Journal of Food Quality and Hazards Control 13 (2026) 89-100

Effect of Retort Pressure on Sterilization of Rembiga Satay in Flexible Packaging Using Overpressure Retorts

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HIGHLIGHTS

- Retort pressure significantly influenced the seal strength of flexible packaging after thermal sterilization.
- Overpressure retort processing maintained package integrity and thereby prevented leakage during sterilization.
- Sterilization modified the texture, color, and proximate composition of Rembiga satay.
- Optimized retort processing facilitates commercial sterilization of Rembiga satay in flexible packaging.

Article type
Original article

Keywords
Food Quality
Sterilization
Food Packaging
Pressure

Article history
Received: 2 May 2025
Revised: 21 Jun 2026
Accepted: 26 Jun 2026

Abbreviations
CUT: Come Up Time
TC: Thermocouple
TPA: Texture Profile Analyzer

ABSTRACT

Background: Flexible packaging, such as retort pouches, is widely used for sterilized food products, since it can preserve product quality and improve distribution efficiency. However, flexible packaging is susceptible to deformation and leakage during thermal processing. This study aimed to evaluate the effects of retort pressure and packaging type on heat penetration characteristics, process lethality (F_0), packaging integrity, and physicochemical properties of Rembiga satay processed using an overpressure retort.

Methods: The study consisted of four stages: heat distribution testing, preparation of Rembiga satay, heat penetration testing, and physicochemical analysis. Rembiga satay was packaged in aluminum and plastic retort pouches and sterilized at 116 °C using different retort pressures. Process optimization was performed using the Ball method. Data were analyzed using analysis of variance (ANOVA) followed by Duncan's multiple range test at a 95% confidence level using SPSS software.

Result: Heat distribution testing produced Come Up Time (CUT) values of 21 min for aluminum packaging and 23 min for plastic packaging. Initial heat penetration trials resulted in F_0 values ranging from 1.06 to 3.66 min, indicating insufficient lethality in several treatments. After process redesign using the Ball method, estimated F_0 values increased to 3.28 min for aluminum packaging and 6.55 min for plastic packaging. The highest tensile strength of the sealing area was observed in aluminum retort pouches processed at 0.8 bar, with a value of 19.4 N/mm². Sterilization also significantly affected the physicochemical properties of Rembiga satay, including texture profile parameters, color values, and proximate composition.

Conclusion: Retort pressure and packaging type significantly affected packaging integrity and thermal processing characteristics of Rembiga satay. Although several initial sterilization treatments resulted in insufficient F_0 values, process redesign using the Ball method successfully achieved F_0 values exceeding the minimum commercial sterility requirement.

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To cite: Adimah, Hari Purnomo, E., Saraswati, and Armetha, V. (2026) 'Effect of retort pressure on sterilization of Rembiga Satay in flexible packaging using overpressure retorts', *Journal of Food Quality and Hazards Control*, 13(2), pp. 89-100.

DOI: 10.18502/jfqhc.13.2.22138 Journal website: http://jfqhc.ssu.ac.ir

Introduction

Beef is a food commodity with a high nutritional content (Rohmah, Mu'tamar and Purwandari, 2018). The beef contained 77.65% water, 14.7% fat, and 18.26% protein (Prasetyo, Padaga and Sawitri, 2013). In Indonesia, beef is often processed into rendang, meat soup, jerky, and satay. Satay meat is one of the most popular processed meat products in Indonesia. In Indonesia, there are various types of satays, including Rembiga satay. The name “Rembiga satay” is chosen because it comes from a village of Rembiga, Lombok Island, West Nusa Tenggara Province (Satriawan, 2019).

The growing popularity of Rembiga satay has led to its use as a souvenir for tourists visiting Lombok, West Nusa Tenggara. However, its limited shelf life poses a challenge to distribution. One potential solution to extend its durability is sterilization after packaging. This sterilization process was performed using a retort. Retort sterilization technology is a thermal processing method that exposes food packaging (semi-rigid or flexible) to high temperatures in a steam chamber (Shah *et al.,* 2017). The ideal packaging for Rembiga satay is flexible packaging, such as aluminum or plastic retort pouches. However, flexible plastic packaging has thermal resistance limitations that may increase the risk of package deformation, seal failure, and leakage at excessively high sterilization temperatures during autoclaving. Therefore, optimizing the sterilization temperature and holding time is necessary to achieve commercial sterility while maintaining packaging integrity. Rembiga satay does not contain liquid ingredients, making it easy to combine with vacuum packaging for better preservation. In addition, flexible packaging can increase visual appeal, shorten sterilization time, decrease weight, and provide convenient portability (Ariyana *et al.,* 2023).

A retort pouch is a type of packaging made from aluminum foil and/or laminated polymer, designed to withstand the sterilization process while ensuring a long shelf life at room temperature (Kurniadi *et al*., 2019). According to the research by Bindu, Ravishankar and Srinivasa Gopal (2007), retort sterilization using retort pouch packaging for black mussels, with an F_0 value of 9 min and a cooking time of 99 min at 121 °C, effectively preserves biochemical and sensory qualities, allowing for a storage period of up to 12 months at room temperature. Flexible packaging is known to have weak integrity compared with canned packaging, especially when subjected to pressure differences between the internal and external environment during the sterilization process. Pamuji *et al.,* (2021) found that an excessive pressure difference between the internal packaging pressure and the external retort chamber pressure was a key factor causing HDPE bottle deformation during sterilization. Reducing the pressure difference from 1.20 bar to 0.40 bar and optimizing retort conditions significantly decreased the percentage of dented bottles from 2.37% to 0.76%, ensuring better packaging integrity. While this study focused on HDPE bottles, research on pressure balance in flexible packaging during retort sterilization remains limited and requires further investigation. Therefore, this study aimed to evaluate the effects of retort pressure and packaging type on heat penetration characteristics, process lethality (F_0), packaging integrity, and physicochemical properties of Rembiga satay processed using an overpressure retort.

Materials and methods

Materials

The ingredients used in the preparation of Rembiga satay are beef tenderloin, oil, soy sauce, tamarind, garlic, pepper, cayenne pepper, cayenne, chili, salt, tomato, shallots, lime, broth powder, water, and ingredients for proximate analysis. The tools used for sterilization of Rembiga satays included an overpressure retort (ABATA-ACL 270, Indonesia), thermocouples (TCs), Pressure Loggers (PLs), data loggers, compressors, boilers, water tanks, vacuum sealers, and automatic sealers, Soxhlet instrument, Kjeldahl furnace instrument, oven (CascadeTEK, USA), chromameter (MSEZ User Manual), tensile strength tester (UTM Shimadzu AGS-IKNX, Japan), and CTX Texture Analyzer (AMETEK Brookfield, Indonesia).

Methods

-Research procedure

This research consisted of four stages: (1) retort heat distribution test, (2) making Rembiga satay, (3) product heat penetration test, and (4) physicochemical quality analysis of Rembiga satay. Subsequently, followed by observation of packaging leakage, packaging tensile strength test, and samples produced in stages 2 and 3 were analyzed for characteristics using various parameters, including texture, color, and proximate analyses.

-Retort heat distribution test and product penetration in the rembiga satay sterilization process

A heat distribution test was conducted to ensure uniform retort temperature (T_r) before the sterilization process began. According to the Indonesian Food and Drug Authority (BPOM, 2019), the heat distribution was tested by identifying the worst condition of the retort based on lifespan, capacity, and position towards the steam source. After completing the distribution test, Rembiga satay was prepared. The beef tenderloin was cut into 1.5 × 1.5 × 1.5 cm pieces. The meat was then coated with spice and allowed to rest for 1 h at 5 °C. It was then skewered (four pieces per

[DOI: 10.18502/jfqhc.13.2.22138]

skewer), grilled over hot coals for 8 min, and then cooled.

The next stage was heat penetration of the product. Sterilization was conducted at 116 °C using an overpressure retort system. The selected temperature was lower than conventional commercial sterilization temperatures, since the plastic retort pouch used in this study had a maximum heat resistance of approximately 120 °C. Processing at temperatures approaching the packaging tolerance limit can increase the risk of package deformation, seal failure, and leakage. Therefore, F_0 was achieved by extending the holding time rather than increasing the processing temperature.

The cooked Rembiga satay was packaged with an aluminum retort pouch (Cast Polypropylene/ Aluminum/Oriented Nylon/Polyethylene Terephthalate) measuring 16x22.5 cm and a plastic retort pouch (Cast Polypropylene/Oriented Nylon) measuring 16x25.5 cm. Each package contained four skewers (100 g) and was equipped with TC and Pressure Logger (PL) for heat penetration measurements. The heat penetration test was conducted in two stages. In the first stage, the heat penetration curve and critical points of the heating lag factor (J) and heating rate index (fh) were determined using pressures of 1, 1.5, and 2 bar for 15 min. The second stage used pressures of 0.8, 1, and 1.5 bar with sterilization times of 20 min for aluminum packaging and 30 min for plastic packaging, based on Ball method calculations. The pressure range in the second stage was adjusted, because preliminary evaluation indicated that 0.8 bar was the minimum pressure required to maintain stable sterilization conditions at 116 °C. Furthermore, increasing the retort pressure above 1.5 bar did not provide substantial additional effects on packaging performance during preliminary observations. Therefore, lower pressure levels were selected for further optimization.

-Packaging integrity testing

Packaging integrity testing was conducted in three stages. First, the packaging was physically inspected to detect any damage or leakage. Second, by weighing the packaging before and after sterilization, weight differences indicated leakage. Third, the package was manually compressed while submerged in water to detect air bubble formation indicating leakage.

-Measurement of F_0 value

The output data of the temperature fluctuation were calculated using the Improved General Method equation developed by Lewis, described by (Azhari *et al*., 2023; Praharasti *et al*., 2020), as follows:

$LR=10^{(T-121.1)/10}$

F_0 can be found through this operation:

$F_0= \int LRdt$

F_0 value was used to determine the correct sterilization value. After determining the lethality rate, F_0 in min was calculated using the following formula:

$F_0= \sum(LR_n+LR_{n-1}/2)\times\Delta t$

-Process design using the ball method

The heat penetration test data was then analyzed using the Ball method to develop process designs for several different process scenarios, involving variations in initial temperature (T_i), process temperature (T_r), and target F_0 value. The heat penetration data used resulted in the lowest F_0 value based on the trapezoidal method. For calculations using the ball method, the required process data included Come Up Time (CUT), product T_i, process time (P_t), and sterility value at other temperatures (F_i). The first step in developing process alternatives is to recalculate F_0 value using the ball method. The heat penetration data at the initial process conditions, namely retort temperature (T_r) and product temperature (T_p, measured at the geometric center of the product), were mapped as the relationship between ($T_r - T_p$) and time to generate a semi-logarithmic curve. The linear portion of this curve was then identified to determine the value of fh, which is the time (min) taken for the heating curve to change through one log cycle or 2.303/slope. From the linear portion of the curve, the JI value, which is the difference between the T_r and the apparent T_i obtained at the intersection point of the heating curve with time 0 min after 0.6 * CUT, was also determined. Furthermore, J value was calculated as a lag time factor before the heating curve became linear using the formula J = JI/I, where I was the difference between the T_r and T_i. The fh and J values became constants used in the process design. Additional parameters, including B, B/fh, and heating parameter (log g), were also calculated, as presented in Table 1.

The purpose of developing alternative processes is to determine P_t under different process scenarios (T_r, T_i, and F_0) (Kusnandar *et al*., 2023). If heat penetration test results show an excessively high F_0 value, the Tr, product T_i, and F_0 value can be lowered from the initial process conditions to produce different fh/U values. Furthermore, the log g value was obtained from the table of log g versus fh/U at Z = 10 °C (Singh and Heldman, 2009). The g value is the difference between the Tr and the temperature of the product inside the package at the end of heating (T_p). The log JI and log g values were used to calculate the total P_t (B) (Equation 1), which then allowed the determination of the P_t (Equation 2).

$$B=fh\,(\log ji-\log g) \quad (1)$$

$$P_t=B-(0.4\times CUT) \quad (2)$$

Table 1: Parameters in ball method calculation

Parameter	Description
CUT (min)	Come up time
T_i (°F)	Initial temperature of product
T_r (°F)	Retort temperature
P_t (min)	Applied process time
fh = 2.303/slope	Heating rate index (min)
JI = TR-T	Difference between retort temperature and product temperature
$I = T_r - T_i$ (°F)	Difference between retort temperature and initial product temperature
J = JI/I	Heating lag factor
$B = P_t + 0.4$ CUT (min)	Ball process time (min)
B/fh	Ratio of process time to heating rate index
Log g = log JI – B/fh	Heating parameter
fh/U	Read from table log g against fh/u
F_i = 10) (min)	Temperature correction factor
U =)	Sterilization value
$F_0 = U/F_i$ (min)	Process lethality value (min)

-Tensile strength testing

This test measured the maximum tensile force that could be applied to the packaging before it tore or became damaged. The packaging material was cut into strips according to the specifications of the testing equipment and then secured on a Shimadzu AGS-IKNX UTM machine. The instrument recorded the force, in newtons, required to cause the packaging to tear or break.

-Physical and chemical characteristics of rembiga satay

The analysis of the physical quality of the Rembiga satay consists of Texture Profile Analyzer (TPA) and color analysis (chromameter). A proximate analysis was performed by AOAC (2012). Analysis components include analysis of moisture content (oven method), ash content (gravimetric method), fat content (soxhlet method), and protein content (kjeldahl method).

-Statistical analysis

The data analysis used t-test and ANOVA statistical tests with a two-factor factorial completely randomized design, namely retort pressure (0.8, 1, and 1.5 bar) and type of flexible packaging (aluminum and plastic). A t-test analysis was performed to evaluate the effect of sterilization treatment on proximate, physical, and organoleptic quality. ANOVA was performed on the tensile strength of the packaging. All data are presented as mean ± standard deviation. Duncan's post hoc test (DMRT) was carried out to see the significant difference between treatments.

Results and discussion

Heat distribution profile of the retort

Heat distribution profile testing was conducted using 15 TCs placed at various points in the retort to ensure the uniformity of heat distribution throughout the retort, with data recorded using a data logger. The overpressure water spray method was applied, where the retort was operated at a pressure of 2 bar for both aluminum foil and plastic packaging, with the sterilization Tr set at 116 °C. The aluminum foil packaging took 21 min to reach CUT with a relatively uniform heat distribution graph across the TC placement points (Figure 1). In contrast, plastic packaging required 23 min to reach the CUT (Figure 2). This difference is due to the higher thermal conductivity of aluminum compared to plastic; therefore, aluminum absorbs and distributes heat faster. Yuriandala, Syamsiah and Saptoadi (2016) also showed that the use of aluminum foil-coated plastic can accelerate the increase in temperature to the optimal point, supporting the results of this test. The heat distribution graph for the plastic packaging shows a significant temperature difference between the upper and lower baskets. This finding is consistent with that of Sembiring (2023), who stated that the lower basket is the first area exposed to heat from steam during the sterilization process, causing it to heat more quickly than the upper basket.

[DOI: 10.18502/jfqhc.13.2.22138]

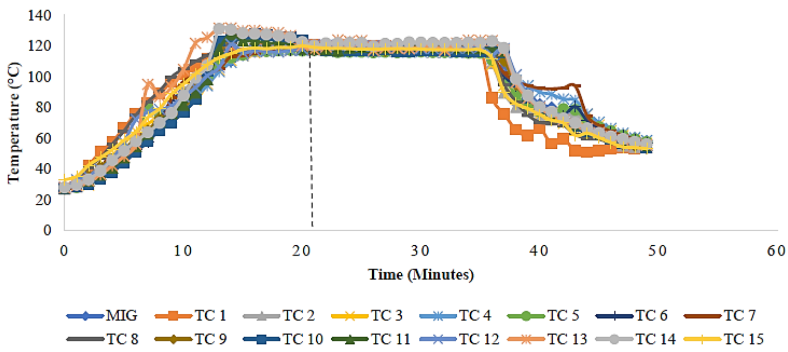

Figure 1: The value on the x-axis marked by the dashed line indicates the Come Up Time (CUT), at which the target process temperature (T_r) has generally been uniformly reached at all measured points.

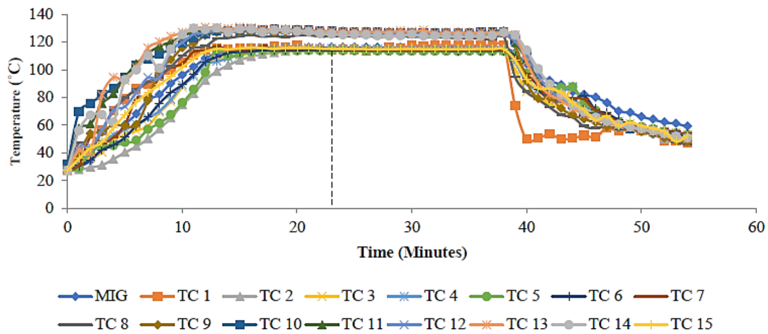

Figure 2: The value on the x-axis marked by the dashed line indicates the Come Up Time (CUT), at which the the target process temperature (T_r) has generally been uniformly reached at all measured points.

Heat penetration, pressure profile, and F0 value

The heat penetration profile during the sterilization of Rembiga satay using water spray overpressure retort mode demonstrated the effect of different pressure (1, 1.5, and 2 bar) and types of flexible packaging (aluminum foil and plastic retort pouch) on the heat transfer rate and temperature stability. The corresponding temperature and pressure profiles are presented in Figures 3 and 4. The sterilization process was performed at 116 °C for 15 min. Heat penetration measurements were performed at the coldest point inside the retort. During the sterilization process, the temperature and pressure inside the retort were recorded using a thermal logger, with data capture intervals of every one minute.

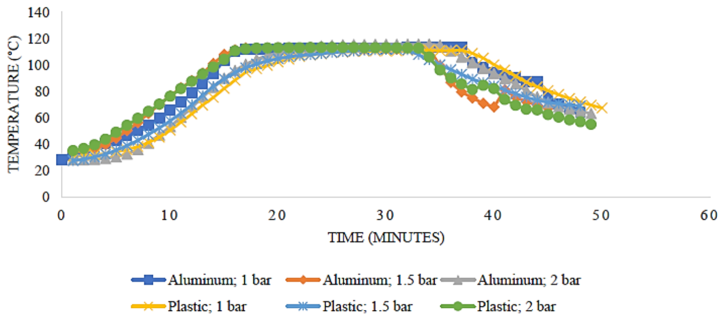

Figure 3: Temperature of Rembiga satay products in flexible packaging during sterilization using overpressure retort.

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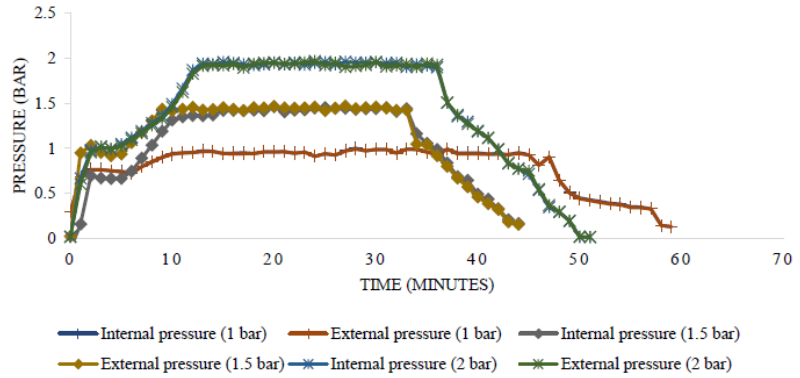

Figure 4: Pressure profiles of Rembiga satay products in flexible packaging during sterilization using overpressure retort.

Figure 3 shows the temperature profile of the product in the aluminum foil and plastic package during the heating process. The results of the heat penetration profile for aluminum packaging show high thermal conductivity and a faster heating time to reach the target temperature compared to plastic packaging, especially at a pressure of 1.5 bar. This can be seen from the graph, which shows a sharp rise in temperature during the initial phase of heating (0-20 min). In contrast, plastic packaging takes longer to reach the sterilization temperature because of its insulating properties. The effect of pressure is clearly visible in Figure 4; at 1 bar pressure, the rate of temperature increase is slower, so the time required to reach 116 °C is longer than that at higher pressures. A pressure of 1.5 bar provided the best balance, resulting in even heat penetration and temperature stability during the sterilization phase (20-35 min). A pressure of 2 bar allows the fastest heating time, but in the cooling phase (35-50 min), there are significant temperature fluctuations, which may increase the risk of package deformation owing to internal and external pressure differences. The results of a study using an overpressure retort on flexible packaging with various pressures (1, 1.5, and 2 bar) showed that there was no pressure difference inside and outside the packaging. This is because packaging of Rembiga satay is vacuum, so there is no air left in the packaging that can expand or contract. This causes the pressure inside and outside the package to remain balanced, even though the retort pressure varies. The accumulated minimum F_0 values obtained during the sterilization process are presented in Figure 5.

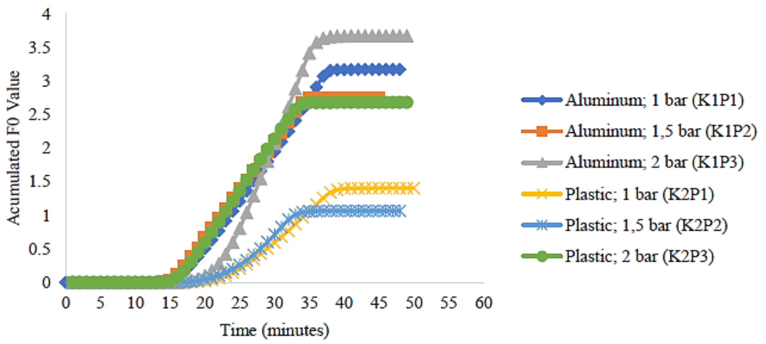

Figure 5: Accumulated minimum F_0 value as a function of the heating time of the Rembiga satay with flexible packaging.

The F_0 value is calculated based on the relationship between time and temperature during the sterilization process, and represents the equivalent duration at a reference temperature of 121.1 °C (Hariyadi, 2008). The F_0 value is used to ensure food safety by destroying harmful microorganisms, especially *Clostridium botulinum* spores (Biewendt, 1994). Based on the minimum F_0 values as shown in the curve, it can be seen that each treatment produces different minimum F_0 values (Figure 5). The results of the minimum F_0 values are as follows: K1P1 by 3.16; K1P2 by 2.75; K1P3 by 3.66; K2P1 by 1.40; K2P2 by 1.06; and K2P3 by 2.67 min.

Process design using the ball method

The results of the penetration test indicated that the sterilization process for Rembiga satay was insufficiently executed, as demonstrated by an F_0 value below the minimum standard of 3.0 min. Therefore, it is essential to redesign the process to improve the F value using the Ball method approach. The initial step in this redesign involves transforming the heat penetration data into a curve that depicts the temperature differential between the retort and the product during the heating phase (Kusnandar *et al.*, 2023). The Ball method operates under

[DOI: 10.18502/jfqhc.13.2.22138]

the assumption that T_r remains relatively constant throughout the process. Although minor temperature fluctuations may occur in overpressure retort systems, this method is still widely employed for estimating industrial thermal processes. However, when applied to low-conductivity flexible packaging, the Ball method may result in estimation errors. The measurement curves are shown in Figures 6 and 7.

The data used in the ball method calculations were selected from the treatments K1P2 for aluminum packaging and K2P2 for plastic packaging. This selection was based on the lowest F value produced in both treatments. From the linear curves of aluminum and plastic packaging heating, an exponential equation was obtained with slope values of 0.152 and 0.101, and constants of 253.83 and 233.83, respectively. Based on these equations, important parameters, such as fh and J values, were calculated, as well as additional parameters, including process data (CUT, T_r, T_i, P_t), calculation data (B, JI, I, B/fh, F_i, and U), and reading of fh/U values from table of fh/U values against log g (Table 2).

The calculation of the Ball method shows that F_0 value obtained is slightly lower than the trapezium method, which is 2.61 min for aluminum packaging and 0.93 min for plastic packaging. As the worst scenario, F_0 value under the current conditions is recommended based on the calculation results using the ball method. The obtained parameters were then used to redesign P_t to increase F_0 value to 4.0 min. The results of the alternative process development using the Ball method show that the P_t required to achieve F_0 value of 4.0 min is 20 min for aluminum packaging and 30 min for plastic packaging (Table 3). This process design is expected to produce Rembiga satay in flexible packaging with an F value that meets food safety standards and better product quality.

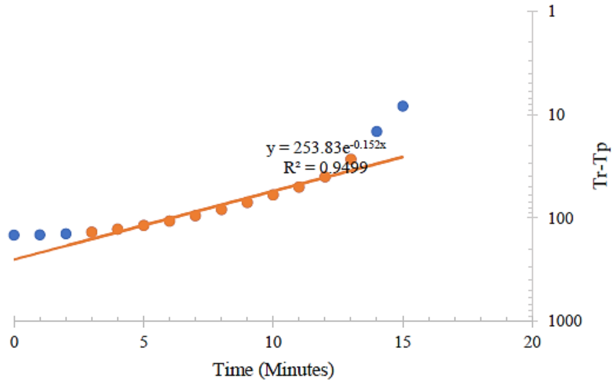

Figure 6: Semi-logarithmic plot of process time (P_t) versus the temperature difference between retort and product (T_r – T_p) for Rembiga satay packaged in aluminum pouches

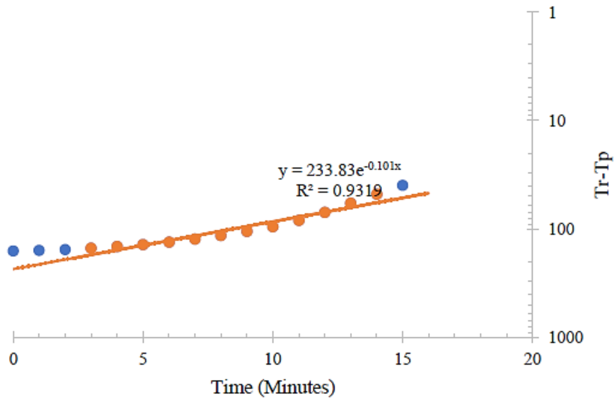

Figure 7: Semi-logarithmic plot of process time (P_t) versus the temperature difference between retort and product (T_r – T_p) for Rembiga satay packaged in plastic pouches

Table 2: Parameter values in the calculation of F_0 by the Ball method in flexible packaging

Aluminum			Plastic		
Parameter	**Value**	**Unit**	**Parameter**	**Value**	**Unit**
Pt	15	min	P_t	15	min
CUT	18	min	CUT	19	min
T_i	93.43	°F	T_i	81.41	°F
T_r	240.80	°F	T_r	240.80	°F
a	253.83		A	233.83	
b	0.15		B	0.10	
fh	15.15		Fh	22.80	
Ji	49.16		Ji	73.93	
I	147.37	°F	I	159.39	°F
J	0.33		J	0.46	
$B=P_t+0.4CUT$	22.20		$B=P_t+0.4CUT$	22.60	
B/Fh	1.46		B/Fh	0.99	
log ji	1.69		log ji	1.87	
log g	0.23		log g	0.87	
Fh/U	1.79		Fh/U	7.55	
U	8.46		U	3.02	
$F_i = 10$^((250-TR)/z)	3.24		Fi = 10^((250-TR)/z)	3.24	
F_0 = U/Fi	2.61	min	F_0 = U/Fi	0.93	min
F_0 trapezium	2.75	min	F_0 trapezium	1.06	min

Table 3: Process design to provide an F_0 value of 4.0 min

Aluminum			Plastic		
Parameter	**Value**	**Unit**	**Parameter**	**Value**	**Unit**
J	0.33		J	0.46	
fh	15.15		*fh*	22.80	
F_0	4.00	min	F_0	4.00	min
T_R	240.80	°F	T_r	240.80	°F
T_i	93.43	°F	T_i	81.41	°F
I	147.36		I	159.39	
Ji	49.16		Ji	73.94	
Fi	3.24	min	F_i	3.24	min
fh/U= *fh*/ F_0*F_i	1.17		*fh*/U= *fh*/ F_0*F_i	1.76	
log g	-0.11		log g	0.21	
log ji	1.69		log ji	1.87	
log ji-log g	1.81		log ji-log g	1.65	
B= *fh* (log ji-log g)	27.42		B= *fh* (log ji-log g)	37.73	
0.4CUT	7.20		0.4CUT	7.60	
Pt=B-0.4CUT	20.22	min	Pt=B-0.4CUT	30.13	min

Packaging integrity

Based on the process design calculations using the Ball method, the sterilization of Rembiga satay was subsequently applied using different pressure levels. The reduction in pressure was made because the heat penetration profile observed previously indicated no significant pressure difference between the inside and outside of the packaging. Therefore, it was possible to reduce the applied pressure without compromising the packaging integrity. The selection of 0.8 bar was based on the minimum required pressure to achieve a sterilization temperature of 116 °C in an overpressure retort system.

Observations on packaging leakage showed that sterilization at 0.8 bar, 1 bar, and 1.5 bar at 116 °C did not result in any leakage, either in aluminum foil packaging or retort pouch plastic packaging. The application of overpressure in the retort helps maintain the structural integrity of the packaging during heating, thereby preventing potential damage (Hariyadi, 2015). These findings are in line with a study by Koutchma *et al*., (2010), which reported that High Pressure-High Temperature (HP-HT) sterilization at 688 MPa and 130 °C on flexible packaging did not show any signs of leakage or seal surface damage.

Tensile strength

The area where the packaging is sealed is particularly susceptible to damage during sterilization because it acts as the main connection point between the layers of packaging materials. Consequently, conducting tensile strength tests in this region is crucial for assessing the seal's ability to endure the High Pressure-High Temperature (HP-HT) conditions encountered during the retort process. The results of the tensile strength test on the sealing area of the packaging (Figure 8) show that the type of packaging material and pressure during the retort process significantly affect the strength of the seal area. In the control treatment of the aluminum foil packaging, the tensile strength of the seal area reached 21.91 N/mm². In the sterilization treatment with 0.8 bar and 1 bar pressure, the tensile strength of the seal area decreased to 19.4 N/mm² and 17.65 N/mm², respectively, indicating the effect of pressure

[DOI: 10.18502/jfqhc.13.2.22138]

on the seal stability. A significant decrease was observed at a pressure of 1.5 bar, where the tensile strength dropped to only 11.42 N/mm², suggesting that high pressure can considerably weaken the seal area of aluminum foil packaging. The decrease in tensile strength may be associated with seal weakening, thermal stress, moisture exposure, and mechanical stress during heating and cooling cycles. The process at high temperatures can cause changes in the fracture surface of packaging (Panowicz *et al*., 2021).

The tensile strength of the nylon plastic seal area in the control treatment was the highest, reaching 28.36 N/mm², indicating excellent seal strength. However, the tensile strength of the seal area gradually decreased by increasing pressure, dropping to 23.62 N/mm² at 0.8 bar, 19.39 N/mm² at 1 bar, and 17.81 N/mm² at 1.5 bar. The reduction in the tensile strength of the nylon plastic seal under higher pressures suggests that retort pressure and temperature may lead to thermal degradation of the sealing material, thereby reducing the adhesive strength between the seal layers. Nylon-based packaging materials processed at high temperatures may undergo changes in their elastic properties, particularly in the plastic deformation zone, which contributes to the decreased mechanical strength of the seal area (Djukic *et al*., 2020).

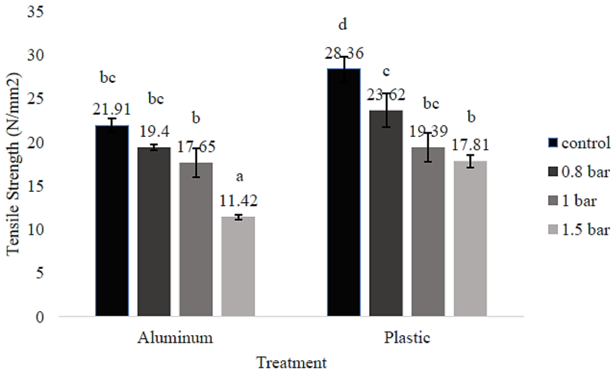

Figure 8: Tensile strength of flexible packaging at various retort pressures
Different superscript letters indicate significant differences based on Duncan's test ($p<0.05$).

Physical and chemical characteristics of rembiga satay

Based on previous analyses, including heat distribution, heat penetration profile, F_0 value, packaging integrity, and tensile strength, the optimal treatment was obtained using aluminum foil packaging at a pressure of 0.8 bar. Therefore, the analysis of texture, color, and proximate composition in this study focused on the sample sterilized under this selected treatment.

-TPA

Based on Table 4, the results of the texture test using TPA show that the hardness parameter of Rembiga satay before sterilization reached 4.87±0.70 kilogram-force (kgf), while after sterilization it dropped to 3.45±0.47 kgf. This decrease in hardness indicates that the sterilization process causes coagulation and denaturation of proteins and changes in fat structure, so that the meat has a softer texture (Purnomo, 2012). The cohesiveness value of Rembiga satay before sterilization was 0.49±0.12, while after sterilization it dropped to 0.26±0.05. Cohesiveness in thermally processed food items tends to decrease as the processing temperature increases (Xavier *et al.*, 2013).

Table 4: TPA results of Rembiga satay before and after sterilization at 116 °C and 0.8 bar pressure with aluminum retort pouch packaging

Parameter	Samples		*p-value t-test*
	Before sterilization	After sterilization (0.8 bar)	
Hardness (kgf)	4.87±0.70	3.45±0.47	0.044
Cohesiveness	0.49±0.12	0.26±0.05	0.045
Springiness (mm)	0.45±0.04	0.26±0.04	0.005
Gumminess (kgf.mm)	2.44±0.94	0.93±0.29	0.057
Chewiness (kgf.mm)	1.0±0.30	0.23±0.04	0.009

The springiness of Rembiga satay before sterilization was 0.45±0.04 mm, while after sterilization it dropped to 0.26±0.04 mm. The decrease in the springiness value is caused by sterilization treatment, which reduces the ability of the material to return to its original shape after the first pressure (Xavier *et al*., 2013). The gumminess value of the Rembiga satay was not significantly different from that of the other samples ($p>0.05$). Chewiness of the satay before sterilization was 1.0±0.30 kgf.mm, while after sterilization it decreased to 0.23±0.04 kgf.mm. The decrease in chewiness in this study was caused by heat treatment during sterilization, which resulted in protein denaturation

[DOI: 10.18502/jfqhc.13.2.22138]

and destruction of muscle cells during thermal processing (Majumdar, Roy and Saha, 2017). This study is in line with Rajkumar, Dushyanthan and Das (2010), who reported a decrease in hardness, cohesiveness, springiness, and chewiness after heating a retort for Chettinad-style goat curry products.

- Color

Based on the L* (brightness) parameter (Table 5), Rembiga satay before sterilization had a value of 46.40±0.22, indicating a brighter color. However, after sterilization, the value decreased to 31.42±0.12, reflecting a darker color. This change is caused by Maillard reaction and protein denaturation due to high heating, which produces dark-colored melanoidin through the mechanism of aldol reaction and Maillard intermediates (Bork *et al*., 2021). The a* (red intensity) parameter decreased from 13.41±0.29 to 8.45±0.07, which can be attributed to the degradation of meat pigments, such as myoglobin, which is oxidized during thermal processing. Similarly, the b* (yellow intensity) value decreased from 28.26±0.17 to 20.61±0.14, which may be due to chemical changes in fat and protein that affect the distribution of yellow pigment. Bindu, Ravishankar and Srinivasa Gopal (2007) argued that the Maillard reaction between sugars and amino acids can cause a decrease in color score in products processed by the retort method. Research by Rajkumar, Dushyanthan and Das (2010) on mutton curry with pouch retort process showed that the color parameters L*, a*, and b* decreased significantly due to the retort process.

Table 5: Color parameters (L*, a*, and b*) of Rembiga satay before and after sterilization at 116 °C and 0.8 bar pressure with aluminum retort pouch packaging

Parameter	Samples		*p-value t-test*
	Before sterilization	After sterilization (0.8 bar)	
L*	46.40±0.22	31.42±0.12	0.000
a*	13.41±0.02	8.45±0.07	0.000
b*	28.26±0.17	20.61±0.13	0.000

-Proximate content

Sterilization using a retort causes changes in the proximate content of the Rembiga satay. The results of the proximate analysis (Table 6) showed that water content of Rembiga satay increased from 60.12% to 61.26% after the sterilization process. Research by Shah *et al.*, (2017) on Rogan Josh products showed that meat water content reached 64.2% after sterilization with a retort. Ash contents were not significantly different. This indicates that sterilization did not cause significant mineral loss in the Rembiga satay. The analysis of fat content in the Rembiga satay showed a significant decrease from 6.50% to 5.20% after the sterilization process. A decrease also occurred in the protein content of Rembiga satay, which decreased from 31.69% to 30.03% after sterilization. Girish *et al.*, (2018) reported that there was a decrease in fat content in pork curry after retort sterilization process, which was due to processing at high temperatures. Leander *et al*. (1980) also reported that when meat is cooked, soluble protein and fat will escape from the tissue, which causes a decrease in protein levels in Rembiga satay after the sterilization process.

Table 6: Proximate content of Rembiga satay before and after sterilization at 116 °C and 0.8 bar pressure with aluminum retort pouch packaging

Parameter (%bb)	Sample		*p-value t-test*
	Before sterilization	After sterilization (0.8 bar)	
Water Content	60.12±0.12	61.26±0.06	0.007
Ash Content	1.80±0.17	2.37±0.12	0.065
Fat Content	6.50±0.17	5.20±0.03	0.009
Protein Content	31.69±0.03	30.03±0.04	0.001

Conclusion

The heat distribution test produced CUT values of 21 min for aluminum packaging and 23 min for plastic packaging. Retort pressure variation affected packaging integrity, as demonstrated by differences in tensile strength values after sterilization. Initial heat penetration trials resulted in insufficient F_0 values for several treatments. However, process redesign using the Ball method successfully increased the estimated F_0 values beyond the minimum commercial sterility requirements. Sterilization using an overpressure retort also significantly affected the physicochemical properties of Rembiga satay, including its texture profile, color characteristics, and proximate composition. Overall, the combination of retort pressure optimization and flexible packaging demonstrated the potential for the commercial sterilization of Rembiga satay using overpressure retort technology.

Author contributions

A conducted the experiment, analyzed data, interpreted

[DOI: 10.18502/jfqhc.13.2.22138]

statistical analysis, and wrote the main draft of the manuscript; E.H.P and S supervised the research and critically revised the article for important intellectual content; V.A participated in editing of the original draft. All authors read and approved the final manuscript.

Acknowledgments

The authors wish to thank Lembaga Pengelola Dana Pendidikan (LPDP), Ministry of Finance of the Republic of Indonesia, for financial support, and the Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia, for research facilitation.

Conflicts of interest

The authors declare no conflict of interest.

Funding

This research was partially funded by Lembaga Pengelola Dana Pendidikan (LPDP), Ministry of Finance of the Republic of Indonesia and partially facilitated through research projects supported by the Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research, and Technology.

Ethical consideration

Not applicable.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this study the author(s) used Paperpal in order to check grammar and spelling. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

References

AOAC (2012) *Official Method of Analysis of The Association of Official Analytical of Chemist*. 19th edn. Washington DC: AOAC International.

Ariyana, M.D., Handayani, B.R., Amaro, M., Rahayu, T.I., Afriliya, N.S., Widyastuti, S., Nazaruddin, Perdhana, F.F., Sinaga, Y.M.R. and Nurhikmat, A. (2023) 'Sensory quality of Rembiga satay in a retort pouch packaging with different sterilization time', in *7th International Conference on Food, Agriculture, and Natural Resources (IC-FANRES 2022)*, pp. 379-387. Available at: https://doi.org/10.2991/978-94-6463-274-3_35

Azhari, E., Aliredjo, M.S., Dharmayanti, N. and Purnomo, A.H. (2023) Sterilization of ready-to-eat products: Skipjack tuna (Katsuwonus pelamis Linnaeus 1778) in retort pouch packaging ', *Jurnal Pengolahan Hasil Perikanan Indonesia*, 26(1), pp. 77-86. Available at: https://doi.org/10.17844/jphpi.v26i1.41863

Biewendt, H.G. (1994) 'Sterilization values for ultrahigh heating of milk', *Food / Nahrung*, 38(3), pp. 233-252. Available at: https://doi.org/10.1002/food.19940380302

Bindu, J., Ravishankar, C.N. and Srinivasa Gopal, T.K. (2007) 'Shelf life evaluation of a ready-to-eat black clam (villorita cyprinoides) product in indigenous retort pouches', *Journal of Food Engineering*, 78(3), pp. 995-1000. Available at: https://doi.org/10.1016/j.jfoodeng.2005.12.040

Bork, L., Haase, P.T., Rohn, S. and Kanzler, C. (2021) 'Formation of melanoidins - Aldol reactions of heterocyclic and short-chain Maillard intermediates', *Food Chemistry*, 380, p. 131852. Available at: https://doi.org/10.1016/j.foodchem.2021.131852

BPOM (2019) *Protokol Validasi Kecukupan Panas Proses*. Jakarta: Badan Pengawas Obat dan Makanan.

Djukic, S., Bocahut, A., Bikard, J. and Long, D.R. (2020) 'Mechanical properties of amorphous and semi-crystalline semi-aromatic polyamides', *Heliyon*, 6(4), p. e03857. Available at: Available at: https://doi.org/10.1016/j.heliyon.2020.e03857

Girish, P.S., Nath, L., Thomas, R., Rajkumar, V. and Alam, T. (2018) 'Development of shelf stable ready-to-eat pork curry using retort processing technology', *Journal of Packaging Technology and Research*, 2(1), pp. 61-66. Available at: https://doi.org/10.1007/S41783-018-0026-5

Hariyadi, P. (2008) 'The food-canning industry in Indonesia: need for safety assurance regulation and quality optimisation', *Food Manufacturing Efficiency*, 2(1), pp. 45-48. Available at: https://doi.org/10.1616/1750-2683.00xx

Hariyadi, P. (2015) 'Overpressure retort: untuk produk pangan dengan kemasan inovatif', *Jurnal Food Review Indonesia*, 10(4), pp. 34-38.

Koutchma, T., Song, Y., Setikaite, I., Juliano, P., Barbosa-Cánovas, G.V., Dunne, C.P. and Patazca, E. (2010) 'Packaging evaluation for high-pressure high-temperature sterilization of shelf-stable foods', *Journal of Food Process Engineering*, 33(6), pp. 1097-1114. Available at: https://doi.org/10.1111/j.1745-4530.2008.00328.x

Kurniadi, M., Kusumaningrum, A., Nurhikmat, A. and Susanto (2019) Thermal process of fried rice in retort pouch packaging and its shelf life prediction', *Indonesian Journal of Industrial Research*, 11(1), pp. 9-21.

Kusnandar, F., Dafiq, H.H., Rahayu, W.P. and Irmawan, D. (2023) 'Heat treatment adequacy evaluation and redesign of commercial sterilization process for canned button mushrooms', *Jurnal Mutu Pangan*, 10(2), pp. Available at: https://doi.org/100-107. 10.29244/jmpi.2023.10.2.100

Leander, R.C., Hedrick, H.B., Brown, M.F. and White, J.A. (1980) 'Comparison of structural changes in bovine long and semitendinosus muscles during cooking', *Journal of Food Science*, 45(1), pp. 1-6. Available at: https://doi.org/10.1111/j.1365-2621.1980.tb03857.x

Majumdar, R.K., Roy, D. and Saha, A. (2017) 'Textural and sensory characteristics of retort-processed freshwater prawn (Macrobrachium rosenbergii) in curry medium', *International Journal of Food Properties*, 20(11), pp. 2487-2498. Available at: https://doi.org/10.1080/10942912.2016.1242139

Pamuji, M.W., Purnomo, E.H. and Sitanggang, A.B. (2021) 'Industrial practice for reducing defective sterile milk products produced using overpressure rotary retorts', *International Journal of Food Studies*, 10(1), pp. 221-232. https://doi.org/10.7455/ijfs/10.1.2021.a8

Panowicz, R., Konarzewski, M., Durejko, T., Szala, M., Łazińska, M., Czerwińska, M. and Prasuła, P. (2021) 'Properties of polyethylene terephthalate (PET) after thermo-oxidative

[DOI: 10.18502/jfqhc.13.2.22138]

aging', *Materials*, 14(14), p. 3833. Available at: https://doi.org/10.3390/ma14143833

Praharasti, A.S., Kusumaningrum, A., Nurhikmat, A., Susanto, A., Suprapedi, Maulani, M.D. and Wiratama, W. (2020) 'Estimation of sterilization value using general method and ball formula for beef rendang in retort pouch', *International Journal on Advanced Science, Engineering and Information Technology*, 10(5), pp. 2118-2125. Available at: https://doi.org/10.18517/ijaseit.10.5.8149

Prasetyo, H., Padaga, M.C. and Sawitri, M.E. (2013) 'Study on physico-chemical quality of beef in the market of Malang City ', *Jurnal Ilmu dan Teknologi Hasil Ternak*, 8(2), pp. 1-8.

Purnomo, H. (2012) *Teknologi Pengolahan Dan Pengawetan Daging*. Malang: Universitas Brawijaya Press.

Rajkumar, V., Dushyanthan, K. and Das, A.K. (2010) 'Retort pouch processing of Chettinad style goat meat curry a heritage meat product', *Journal of Food Science and Technology*, 47(4), pp. 372-379. Available at: Available at: https://doi.org/10.1007/s13197-010-0062-9

Rohmah, Mu'tamar, M.F.F. and Purwandari, U. (2018) 'Analisis sifat fisik daging sapi terdampak lama perendaman dan konsentrasi kenikir (Cosmos caudatus kunth)', *Jurnal Teknologi Industri Pertanian*, 12(1), pp. 51-54.

Satriawan (2019) *The effect of drying time on the quality and shelf life of instant rembigas satay*. Undergraduate thesis. Universitas Mataram.

Sembiring, Y.E.N. (2023) *Desain proses termal pada sterilisasi produk tongseng kambing dalam retort pouch di HNR Food*. Undergraduate thesis. IPB University.

Shah, M.A., Bosco, S.J.D., Mir, S.A. and Sunooj, K.V. (2017) 'Evaluation of shelf life of retort pouch packaged Rogan josh, a traditional meat curry of Kashmir, India', *Food Packaging and Shelf Life*, 12, pp. 76-82. Available at: https://doi.org/10.1016/j.fpsl.2017.04.001

Singh, R.P. and Heldman, D.R. (2009) *Introduction to Food Engineering*. 4th edition. Amsterdam: Academic Press.

Xavier, K.A.M., Ravishankar, C.N., Bindu, J. and Gopal, T.K.S. (2013) 'Textural and colour changes of mackerel (Rastrelliger kanagurta) thermal processed at different retort temperatures', *Fishery Technology*, 50, pp. 133-138.

Yuriandala, Y., Syamsiah, S. and Saptoadi, H. (2016) 'Pirolisis campuran sampah plastik polistirena dengan sampah plastik berlapisan aluminium foil (multilayer)', *Jurnal Sains and Teknologi Lingkungan*, 8(1), pp. 10-20. Available at: https://doi.org/10.20885/jstl.vol8.iss1.art2

[DOI: 10.18502/jfqhc.13.2.22138]

