aldehydes, ketones, and epoxides, causing the accumulation of secondary oxidation products; thus, it is only reliable to measure the peroxide content during the early stages of lipid oxidation, when the peroxide content increases to its maximum value, as it decreases with extended storage time [27]. Therefore, malondialdehyde, reflecting the peroxide content, is useful for evaluating food oxidation in the early stages [28]. In this study, the peroxide content increased and then decreased with storage time in hamburgers without soybean meat, but these changes were not observed in hamburgers with soybean meat, suggesting that the progress of oxidation was delayed in hamburgers with soybean meat. The hamburger containing soybean meat was considered to show delayed progression of oxidation.

Soybeans contain various antioxidants, and one of the fat-soluble antioxidants is tocopherol. Tocopherols, which are present in soybean oil, reportedly have antioxidant properties, and prevent fat and oil oxidation by scavenging free radicals generated in the initial stages of oxidation, indicating that oxidation is suppressed by soybean oil [29]. A previous study measured the peroxide content of soybean and sesame oils and reported that it increases from 1.2 meq/kg^{-1} at month 0 to 21.6 meq/kg^{-1} at month 44 and from 0.2 meq/kg^{-1} at month 0 to 109.8 meq/kg^{-1} at month 44, respectively. This finding indicated that oxidation was suppressed in soybean oil [30].

Soybean meat is composed of dried, processed soy protein, and its characteristics vary depending on the type of soybean used. Currently, there are only a few soybean meat products available; therefore, comparing various types of soybean meat products is challenging. Novel soybean meat products are expected to be introduced in the market. Moreover, meat quality may depend on its region of origin; however, this was not examined in this study, warranting further investigation to understand the effects of different regions of origin of meat on its quality. As soybean meat has only recently been commercialized and there are only a few studies on this product, the present study is a pioneer in the characterization of soybean meat and investigation of its possible benefits. Nevertheless, further characterization of soybean meat should be conducted in the future.

Conclusion

This study investigated the percentage of soybean meat acceptable in a hamburger and quality preservation in hamburgers produced with added soybean meat. In the sensory evaluation of hamburgers with soybean meat, more than 80% of the respondents answered that hamburgers were acceptable when the soybean meat content was ≤50%, whereas less than 40% answered that hamburgers were acceptable when the soybean meat content was ≥60%. Regarding quality deterioration over time, specifically color, hamburgers containing soybean meat tended to have higher L- and b-values and lower a-values than hamburgers without added soybean meat. Hamburgers containing soybean meat tended to have a higher pH and lower bacteria count than hamburgers without soybean meat. Furthermore, hamburgers containing soybean meat had lower peroxide content than pure animal protein hamburgers. Therefore, hamburgers containing less than 50% soybean meat are deemed acceptable and their quality preservation is higher than that of 100% animal protein hamburgers.

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The authors declare that there is no conflict of interest.