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Effects of *Sous-vide* Cooking on the Initial Yield, Peak Force, and Elastic Modulus of Cooked Beef *Semitendinosus*

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ABSTRACT

The objective of this study was to compare the traditional cooking method with sous-vide cooking at various cooking temperatures and times on the initial yield, peak force, and elastic modulus of *semitendinosus* (ST) beef. This study also examined the colour properties, cooking loss, and water retention of ST beef. Sous-vide samples were cooked inside vacuumized pouches at temperatures 60, 70, and 80 ℃ for 3 and 6 h. Meanwhile, the traditional cooking method was treated at 90℃ for 30 min. Reduced the initial yield, peak force, and elastic modulus of ST beef could be attained in 6 h at 60 ℃. Higher temperature and prolonged cooking time seem to cause meat to be tougher, likely due to the longitudinal myofibrils shrank. In terms of water retention and cooking loss, sous-vide cooked at 60 °C (regardless of cooking time) significantly exhibited better water retention and lower cook loss. This mild cooking temperature also best preserved the colour properties of lightness (L^*) and redness (a^*) than the other treatments.

Keywords: Sous-vide, *semitendinosus*, beef, initial yield, peak force, elastic modulus

INTRODUCTION

Sous vide is a cooking process that immerses vacuum packaged in a water bath under controlled temperature and time (Ismail, Hwang, & Joo, 2019b). Sous vide is a French word referred to under vacuum and cooked at mild temperature, and frequently described as low-temperature and long-time cooking (LTLT) (Ayub & Ahmad, 2019). LTLT cooking method can cook the food evenly from edge to edge without overcooking outside of the meat. This LTLT method can retain moisture inside of the meat. However, conventional cooking cannot allow greater control over doneness and it negatively affects the meat quality as the higher temperature withdraw the water from meat cause the meat to be less juicy, increase toughness, loss of nutrient, and pale in colour (Baldwin 2012). Sous vide cooking uses temperature lower than the boiling point in the range of 50-80^{o}C and cooking time from 2 to 48 hours, depends on the type of meat, size of cut meat, and intramuscular connective tissue and myofibrillar protein component (Baldwin, 2012; Ismail et al., 2019b).

The most significant trait in meat consumption is tenderness, a textural property (Dominguez-Hernandez, Salaseviciene, & Ertbjerg, 2018). It is necessary to have or adjust meat texture to satisfy customer demands for tenderness. Meat microstructure has a significant impact on tenderness and hardness. The amount of connective tissue, sarcomere length (the repeating unit of myofibril), and post-mortem degradation of structural proteins are widely recognized as the three key determinants of tenderness in raw meat (James & Yang, 2012). The heat treatment induces modification of the meat structure and its constituents, which can explain the desirable eating quality traits obtained. Denaturation, aggregation, and degradation of myofibrillar, sarcoplasmic and connective tissue proteins occur depending on the combination time and temperature during the LTLT treatment (Ismail et al., 2019b).

Initial yield, peak force and elastic modulus are the parameters that have been measured and generated by the Texture Profile Analysis (TPA) instrument. The peak force expressed as the force at the highest peak (hardness) is the parameter that can be obtained from the exponent software data after running the test (Chandra & Shamasundar, 2015). Initial yield is the first major inflection on force-distance curve that reflects the strength of the myofibrils (Bekhit et al., 2020). The combination of two forces can be related to toughness (Bekhit et al., 2020). TPA and Warner-Bratzler have similarities in concept but differ in the type of device and dispersion of the data (de Huidobro, Miguel, Blázquez, & Onega, 2005). The elastic modulus is described as the elastic and viscous behaviour of meat which that related to protein denaturation (Ismail et al., 2019b).

Muscle type fibre is one of the contributions of meat muscle tenderness or toughness. *Longissimus dorsi* (LD) and *semitendinosus* (ST) are the larger muscles of beef cattle (Kirchofer, Calkins, & Gwartney, 2002). Both are categorized as tough in the ranking of beef muscles for tenderness (Calkins & Sullivan, 2007). The *semimembranosus* (SM) is categorized as intermediate tough meat muscle is also recognized along with the ST muscle specifically around the bottom of the round cut. However, in the present study, ST muscles were used in determination of break force of connective tissue and myofibrillar components at different temperatures and cooking times. The changes in colour properties, cooking loss, and water retention was also investigated.

MATERIALS AND METHODS

Raw materials and sampling

The study was carried out on beef *semitendinosus* (ST) sous-vide cooked at different temperatures and times. Raw and cooked samples were from 24 months castrated male bovine obtained from a local meat processing plant at 36 h postmortem. The ST muscles of about 16 kg weight were cut into steaks 2.5 cm thick (approximately 70 – 90 g in weight). The sous-vide cooking steaks were placed in vacuum packaging (nylon) and kept at 4 ℃ prior to heat treatment at 48 h postmortem.

In this trial, all steaks were cooked by sous-vide at 60, 70, and 80 ºC for 3 and 6 hr (n = 4). For the traditional cooking (labelled as control), the steaks were selected from the distal and proximal end which were the excess cuts from ST muscles (n = 4). All the sous-vide treatment were cooked using an electronic water bath (Water bath WNB 7, Germany), while for the traditional cooking method, the steaks were cooked inside polypropylene plastic bag (without vacuum) using an induction stove preheated to 90 ℃ for 30 min.

Texture profile analysis

The meat samples were cut into small cube with a dimension of 1 x 1 x 1 cm. The small cube cut samples were placed under cylindrical probe (P/75, 7 mm Compression Platen). Probe operation was set according to a default setting for meat, where constant speed of pre-test, test speed, and post-test was set to 1.00, 5.00 and 5.00 mm, respectively. Samples was compressed at a crosshead speed of 5.0 mm at final strain of 50% through 2- cycle sequence with load cell of 30 kg. This texture analysis was performed using a texture analyzer (Texture analyzer, Double Arm TA.XT Plus, Stable Micro System Ltd, England).

Initial yield, peak force, and elastic modulus

Initial yield, peak force and elastic modulus value were obtained from TPA measurement. Initial yield (the first significance peak at first compression) and peak force (the highest peak measured during first cycle) obtained from force-deformation curve. Elastic modulus (E) which derived from Hooke's law is equal to the ratio of stress to strain, were calculated as shown in equation below. The yield force of the first compression were divided over the cross-section area to obtain stress value (σ), while strain value (ε) was obtained by dividing the displacement data to the initial sample height.

$$\text{Elastic modulus, E} = \frac{\text{Stress value, } \sigma}{\text{Strain value, } \varepsilon}$$

$$\text{Stress value, } \sigma = \frac{\text{Force exerted on sample, F}}{\text{Area on which force exerted, A}}$$

$$\text{Strain value, } \varepsilon = \frac{\text{Change in sample height, } \Delta\text{L}}{\text{initial sample height, Lo}}$$

Cooking loss and water retention

The cooking loss was measured after removing the steaks from vacuum bag and wiped with clean wipe to remove excess moisture on meat surface. The percentage of cooking loss was measured by a weight difference before and after cooking of steaks. Water retention was determined by oven drying of 4 g samples at 105 ℃ for 16 h, based on AOAC (2002) official method 950.46.

Colour properties

The colour of raw and cooked steaks was measured using Konica Minolta Colorimeter (Chroma meter, CR-400, Japan). The instrument was equipped with standard illuminant D65, 2° position of observer with 8 mm reading distance between the sample. The instrument was calibrated before each series of measurement using calibration white ceramic plate (Y= 85.0, x= 0.3155, y= 0.3213) and L*(lightness), a*(redness) and b*(yellowness) values of steaks were recorded.

Statistical analysis

All data were analyzed by one-way analysis of variance (ANOVA) as the sole source of variation and a Duncan test for multiple mean comparisons. All statistical analyses were performed using measurement means and standard deviation with the SPSS version 20 (IBM Corp., SPSS, Statistic, Armonk, NY, USA). Each trial was run in triplicate.

RESULTS AND DISCUSSION

Initial yield, peak force, and elastic modulus

The initial yield, peak force, and elastic modulus at different cooking conditions are shown in Table 1. Cooking temperatures and times give significant effect to the textural properties of cooked beef ST. Sous-vide meat cooked at lower temperatures and prolonged heating caused a significantly lower (p<0.05) initial yield and peak force than that cooked by traditional cooking at 90 °C for 30 min. Initial yield reflects the myofibrillar contribution to meat toughness, and higher values indicate tough meat. According to Dominguez-Hernandez et al. (2018) and Warner et al. (2021) peak force reflects primarily myofibrillar properties and much lesser the connective tissue contribution to meat toughness. Meanwhile, according to Baldwin (2012) and Alahakoon, Oey, Bremer, and Silcock (2019), a decrease in the toughness of meat with prolonged sous vide time can contribute to the collective impact of the weakening of structural proteins of myofibrils and collagen element. Alahakoon et al. (2019) observed that sous-vide treatment at 60 °C with increasing cooking time (12, 18, 24 h) decreased the peak force. Similarly, Roldán, Antequera, Hernández, and Ruiz (2015) also found hardness of lamb loins sous vide significantly lower after treatment for 24 h at 60 °C. This can be evidenced that higher temperatures could not always reach tender meat due to the longitudinal shrinkage (sarcomere shorten). Instead, a lower temperature (60 °C) and prolonged cooking could give better tenderness, likely due to the transverse shrinkage and solubility of collagen (Ismail et al., 2019b).

For elastic modulus, quantitatively the trend of increasing elastic modulus depending on an increasing heating temperature. The increased elastic modulus of the whole meat system is a sign of conversion from a viscoelastic to less elastic or less tender meat (Tornberg, 2005). The elastic modulus of control (30 min, 90℃) shows no significant difference ($p>0.05$) between samples treated for 3 and 6 h at 60, 70, and 80 ℃, except for 6 h at 80℃. Interestingly, sous-vide cooked at 60℃ for 3 h and 6 h shows the lowest elastic modulus in tandem to the lower initial yield and peak force described in Table 1. When temperature and time increase, the elastic modulus gradually increases, and meat samples become tougher. Nevertheless, the temperature was the main factor to modify the textural properties (tender/tough) of meat. The control sample cooked at a higher temperature (90 °C) even at a shorter period contributed to the higher elastic modulus and tensile stress. According to previous literature (Baldwin, 2012; Ismail et al., 2019b; Tornberg, 2005), a more significant tensile stress caused by the increase of elastic modulus resulted in the meat cooked over 65 °C.

Table 1. The Initial yield, peak force, and elastic modulus of cooked meat at different cooking time and temperature.

Time	Temperature °C	Initial yield, N	Peak force, N	Elastic modulus, kPa
30 min	90	64.90 ± 3.62^{b}	78.95 ± 0.66^{b}	5.05 ± 0.32^{bc}
3 h	60	26.87 ± 0.37^{d}	36.05 ± 2.35^{d}	4.63 ± 0.17^{c}
	70	45.36 ± 0.52^{c}	51.25 ± 0.99^{c}	4.96 ± 0.28^{bc}
	80	77.90 ± 0.71^{a}	88.83 ± 0.71^{a}	5.97 ± 0.51^{ab}
6 h	60	16.94 ± 0.49^{e}	24.65 ± 0.53^{e}	4.37 ± 0.22^{c}
	70	26.32 ± 0.38^{d}	34.81 ± 0.78^{d}	5.95 ± 1.17^{ab}
	80	43.83 ± 0.66^{c}	53.26 ± 1.76^{c}	6.56 ± 0.41^{a}

Each value expressed as mean ± standard deviation (SD).
Different superscript letters (a-e) within the same column indicates a mean significant difference between treatments ($p < 0.05$).

Cooking loss and water retention

The cooking loss due to the thermal treatment affects the juiciness and yield of the final products. The effect of different times and temperatures on cooking loss and water retention is shown in Table 2. Generally, cooking loss of meat increases with the cooking temperature and cooking time. Sous-vide cooked at a shorter period (3 h) showed a lower ($p < 0.05$) cooking loss than prolonged cooking time (6 h). Meanwhile, a higher temperature in the traditional cooking method contributed a higher loss as shown in control (90 °C) cooked for only 30 min. The higher cooking loss of the current study is in line with Alfaia et al. (2010) and Vaudagna et al. (2002). They found that cooking losses increased with the meat's final internal temperature. The other reasons for lower cooking loss in sous-vide cooked samples were likely due to the vacuum-sealed pouch, which prevented moisture evaporation to the air (Baldwin, 2012). The increase in cooking loss and the temperature rise attributed to collagen and actin denaturation take place above 60 °C and result in muscle fibre shrinkage parallel to the fibre axis, which, in turn, squeezes out the water present between the fibres (Ishiwatari, Fukuoka, Hamada-Sato, & Sakai, 2013). Cooking loss for sous vide beef in this study was lower than reported by Ismail, Hwang, and Joo (2019a). This might be due to external factors such as different animal, breed, sex, animal cuts, and internal factors such as condition after post-slaughtering, pH, and cooking conditions.

The effects of cooking time and temperature on water retention is presented in Table 2. Cooking time and temperature significantly affected moisture content, as the percentage of moisture content decreased with temperature ($p < 0.05$). The water retention was decreased significantly ($p < 0.05$) at temperature 80 °C for both 3 and 6 h, and no difference was observed between sous-vide cooked at 80 °C for 6 h and control at 90 °C for 30 min. Again, temperature plays a significant effect on the water retention of meat over cooking time. From

Table 1, the data obtained between water retention and cooking loss was inversely proportionate to each other. These results were in agreement with previous literature, studied by Ismail et al. (2019b) on beef, Ismail et al. (2019a) on goat meat, Roldan, Antequera, Martin, Mayoral, and Ruiz (2013) on lamb loins, and Sanchez Del Pulgar, Gazquez, and Ruiz-Carrascal (2012) on pork. The temperature increase caused a structural change and protein denaturation, resulting in weak water retention and a higher cooking loss (James & Yang, 2012).

Table 2. Cooking loss and moisture content of cooked muscle at different cooking time and temperature

Time	Temperature °C	Cooking Loss (%)	Moisture content (%)
30 min	90	38.00 ± 0.01^{c}	58.30 ± 0.33^{d}
3 h	60	24.09 ± 0.01^{g}	68.85 ± 0.54^{a}
	70	34.14 ± 0.00^{e}	63.52 ± 0.22^{c}
	80	47.71 ± 0.00^{b}	54.21 ± 0.55^{e}
6 h	60	27.67 ± 0.01^{f}	67.06 ± 0.23^{b}
	70	36.50 ± 0.01^{d}	64.09 ± 0.29^{c}
	80	49.24 ± 0.02^{a}	58.32 ± 0.99^{d}

Each value expressed as mean ± standard deviation (SD)
Different superscript letters (a-g) within the same column indicates mean significant differences between treatments ($p < 0.05$).

Colour properties

The mean values of lightness (L^*), redness (a^*), and yellowness (b^*) of control and sous-vide meat at different temperatures and times is presented in Table 3. The L^* values of control and sous-vide cooked at 80℃ for 3 and 6 h were no statistically different ($p > 0.05$). This clearly proved that increasing temperature (regardless of cooking time) significantly reduces the lightness of the meat samples. The higher L^* values indicate the closest to absolute white, and sous-vide cooked at lower temperature (60 °C) exhibited a lighter colour than treatment with higher temperature (> 70 °C). The higher lightness values were related to the higher water retention (Ismail et al., 2019b) and expressed water remain permeate on the cut surface of meat (Rees, Trout, & Warner, 2003). These findings were in accordance with those studies reported by Sanchez Del Pulgar et al. (2012) and Roldan et al. (2013).

In the present study, the a^* values ($p<0.005$) were mainly affected by the cooking temperature as shown in Table 3. The highest redness value was observed in sous-vide cooked at 60 °C for both 3 and 6 h whereas there was no significant difference in a^* values of sous-vide cooked at 70 and 80℃ (for both 3 h and 6 h) with the control. As far as cooking temperature effect on a^* values, the significant increases at the lower temperature could be the denaturation of myoglobin occurs at slower rate. In this sense, the degree of myoglobin denaturation increased as temperature and cooking time increased, with the most extreme when temperature rose beyond 70 ℃ (Hunt, Sørheim, & Slinde, 1999). This clearly be seen in Table 3; control treated at higher temperature and sous-vide cooked for an extended time (6 h) represented the lower a^* values. As shown in Fig 1, the reddish-pink colour attributed by sous-vide cooked ST at 60 ℃, meanwhile the apparent changes to greyish-dull brown colour were observed for samples cooked at 70 ℃, 80 ℃, and 90 ℃, regardless of cooking time. According to Ismail et al. (2019a) the changes of redness properties of meat was more intense with prolonged heating. Similar findings have been reported previously for sous-vide beef (Vaudagna et al., 2008) and pork (Sanchez Del Pulgar et al., 2012). Contrarily, Dominguez-Hernandez et al. (2018) reported that time of cooking does not affect the a^* values of sous-vide cooked meat.

In addition, there was a significant effect showing that increasing in temperature and time increase the *b** values, but the results were not consistent. The increase in the b* value was associated to the formation of metmyoglobin in cooked meat, resulting in brownish colour.

Table 3. Means of colour properties (*L**, *a**, *b**) of cooked *semitendinosus* at different cooking temperature and time.

Time	Temperature °C	Lightness, *L**	Redness, *a**	Yellowness, *b**
30 min	90	37.50 ± 0.33^{e}	6.72 ± 0.44^{c}	9.35 ± 0.85^{b}
3 h	60	48.79 ± 0.27^{b}	13.31 ± 1.32^{a}	11.31 ± 1.12^{ab}
	70	40.63 ± 0.30^{d}	7.39 ± 0.55^{c}	9.99 ± 1.12^{ab}
	80	37.06 ± 0.11^{e}	7.17 ± 0.40^{c}	9.55 ± 0.34^{b}
6 h	60	51.36 ± 0.37^{a}	9.34 ± 1.15^{b}	10.04 ± 2.04^{ab}
	70	42.74 ± 0.18^{c}	7.40 ± 0.69^{c}	10.16 ± 0.52^{ab}
	80	37.27 ± 0.31^{e}	6.58 ± 0.40^{c}	12.04 ± 0.70^{a}

Each value expressed as mean ± standard deviation (SD).
Different superscript letters (a-e) within the same column indicates mean significant differences between treatments ($p < 0.05$).

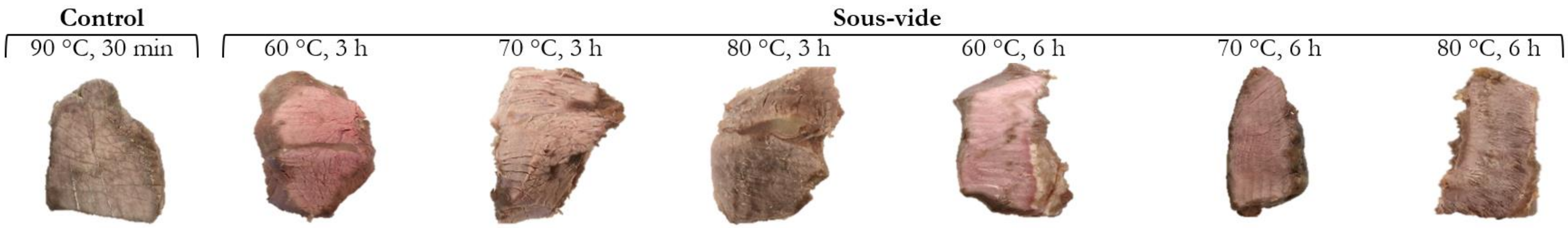

Fig 1. Cuts of cooked beef different time (30 min, 3 h, 6 h) and temperature (60 °C, 70 °C, 80 °C, 90 °C).

CONCLUSION

Temperature and time play significant roles in modifying the toughness of *semitendinosus* cuts. However, the effect of temperature strongly influences the breaking strength of meat than cooking time. Lowering the cooking temperature and prolonged cooking time (at 60 °C, 6 h) significantly reduce the initial yield, peak force, and elastic modulus, which in turns provide more tender meat. Sous-vide cooked at 60 °C (both 3 and 6 h) was successfully preserved redness properties and prevented excessive cooking loss as compared to the traditional cooking method.

REFERENCES

Alahakoon, A. U., Oey, I., Bremer, P., & Silcock, P. (2019). Process optimisation of pulsed electric fields pre-treatment to reduce the sous vide processing time of beef briskets. *International Journal of Food Science & Technology, 54*(3), 823-834. doi:https://doi.org/10.1111/ijfs.14002

Alfaia, C. M. M., Alves, S. P., Lopes, A. F., Fernandes, M. J. E., Costa, A. S. H., Fontes, C. M. G. A., . . . Prates, J. A. M. (2010). Effect of cooking methods on fatty acids, conjugated isomers of linoleic acid and nutritional quality of beef intramuscular fat. *Meat Science, 84*(4), 769-777. doi:https://doi.org/10.1016/j.meatsci.2009.11.014

AOAC. (2002). Official methods of analysis. 16th ed. Arlington: Association of Official Analytical Chemists.

Ayub, H., & Ahmad, A. (2019). Physiochemical changes in sous-vide and conventionally cooked meat. *International Journal of Gastronomy and Food Science, 17*, 100145. doi:https://doi.org/10.1016/j.ijgfs.2019.100145

Baldwin, D. E. (2012). Sous vide cooking: A review. *International Journal of Gastronomy and Food Science, 1*(1), 15-30. doi:https://doi.org/10.1016/j.ijgfs.2011.11.002

Bekhit, A., Dunshea, F., Morton, J., Ha, M., Purslow, P., Miller, R., . . . Li, X. (2020). Meat tenderness and texture– historical perspective and recent advances. *Meat and Muscle Biology, 4*. doi:10.22175/mmb.10489

Calkins, C. R., & Sullivan, G. (2007). Ranking of beef muscles for tenderness. *Universidad de Nebraska*, 1-5.

Chandra, M. V., & Shamasundar, B. A. (2015). Texture Profile Analysis and Functional Properties of Gelatin from the Skin of Three Species of Fresh Water Fish. *International Journal of Food Properties, 18*(3), 572-584. doi:10.1080/10942912.2013.845787

de Huidobro, F. R., Miguel, E., Blázquez, B., & Onega, E. (2005). A comparison between two methods (Warner–Bratzler and texture profile analysis) for testing either raw meat or cooked meat. *Meat Science, 69*(3), 527-536. doi:https://doi.org/10.1016/j.meatsci.2004.09.008

Dominguez-Hernandez, E., Salaseviciene, A., & Ertbjerg, P. (2018). Low-temperature long-time cooking of meat: Eating quality and underlying mechanisms. *Meat Science, 143*, 104-113. doi:https://doi.org/10.1016/j.meatsci.2018.04.032

Hunt, M. C., Sørheim, O., & Slinde, E. (1999). Color and heat denaturation of myoglobin forms in ground beef. *Journal of Food Science, 64*(5), 847-851. doi:https://doi.org/10.1111/j.1365-2621.1999.tb15925.x

Ishiwatari, N., Fukuoka, M., Hamada-Sato, N., & Sakai, N. (2013). Decomposition kinetics of umami component during meat cooking. *Journal of Food Engineering, 119*(2), 324-331. doi:https://doi.org/10.1016/j.jfoodeng.2013.05.040

Ismail, I., Hwang, Y.-H., & Joo, S.-T. (2019a). Effect of different temperature and time combinations on quality characteristics of sous-vide cooked goat *gluteus medius* and *biceps femoris*. *Food and Bioprocess Technology, 12*, 1000-1009. doi:https://doi.org/10.1007/s11947-019-02272-4

Ismail, I., Hwang, Y.-H., & Joo, S.-T. (2019b). Interventions of two-stage thermal sous-vide cooking on the toughness of beef semitendinosus. *Meat Science, 157*, 107882. doi:https://doi.org/10.1016/j.meatsci.2019.107882

James, B. J., & Yang, S. W. (2012). Effect of cooking method on the toughness of bovine *M. semitendinosus*. *International Journal of Food Engineering, 8*, 1-18. doi:https://doi.org/10.1515/1556-3758.2762

Kirchofer, K., Calkins, C., & Gwartney, B. (2002). Fiber-type composition of muscles of the beef chuck and round. *Journal of Animal Science, 80*, 2872-2878. doi:10.2527/2002.80112872x

Rees, M. P., Trout, G. R., & Warner, R. D. (2003). The influence of the rate of pH decline on the rate of ageing for pork. I: interaction with method of suspension. *Meat Science, 65*(2), 791-804.

Roldán, M., Antequera, T., Hernández, A., & Ruiz, J. (2015). Physicochemical and microbiological changes during the refrigerated storage of lamb loins sous-vide cooked at different combinations of time and temperature. *Food Science and Technology International, 21*(7), 512-522. doi:https://doi.org/10.1177/1082013214552861

Roldan, M., Antequera, T., Martin, A., Mayoral, A. I., & Ruiz, J. (2013). Effect of different temperature-time combinations on physicochemical, microbiological, textural and structural features of sous-vide cooked lamb loins. *Meat Science, 93*(3), 572-578. doi:https://doi.org/10.1016/j.meatsci.2012.11.014

Sanchez Del Pulgar, J., Gazquez, A., & Ruiz-Carrascal, J. (2012). Physico-chemical, textural and structural characteristics of sous-vide cooked pork cheeks as affected by vacuum, cooking temperature, and cooking time. *Meat Science, 90*(3), 828-835. doi:https://doi.org/10.1016/j.meatsci.2011.11.024

Tornberg, E. (2005). Effects of heat on meat proteins - Implications on structure and quality of meat products. *Meat Science, 70*(3), 493-508. doi:https://doi.org/10.1016/j.meatsci.2004.11.021

Vaudagna, S. R., Pazos, A. A., Guidi, S. M., Sanchez, G., Carp, D. J., & Gonzalez, C. B. (2008). Effect of salt addition on sous vide cooked whole beef muscles from Argentina. *Meat Science, 79*(3), 470-482. doi:https://doi.org/10.1016/j.meatsci.2007.11.001

Vaudagna, S. R., Sánchez, G., Neira, M. S., Insani, E. M., Picallo, A. B., Gallinger, M. M., & Lasta, J. A. (2002). Sous vide cooked beef muscles: effects of low temperature–long time (LT–LT) treatments on their quality characteristics and storage stability. *International Journal of Food Science & Technology, 37*(4), 425-441. doi:https://doi.org/10.1046/j.1365-2621.2002.00581.x

Warner, R., Miller, R., Ha, M., Wheeler, T. L., Dunshea, F., Li, X., Purslow, P. (2021). Meat Tenderness: Underlying Mechanisms, Instrumental Measurement, and Sensory Assessment. *Meat and Muscle Biology, 4*(2), 17-25.

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