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COMBINED EFFECTS OF DIFFERENT TEMPERATURE-TIME MODES ON THE MECHANICAL CHARACTERISTICS OF SOUS-VIDE AND CONVENTIONAL OVEN-COOKED CAMEL MEAT

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Keywords: *camel meat; sous-vide; conventional oven; mechanical properties*

Abstract
Camel meat was subjected to sous-vide and conventional oven cooking at different combinations of temperature (70, 80, 90, and 100 °C) and time (30, 60, 90, 120, 150, and 180 minutes). The influence on the mechanical properties (shear force, penetration force, and texture profile) were studied. In general, our results revealed significant differences ($p \leq 0.05$) between the sous-vide and conventional oven cooking methods for most of the studied parameters. Increasing the sous-vide cooking temperature-time combination resulted in lower shear and penetration forces. Moreover, a clear decline in meat hardness, chewiness, and gumminess was observed. Sous-vide cooking depends on water for cooking, where the thermal conductivity coefficient is high and uniform. The textural changes during sous-vide cooking made the meat more homogenous and tender. Conversely, the conventional oven method depends on dry air heat where the thermal conductivity coefficient is low in comparison with sous-vide cooking. The elevation of the penetration force, hardness, chewiness, and gumminess along with the increasing temperature-time values combination was obvious for the conventional oven-cooked meat.

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Introduction

Sous-vide or "under vacuum" cooking is a method of cooking food inside the heat-stable vacuumed pouches under the controlled temperature and time conditions [1]. Unlike sous-vide cooking, convection cooking involves using a conventional oven with a heating element to raise the temperature to a preset level, and hot air circulates within the oven's cavity. Convection cooking uses higher temperature settings than sous vide cooking. This is caused by the fact that air does not conduct heat as well as water does. Because of the longer cooking time at a higher temperature, the food may be over-cooked on the outside and undercooked in the center. Sous-vide cooking has been endorsed worldwide for meat cooking, possibly for its simplicity and potential in enhancing meat tenderness [2,3,4] and for its ability to improve the sensory characteristics in a range of meat varieties, particularly firm meat cuts, due to the uniform thermal dispersion during the vacuumed cooking process [5,6]. Moreover, the growing consumer awareness towards healthy and quality food products has changed the consumers' preferences for high quality, freshly preserved food, with minimum volume of additives, and with the lowest degree of food processing [7]. Various studies have been carried throughout the recent few years for better understanding of the effect of sous-vide cooking on meat quality characteristics such as physical, and biochemical properties [8,6,9,10,11]. However, meat texture remains the most important parameter of consumptive quality of meat [12]. The recommended sous-vide cooking temperature-time combinations vary for different types of meat, for example, a temperature-time combination around 58–63 °C for 10–48 hours is recommended for beef, pork and lamb [13]. Camel meat is another type of red meat, and it is known to have similar characteristics as beef [14], in fact, it has nutritive advantage over beef or lamb due to its low proportion of intramuscular fat, low cholesterol content, and high iron content [15]. Very insufficient research is available about the use of novel processing techniques such as sous-vide which can improve the consumer acceptability of camel meat. Camel meat is tougher than almost all other types of red meat [14] and hence, may require different sous-vide cooking temperature-time combinations. It has been widely noted that consumers are ready to pay more for meat with high-quality characteristics that satisfy their eating aspirations on a continuous basis [16,17]. Meat palatability and quality characteristics, particularly the mechanical characteristics (shear force, penetration force, and texture) are affected by a complex series of processing parameters such as processing temperature and time [18]. Structural changes of meat tissue occur during the various thermal processes. Accordingly, the meat proteins denaturize [19] and cause structural changes (fiber shrinkage, aggregation, solubilisation of collagen and connective tissues, formation of sarcoplasmic and myofibril gel) [20]. Hence, the mechanical characteristics of meat are altered [21]. The tenderness of meat is inversely proportional to shear force [20]. Previous studies on sous-vide cooking were mainly focused on beef [22,23,24], goat [25], and chicken meat [26]. However, fewer studies investigate the effects of sous-vide cooking on camel meat quality, particularly the mechanical characteristics. The selection of accurate sous-vide cooking temperatures and duration of exposure is fundamental and may greatly improve the tenderness and overall qualities of the tough camel meat. This study is aimed at evaluating the combined effects of different temperature-time modes on the mechanical characteristics of sous-vide and conventional oven-cooked camel meat.

Objects and methods

Preparation of meat samples

Camel meat samples (shoulder cutlets muscle: Latissimus dorsi) were prepared from healthy male camels between 6/7 months old, obtained from a company specialized in selling fresh camel meat (Umm Al Hammam Butchery — Riyadh, KSA), the meat was delivered within 24 hours after slaughter. *Longissimus dorsi* shoulder cutlets samples were prepared and shaped into similar sizes (8 × 6 × 1.3 cm chops) as described by Palka and Daun [27], and Dawood [21]. The prepared samples were then placed in plastic bags and stored in deep freeze at –20 °C for 72 hours prior to processing.

Cooking methods

Two different cooking methods were used in this study: sous-vide and conventional oven cooking. Before cooking, the prepared samples were thawed for 24 hours in the refrigerator at 3 °C [19]. For the sous-vide cooking the thawed samples were placed in sous-vide cooking pouches, (20.3×15.2 cm and 85 μm thickness) obtained from the company Sous-vide Supreme, Broomfield — USA, and vacuum sealed by a vacuum device as described by Baldwin et al [5]. The samples were then placed in a thermostatic circulating water bath (GFL Water bath, Model1083, Germany) at different temperatures (70, 80, 90, 100 °C) and time duration (30, 60, 90, 120, 150 and 180 minutes) combinations as described by Garcia-Segovia et al [23]. For the conventional oven cooking, a forced convection oven (Drying oven Binder, Model E240. Germany) was heated up to 100 °C, the thawed samples were then placed inside and cooked at the temperatures-time combinations defined above. For analysis accuracy, three replicates were cooked for each treatment mode [23].

Mechanical characteristics analysis

The influence of cooking on the meat texture profile, shear force, and penetration force was determined using a TA HDi Texture Analyzer, HD3128. Cooked meat samples were cut into 1 cm^3 chunks [27]. The direction of cutting was parallel to that of the fiber.

Texture profile analysis

The texture profile components (hardness, gumminess and chewiness) were analyzed by using a circular piston with diameter of 75 mm. The apparatus was set to have a depth penetration of 10 mm pressing and a piston speed was set at 1.5 mm/second, and the time between two test operations was set to 10 seconds.

Shear and Penetration tests

The test procedure followed the method described in ASAE Standards (2000), specifically in ASAE S368.4 DEC99 [28]. The samples were compressed with 'V' shaped craft knife (Craft knife HD/Bs) down to 75% of their original height at distance of 22 mm down, and a column speed of 1.5 mm/s. The curves of dependence of shear force, and the penetration force vs time were generated.

Statistical analysis

The study was arranged in a complete random design (CRD) with a 3-way factorial design of 2 × 4 × 6. The statistical analysis of the data was performed using ANOVA in GLM (SPSS Software for Windows, version 27.0. software program provided by IBM Corp 2020).

The data were analyzed using ANOVA in GLM (SPSS Software for Windows, Version 27.0. Armonk, NY, USA: IBM Corp 2020). The data were assessed under normal distribution, and the mean values were used to represent the results. If any significant differences were observed at $p \leq 0.05$, a post hoc analysis was conducted using the least significant difference (LSD) method.

Results and discussion

Effects of cooking methods on the mechanical properties of camel meat

The mechanical qualities of camel meat are the key factors that influence consumer satisfaction. Thus, the effect of cooking methods and different temperature-time combinations on the mechanical properties of camel meat are investigated. These properties include texture profile (hardness, chewing and gumminess), shear force, and penetration force. The results (Table 1) show that the mechanical characteristics were significantly ($p \leq 0.05$) influenced by the cooking methods at all tested temperature-time combinations.

Textural profile analysis (TPA)

The TPA statistics analysis (Table 1) shows that the hardness, chewiness, and gumminess were significant ($p \leq 0.05$) affected by the cooking time and by the effect of its interaction with temperature of this cooking method. Only the hardness and chewiness were significantly ($p \leq 0.05$) affected by the cooking temperature.

The TPA results for the sous-vide cooked camel meat (Figures 1A, 1C and 1E) show an apparent decreasing of meat hardness, chewiness, and gumminess. This is possibly due to using water in this method, which has a high thermal conductivity coefficient, and results into rapid heat distribution that causes changes in the composition of protein fibers [29]. Extending the temperature-time combination causes collagen gelatinization, which creates the paths through which the dissolved muscle fat can get released and displaced, potentially acting as a moisture sealer during cooking [20,29,30]. Accordingly, the highly fat-lined meat structure shrinks less during cooking and remains juicier [31]. Furthermore, meat with a substantial amount of connective tissue will become tender if cooked for extended periods in moist-heat cooking [20,27].

In contrast, the conventional oven cooking method TPA results (Figures 1B, 1D and 1F) shows an increase in hardness, chewiness, and gumminess. This is possibly explained by the changes in the myofibrillar proteins and connective tissue during the conventional cooking [32]. Initially, when being conventionally heated, meat proteins denature, resulting in texture hardening, possibly due to changes in the tertiary structure and increased collagen fiber concentration in cross sections [33]. According to Hostetler and Landmann [34] the myosin denatures and coagulates during cooking, causing shrinkage of the myofilaments, tightening of the myofilaments microstructure and shortening of sarcomeres [35].

Shear force and penetration force

The results (Table 1) show the values for the shear force and penetration force for the sous-vide and conventional oven-cooked camel meat. The shear force and penetration force were significantly ($p \leq 0.05$) affected by the cooking

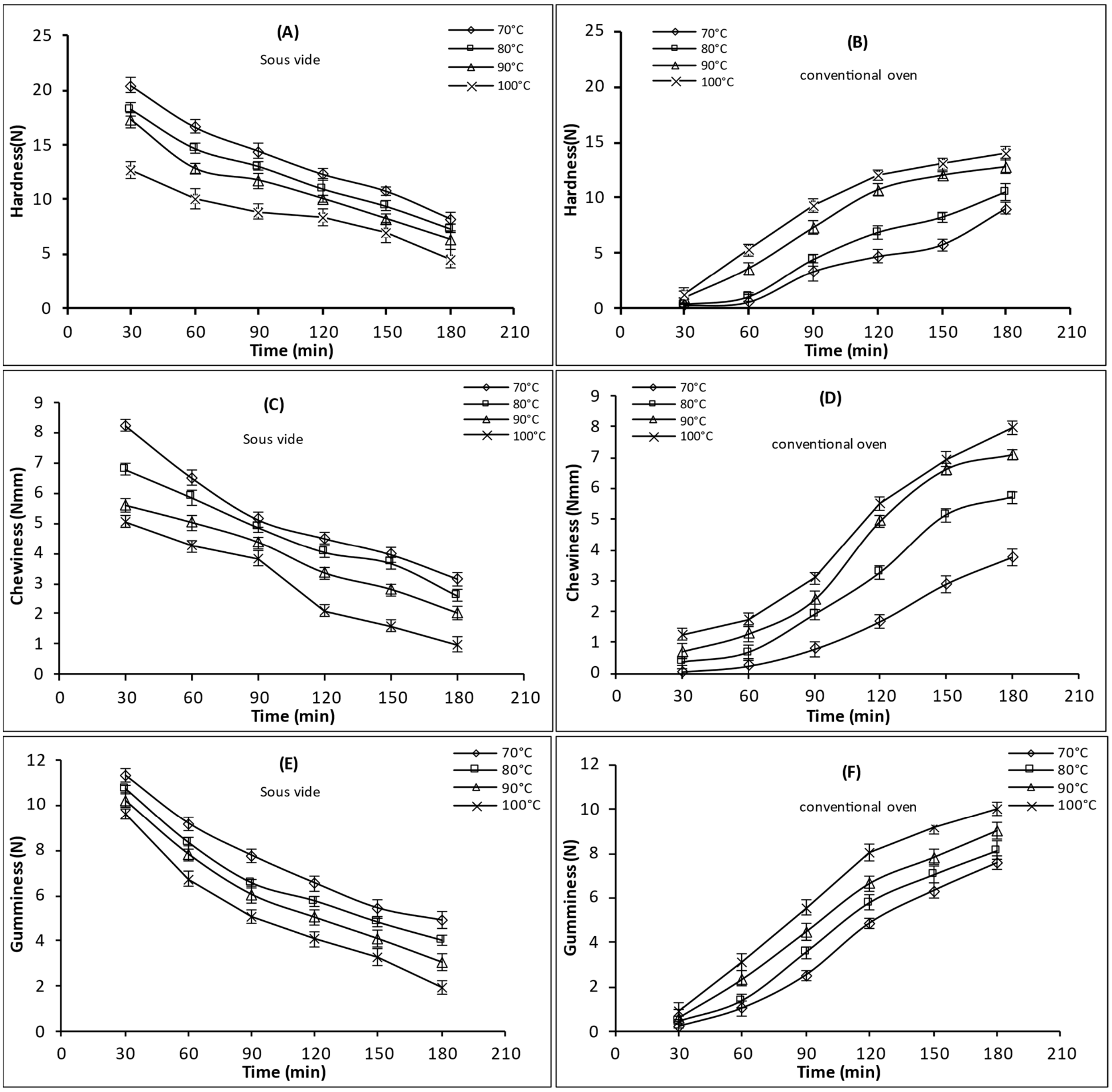

Figure 1. Effect of the cooking method (sous-vide and conventional oven) on the camel meat hardness (A and B), chewiness (C and D) and gumminess (E and F)

Table 1. Influence of the cooking method on the mechanical properties of camel meat

Treatments	Mechanical properties				
	Shear force	Penetration force	Hardness	Chewiness	Gumminess
Cooking method:					
Sous vide	36.36[b]	1.38[a]	11.88[a]	4.18[a]	6.07[a]
Electric oven	45.35[a]	1.14[b]	6.57[b]	3.12[b]	4.51[b]
Cooking temperature (°C):					
70	49.14[a]	1.30[a]	8.92[b]	3.41	6.17[a]
80	41.97[b]	1.28[a]	9.26[a]	3.71	5.54[b]
90	40.77[b]	1.24[b]	9.49[a]	3.79	3.79[c]
100	31.53[c]	1,21[b]	8.89[b]	3.68	5.63[b]
Cooking time (min):					
30	49.14[a]	1.17	8.97[b]	3.50[c]	4.93[b]
60	45.20[b]	1.19	8.12[c]	3.19b[c]	4.78[b]
90	43.15[c]	1.20	9.07[b]	3.29[c]	4.90[b]
120	40.01[d]	1.26	9.53[b]	3.60[b]	5.58[a]
150	37.09[e]	1.31	9.31[b]	4.19[a]	5.83[a]
180	30.52[f]	1.42	10.38[a]	4.05[a]	5.71[a]
SEM	1.82	0.08	0.87	0.42	0.58
Main effects	P-values				
Cooking method	< .001	< .001	0.04	< .001	0.01
Cooking temperature	< .001	< .001	0.03	NS	0.03
Cooking time	< .001	NS	0.01	< .001	0.04

[a, b c, d, e, f] Means within the same column with different superscripts are significantly different. SEM, standard error mean; *p-value*, probability level (considered significant when $p \leq 0.05$); NS, not significantly different.

methods, cooking time and by the cooking temperature. However, the sous-vide cooked meat was less resistant to the shear force than conventional oven cooked meat (Figures 2A and 2B). This can be related to the constant temperature during the sous-vide cooking by means of water bath, which allows the breakdown of the perimysium the tissue that supports the surrounding of the fiber bundle within the muscle. As the meat tissues break down, the meat becomes more tender and the shear force required to cut the meat is reduced [17].

Unlike the shear force, constant increase in penetration force was observed in regards to the conventional oven cooked meat (Figure 2D). In contrast, the penetration force decreased constantly along with the increasing temperature-time values combinations, the similar results were obtained in the preceding studies where sous-vide cooked meat (Figure 2C) showed lower penetration force values [36,37]. The penetration force appears to be very sensitive to changes in connective tissue caused by the dry heat during the conventional oven cooking [37], and hence, increasing the meat toughness, and subsequently increasing the penetration force [38]. Our results agree with Bouton et al. [39] work on the mechanical properties of cooked meat samples. In addition, Lorenzo et al. [40] reported on the dependence between the penetration force values and thermal losses caused during conventional oven cooking, where samples with high thermal loss demonstrated the highest penetration force values.

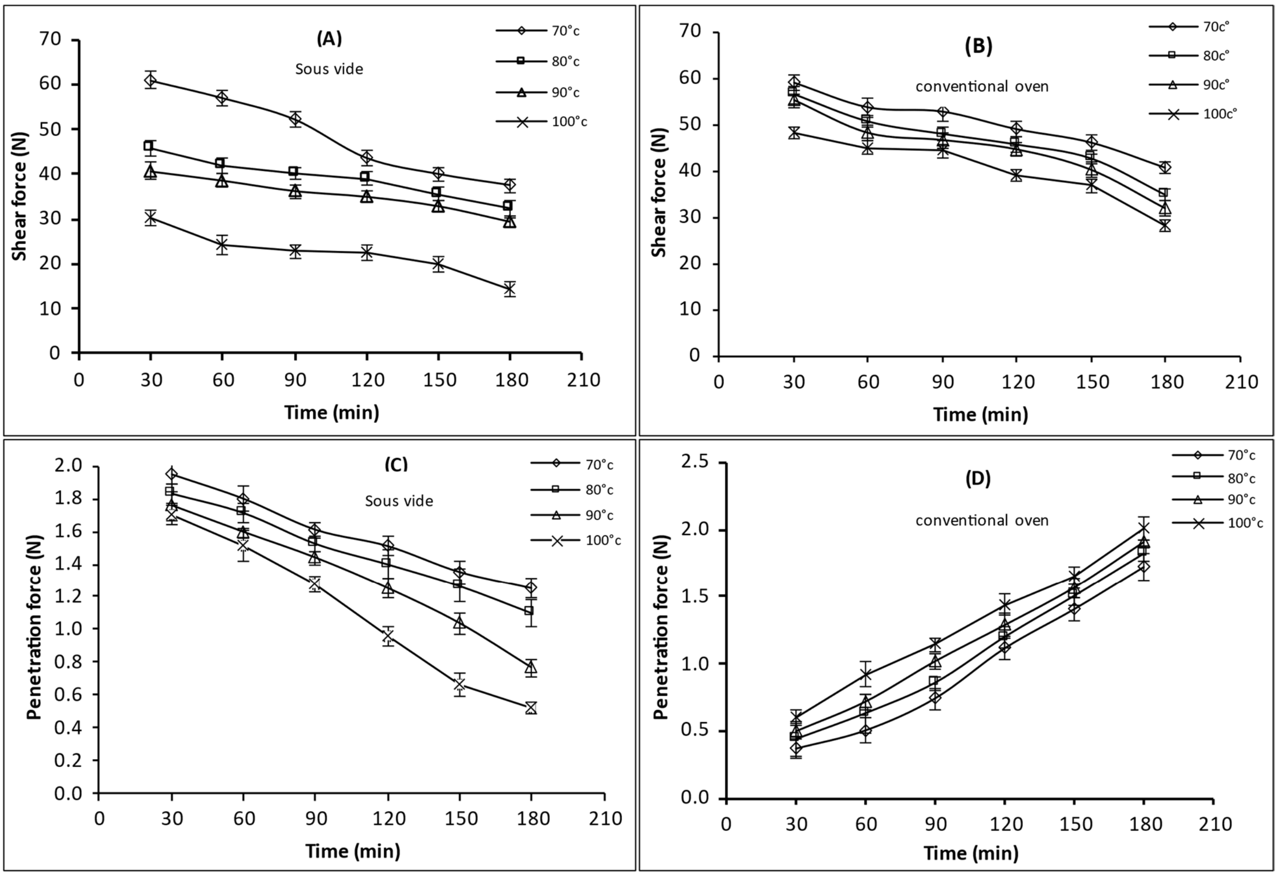

Figure 2. Effect of sous-vide and conventional oven cooking on camel meat shear force (A & B) and penetration force (C and D)

Conclusion

In conclusion, both cooking temperature and cooking time appears to significantly impact the mechanical properties of sous vide and conventionally cooked camel meat. The obtained results showed that increasing the sous vide cooking temperature-time values combination decreased the TPA values (hardness, gumminess chewiness), penetration force and shear force. It is opposite to conventional oven cooking, where all tested parameters increased, except for the shear force which decreased. In addition, the meat cooked using the sous vide method exhibited lower shear force compared to that of the conventional oven. This can be attributed to the uniform cooking temperature, which rapidly breaks down the perimysium tissue supporting the fiber bundles within the muscle, resulting in more tender and juicy meat with a natural flavor profile that may lack the depth of flavor that comes from exposure to high dry heat provided by the conventional oven cooking.

REFERENCES

1. Schellekens, M. (1996). New research issues in sous-vide cooking. *Trends in Food Science and Technology*, 7, 256–262. https://doi.org/10.1016/0924-2244(96)10027-3
2. Ruiz, J., Calvarro, J., Sánchez del Pulgar, J., Roldán, M. (2013). Science and technology for new culinary techniques. *Journal of Culinary Science and Technology*, 11(1), 66–79. http://doi.org/10.1080/15428052.2013.755422
3. Renna, M., Gonnella, M., Giannino, D., Santamaria, P. (2014). Quality evaluation of cook-chilled chicory stems (Cichorium intybus L., Catalogna group) by conventional and sous-vide cooking methods. *Journal of the Science of Food and Agriculture*, 94(4), 656–665. https://doi.org/10.1002/jsfa.6302
4. Ismail, I., Hwang, Y.-H., Bakhsh, A., Joo, S.-T. (2019). The alternative approach of low temperature-long time cooking on bovine semitendinosus meat quality. *Asian-Australasian Journal of Animal Sciences*, 32(2), 282–289. https://doi.org/10.5713/ajas.18.0347
5. Baldwin, D.E. (2011). Sous vide cooking: A review. *International Journal of Gastronomy and Food Science*, 1, 15–30. https://doi.org/10.1016/j.ijgfs.2011.11.002
6. Roldan, M., Antequera, T., Armenteros, M., Ruiz, J. (2014). Effect of different temperature time combinations on lipid and protein oxidation of sous-vide cooked lamb loins. *Food Chemistry*, 149, 129–136. https://doi.org/10.1016/j.foodchem.2013.10.079
7. Kato, H. C. A., Lourenço, L. F. H., Araújo, E. A. F., Sousa, C. L., Joele, M. R. S. Peixoto, Ribeiro, S. C. A. (2016). Change in physical and chemical characteristics related to the binomial time-temperature used in sous pasteurization see Tambaqui (Colossoma macropomum). *Arquivo Brasileiro de Medicina Veterinária e Zootecnia,* 68(1), 224–232. https://doi.org/10.1590/1678-4162-8096
8. Mitra, B., Rinnan, Å., Ruiz-Carrascal, J. (2017). Tracking hydrophobicity state, aggregation behaviour and structural modifications of pork proteins under the influence of assorted heat treatments. *Food Research International,* 101, 266–273. https://doi.org/10.1016/j.foodres.2017.09.027
9. Roldán, M., Antequera, T., Hernández, A., Ruiz, J. (2014). 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. http://doi.org/10.1177/1082013214552861
10. Roldan, M., Loebner, J., Degen, J., Henle, T., Antequera, T., Ruiz-Carrascal, J. (2015). Advanced glycation end products, physico-chemical and sensory characteristics of cooked lamb loins affected by cooking method and addition of flavour precursors. *Food Chemistry*, 168, 487–495. https://doi.org/10.1016/j.foodchem.2014.07.100
11. Sánchez del Pulgar, J., Gázquez, 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, 828–835. https://doi.org/10.1016/j.meatsci.2011.11.024
12. Brooks, J. C., Belew, J. B., Griffin, D. B., Gwartney, B. L., Hale, D. S., Henning, W. R. et al. (2000). National beef tenderness survey-1998. *Journal of Animal Science*, 78(7), 1852–1860. https://doi.org/10.2527/2000.7871852x
13. Myhrvold, N., Young, C., Bilet, M. (2011). Modernist cuisine: The art and science of cooking. Bellevue, The Cooking Lab, 2011.
14. Kadim, I. T., Mahgoub, O, Al-Marzooqi, W. (2008). Meat quality and composition of longissimus tharacis from Arabian camel (Camelus dromedaries) and Omani beef: A comparative study. *Journal of Camelid Sciences*, 1, 37–47.
15. Baba, W. N., Rasool, N., Selvamuthukumara, M., Maqsood, S. (2021). A review on nutritional composition, health benefits, and technological interventions for improving consumer acceptability of camel meat: An ethnic food of Middle East. *Journal of Ethnic Foods*, 8, Article 18. https://doi.org/10.1186/s42779-021-00089-1
16. Shackelford, S. D., Wheeler, T. L., Meade, M. K., Reagan, J. O., Byrnes, B. L., Koohmaraie, M. (2001). Consumer impressions of Tender Select beef. *Journal of Animal Science*, 79(10), 2605–2614. https://doi.org/10.2527/2001.79102605x
17. Lyford, C., Thompson, J., Polkinghorne, R., Miller, M., Nishimura, T., Neath, K. et al. (2010). Is willingness to pay (WTP) for beef quality grades affected by consumer demographics and meat consumption preferences. *Australasian Agribusiness Review*, 18, Article 1. http://doi.org/10.22004/ag.econ.125701
18. Bouton, P. E., Harris, P. V., Macfarlane, J. J., Shorthose, W. R. (1982). Influence of pH on the Warner-Bratzler shear properties of mutton. *Meat Science*, 6(1), 27–36. https://doi.org/10.1016/0309-1740(82)90048-1
19. Devey, C., Gilbert, K. (1968). Studies in meat tenderness: 4. Changes in the extractability of myofibrillar proteins during meat aging. *Journal of Food Science*, 33(1), 2–7. https://doi.org/10.1111/j.1365-2621.1968.tb00873.x
20. Tornberg, E. (2005). Effects of heat on meat proteins — Implications on structure and quality of meat products. *Meat Science*, 70(3), 493–508. https://doi.org/10.1016/j.meatsci.2004.11.021
21. Dawood, A. A. (1995). Physical and sensory characteristics of Najdi-camel meat. *Meat Science,* 39(1), 59–69. https://doi.org/10.1016/0309-1740(95)80007-7
22. Vasanthi, C., Venkataramanujam, V., Dushyanthan, K. (2007). Effect of cooking temperature and time on the physico-chemical, histological and sensory properties of female carabeef (buffalo) meat. *Meat Science*, 76(2), 274–280. https://doi.org/10.1016/j.meatsci.2006.11.018
23. García-Segovia, P., Andrés-Bello, A., Martínez-Monzó, J. (2007). Effect of cooking method on mechanical properties, color and structure of beef muscle (M. pectoralis). *Journal of Food Engineering*, 80(3), 813–821. https://doi.org/10.1016/j.jfoodeng.2006.07.010

24. Nikmaram, P., Yarmand, M. S., Emamjomeh, Z., Darehabi, H. K. (2011). The effect of cooking methods on textural and microstructure properties of veal muscle (Longissimus dorsi). *Global Veterinaria*, 6(2), 201–207.
25. Das, K., Rajkumar, V. (2013). Effect of different fat levels on microwave cooking properties of goat meat patties. *Journal of Food Science and technology*, 50(6), 1206–1211. https://doi.org/10.1007/s13197-011-0443-8
26. Chuaynukool, K., Wattanachant, S., Siripongvutikorn, S., Yai, H. (2007). Chemical and physical properties of raw and cooked spent hen, broiler and Thai indigenous chicken muscles in mixed herbs acidified soup (Tom Yum). *Journal of Food Technology*, 5(2), 180–186.
27. Palka, K., Daun, H. (1999). Changes in texture, cooking losses, and myofibrillar structure of bovine M. semitendinosus during heating. *Meat Science*, 51(3), 237–243. https://doi.org/10.1016/s0309-1740(98)00119-3
28. ASAE Standards (2000). ASAE S368.4 DEC99 Compression Test of food materials of convex shape. American Society of Agricultural Engineers. Retrieved from https://elibrary.asabe.org/abstract.asp?aid=42544&t=2&redir=&redirType= Accessed April 15, 2024
29. Vaskoska, R., Ha, M., Naqvi, Z. B., White, J. D., Warner, R. D. (2020). Muscle, ageing and temperature influence the changes in texture, cooking loss and shrinkage of cooked beef. *Foods*, 9(9), Article 1289. https://doi.org/10.3390/foods9091289
30. Lepetit, J. (2008). Collagen contribution to meat toughness: Theoretical aspects. *Meat Science*, 80(4), 960–967. https://doi.org/10.1016/j.meatsci.2008.06.016
31. Li, C., Wang, D., Xu, W., Gao, F., Zhou, G. (2013). Effect of final cooked temperature on tenderness, protein solubility and microstructure of duck breast muscle. *LWT-Food Science and Technology*, 51(1), 266–274. https://doi.org/10.1016/j.lwt.2012.10.003
32. Christensen, M., Purslow, P. P., Larsen, L. M. (2000). The effect of cooking temperature on mechanical properties of whole meat, single muscle fibres and perimysial connective tissue. *Meat Science*, 55(3), 301–307. https://doi.org/10.1016/S0309-1740(99)00157-6
33. Cheng, C. S., Parrish, F. C. (1976). Scanning electron microscopy of bovine muscle: Effect of heating on ultrastructure. *Journal of Food Science*, 41(6), 1449–1454. https://doi.org/10.1111/j.1365-2621.1976.tb01193.x
34. Hostetler, R. L., Landmann, W. A. (1968). Photomicrographic studies of dynamic changes in muscle fiber fragments. 1. Effect of various heat treatments on length, width and birefringence. *Journal of Food Science*, 33(5), 468–470. https://doi.org/10.1111/j.1365-2621.1968.tb03657.x
35. Lewis, G. J., Purslow, P. P. (1989). The strength and stiffness of perimysial connective tissue isolated from cooked beef muscle. *Meat Science*, 26(4), 255–269. https://doi.org/10.1016/0309-1740(89)90011-9
36. Modzelewska-Kapituła, M., Pietrzak-Fiećko, R., Tkacz, K., Draszanowska, A., Więk, A. (2019). Influence of sous vide and steam cooking on mineral contents, fatty acid composition and tenderness of semimembranosus muscle from Holstein-Friesian bulls. *Meat Science*, 157, Article 107877. https://doi.org/10.1016/j.meatsci.2019.107877
37. Botinestean, C., Keenan, D.F., Kerry, J.P., Hamill R. M. (2016). The effect of thermal treatments including sous-vide, blast freezing and their combinations on beef tenderness of M. semitendinosus steaks targeted at elderly consumers. *LWT — Food Science and Technology*, 74, 154–159. https://doi.org/10.1016/j.lwt.2016.07.026
38. Bouton, P. E., Harris, P. V. (1972). Changes in the tenderness of meat cooked at 50–65 °C. *Journal of Food Science*, 46(2), 475–478. http://doi.org/10.1111/j.1365–2621.1981.tb04889.x
39. Bouton, P. E., Harris, P. V., Ratcliff, D. (1981). Effect of cooking temperature and time on the shear properties of meat. *Journal of Food Science*, 46(4), 1082–1087. https://doi.org/10.1111/j.1365-2621.1981.tb02996.x
40. Lorenzo, J. M., Cittadini, A., Munekata, P. E., Domínguez, R. (2015). Physicochemical properties of foal meat as affected by cooking methods. *Meat Science*, 108, 50–54. https://doi.org/10.1016/j.meatsci.2015.05.021

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