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Original scientific paper

The effects of dry ageing period and subsequent culinary methods on the oral processing parameters of beef

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ABSTRACT

This study investigates the impact of dry aging duration and subsequent cooking methods on the oral processing parameters of beef. Dry aging is a traditional technique that enhances beef by controlled environmental and enzymatic changes. Two dry aging periods (21 and 42 days) were combined with two cooking methods (grilling and sous vide). A sensory panel evaluated the beef samples, assessing parameters such as particle size, chewing rate, and eating rate. The breakdown of food structures during oral processing influences the sensory perception of texture, flavor, and taste, thereby determining a food's overall acceptability and palatability. Results showed that shorter dry aging duration and cooking method significantly affected only some of the oral processing parameters. Shorter dry aging period (21 days) generally led to increased total number and share of smaller particle sizes. In these terms, sous vide cooking resulted in improved oral processing profiles compared to grilling. The longer period (42 days) of dry ageing was without an effect on beef oral processing, irrespective of culinary method applied. These findings contribute to a better understanding of how dry aging and cooking methods influence the sensory experience of beef, potentially aiding in the development of products tailored to consumer preferences.

1. Introduction

Dry aging is a traditional method that enhances beef by exposing it to controlled environmental and enzymatic changes. This technique improves tenderness, deepens flavor, and imparts distinctive texture characteristics. It involves storing large beef cuts, such as ribeye or strip loin, in a tightly regulated setting—typically maintained at low temperatures (2–4 °C), around 85% humidity, and with consistent airflow (*Khan Muhammad et al*., 2016). Over a period of several weeks to months, natural enzymes in the meat, like calpains and cathepsins, break down complex proteins into smaller peptides and amino acids. This enzymatic activity softens the meat and contributes to the development of rich, umami flavours (*O'Quinn et al*., 2018).

The length of the aging period plays a crucial role in determining the final flavor and texture. Generally, longer aging enhances flavour intensity, but the ideal duration depends on factors such as the beef's original quality, the specific aging conditions, and the desired flavor profile (*Cenci-Goga et al.*, 2020). If not carefully monitored, the aging environment—particularly its heat and air circulation—can cause excessive water loss and protein denaturation, leading to a drier texture (*Jadhav et al.*, 2021). Sous vide—meaning "under vacuum"—uses a water bath

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to cook meat at precisely controlled low temperatures, usually between 50 °C and 85 °C (*Gómez and Beriain*, 2019). This method ensures even heat distribution throughout the meat, minimizing temperature differences and allowing for accurate control of internal temperature and protein denaturation (*Przybylski et al.*, 2021).

Oral processing, a multifaceted and intricate initial stage of digestion, encompasses a series of actions within the oral cavity that prepare food for swallowing and subsequent breakdown in the gastrointestinal tract. This process integrates muscle activity, jaw movements, and tongue movements, all contributing to the transformation of food structure into a bolus suitable for ingestion (*Koç et al.*, 2013). The breakdown of food structures during oral processing directly influences the sensory perception of texture, flavor, and taste, thereby determining a food's overall acceptability and palatability (*Foegeding et al*., 2015). The parameters of oral processing, including chewing rate, bolus formation time, and salivary flow rate, are highly variable and are influenced by an array of factors, such as individual physiology, food properties, and cognitive expectations (*Campbell et al.*, 2017). The way that food undergoes changes in the mouth has a big impact on how we experience its texture, which is a core feature that affects how much we enjoy eating (*Devezeaux De Lavergne et al.*, 2021). The idea of this research was to examine the effects of dry ageing duration (21 and 42 days) and subsequent culinary methods (grill and sous vide) on the oral processing parameters of beef.

2. Materials and Methods

2.1. Meat samples and ageing process

Beef hindlegs (shank and chump off, n = 12) were collected from six beef carcasses on the day of slaughter. Paired legs (left and right) from the same animal were randomly assigned to two ageing treatments: in-bag dry-ageing (21 days) or in-bag dry-ageing (42 days). Briefly, in-bag dry-ageing was carried out in water permeable ageing bags (TUBLIN® 10, 50 μm thick, polyamide mix with water vapor transmission rate 920 g/50 μ/m^2/24 h at 7 °C, 50 % RH, and oxygen transmission rate 660 g/m^2/24 h at 7 °C, 50 % RH, TUB-EX ApS, Denmark) at 2 ± 0.5 °C, 0.5 m.s^{-1} air velocity and relative humidity of 75 ± 5 %. Samples without a period of dry ageing were investigated as control samples.

2.2. Food oral processing panel

The food oral processing (FOP) panel consisted of eight panellists (four male and four female members, normal body mass index 18–25 kg/m^2) with previous experience in similar studies. They all confirmed two main pre-conditions for performing this type of research—good general health condition and no dental problems (*Forde et al*., 2013). Before performing the planned FOP study, one 2-hour training session was organized to get the panellists familiar with the methods to be employed (*Djekic et al.*, 2021). During this initial session, all panellists signed written consent to participate voluntarily.

2.3. Oral processing analysis

The first task for the panellists was to consume cubical meat samples (2×2×2 cm). The chewing process was recorded using a digital video camera that was placed 30 cm from each panellist (*Forde et al*., 2013). Video recordings were analysed using stopwatch. This enabled counting of the number of chews and total oral consumption time (*Hennequin et al.*, 2005). In parallel, panellists raised their hand when swallowing to enable counting of the number of swallows per sample (*Djekic et al.*, 2021). The mass of each sample before consumption was measured using a technical balance of 0.01 g accuracy. Based on recorded data, food oral processing parameters were calculated (*Aguayo-Mendoza et al*., 2019). All panellists received two samples from each aging period and another two samples from each culinary method.

2.4. Particle size analysis

To analyse particle distribution of the boluses, the same types of meat samples (2×2×2 cm) were collected from each panellist at the moment before swallowing by expectorating (*Djekic et al.*, 2021). Upon collection, they were: (i) rinsed using distilled water on filter paper; (ii) spread out on white plates and, (iii) photographed with a digital camera. The spreading of boluses was performed with care to prevent damage of the particles. Image analysis was conducted using ImageJ software. This enabled counting of the number of particles and calculation of their surface area (Rizo et al., 2019). Bolus analysis was performed in two replicates.

2.5. Statistical analysis

Data from the texture profile analysis and food oral processing study were subjected to analysis of variance as follows: one-way ANOVA was employed for the effects of culinary method (C), aging days (D), and for the number of particles. The statistical significance of the factors C and D was determined using the Tukey HSD test ($p< 0.05$). The chi-square test for association was used in analysing possible relationships between particle size fragmentation and aging of meat ($p< 0.05$).

3. Results and Discussion

Understanding the relationship between the structure of solid foods and their oral processing is paramount for enhancing features such as texture and taste (*Guo*, 2021). The number of particles in food oral processing relates to the degree of food breakdown during chewing and bolus formation (*van der Bilt*, 2009). The "ideal" number of particles depends on the desired sensory experience and functionality of the food product and there isn't a universally "better" option between a larger or smaller number of particles (*Tyle et al*., 1990). Our results clearly demonstrated that the sous-vide cooking technique resulted in a notably larger number of particles compared to grilling the meat, both without and with the period of dry ageing (Figure 1). However, no significant differences were found in the number of particles between the samples dry aged for 21 and 42 days, irrespective of the cooking technique applied.

The oral processing of food involves the breakdown of food structure into a bolus suitable for swallowing, with particle size being a key characteristic of this bolus (*Koç et al*., 2013). Food particle size plays a critical role in food oral processing, influencing texture perception, taste, and digestion (*Devezeaux De Lavergne et al*., 2021). Smaller particle sizes within the bolus create a larger surface area for digestive enzymes to act upon. This increased surface area facilitates more efficient enzymatic breakdown of carbohydrates, proteins, and fats *(Ramírez et al*., 2019).

Our results demonstrate that the percentage of small particles in the boluses significantly decreased (by 18.41% in grilled and 11.75% in sous-vide beef samples) after the aging period of 21 days compared to day 0, irrespective of the culinary technique applied. Further ageing for the subsequent three weeks increased the number of small particles by only a relatively insignificant margin of only 2.4% on average for

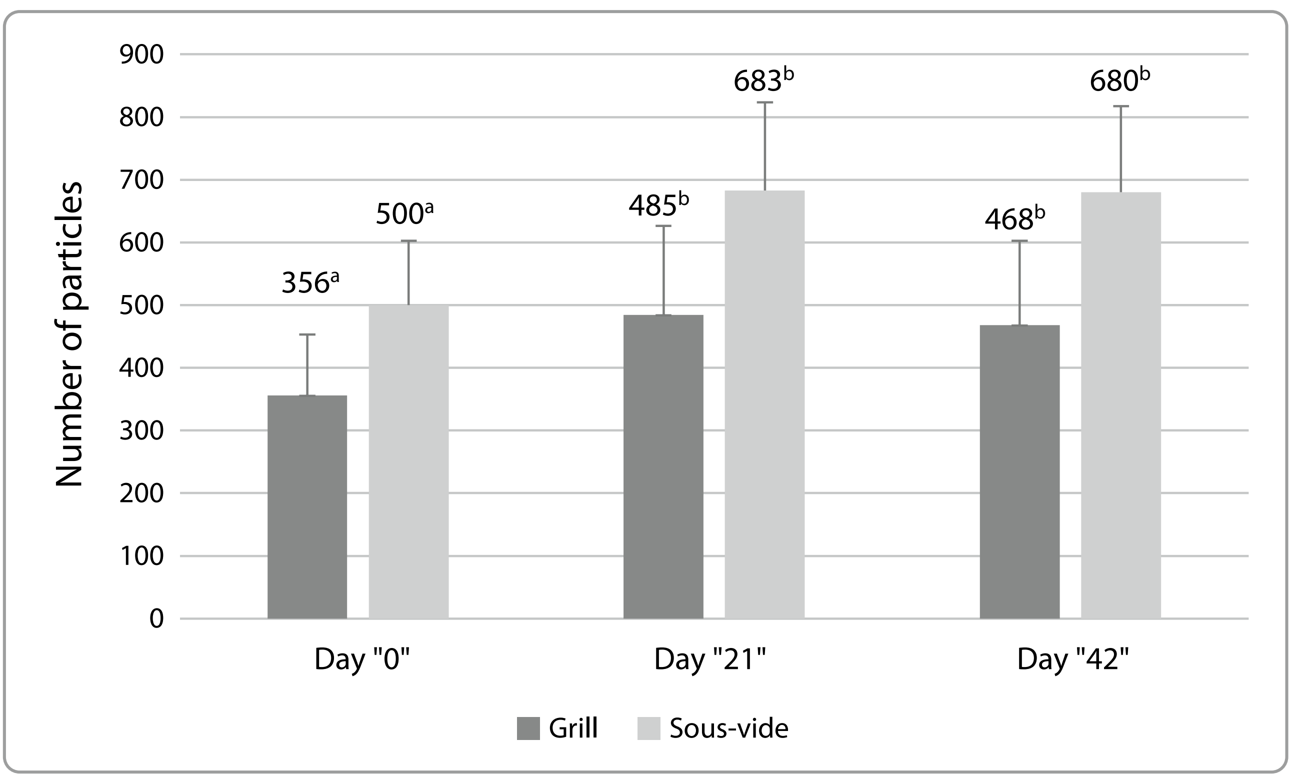

Figure 1. Number of particles of samples obtained in vivo during the aging time for grilled samples (dark grey bars) and sous-vide (light grey bars). Different letters indicate significant differences according to Tukey's test (α=0.05)

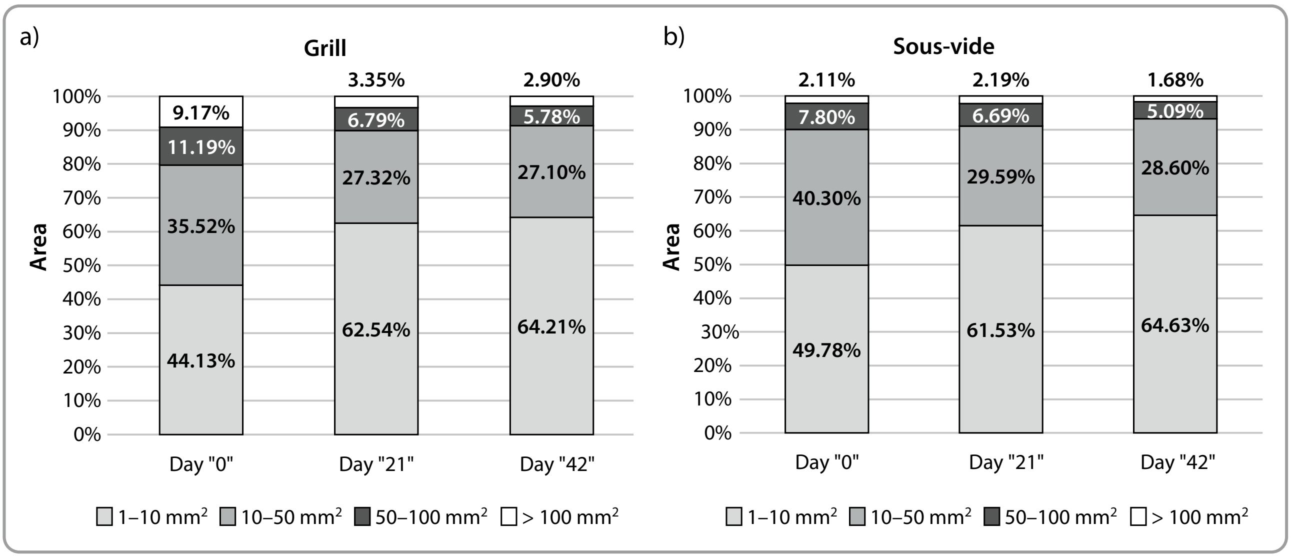

Figure 2. Percentage of area occupied by particles of size: 1–10 mm^2 (light grey), 10–50 mm^2 (dark grey), 50–100 mm^2 (black color), and >100 mm^2 (white color) depending on the aging time

grilled and sous-vide samples. The number of large particles (>100mm^2) for grilled samples was greater than for sous-vide samples by 4-fold on day 0 and continued to remain on the lesser side during the whole period of dry ageing. We already know that a higher number of smaller particles in food samples may result in a smoother texture, while fewer, larger particles could create a coarser or chunkier sensation (*Guo*, 2021).

Eating rate, or how quickly one consumes food, plays a significant role in food oral processing, influencing both sensory perception and overall food intake (Wee et al., 2018). It affects the duration of oral exposure, the number of chews, and the bolus properties at the point of swallowing (*Goh et al*., 2021). Chewing rate specifically measures how quickly someone chews their food and focuses solely on the mastication process, regardless of the amount of food consumed (*Sánchez-Ayala et al*., 2013). Surprisingly, our results did not reveal a statistically significant influence of either dry ageing or the cooking technique applied on any of the food oral processing parameters presented in Table 1. Chewing cycle duration, chewing and rate remained almost a constant throughout the study. Consumption time for one bite and the number of chews were altered by the duration of dry ageing and cooking method, but never to an extent where the differences could be perceived as statistically significant.

Table 1. Food oral processing parameters of beef subjected to grilling and sous-vide cooking methods.

Meat cooking method	Number of chews	Consumption time for one bite [s]	Number of swallows	Chewing cycle duration [s/chew]	Chewing rate [chew/s]	Eating rate [g/s]
Grilling						
Day 0	43.5 ± 12.4	31.2 ± 9.5	2.9 ± 1.3	0.7 ± 0.2	1.4 ± 0.3	0.4 ± 0.1
Day 21	39.0 ± 6.7	26.3 ± 4.7	2.4 ± 1.2	0.7 ± 0.1	1.5 ± 0.1	0.4 ± 0.1
Day 42	39.6 ± 11.7	26.9 ± 6.9	2.4 ± 1.0	0.7 ± 0.1	1.5 ± 0.1	0.4 ± 0.1
Sous-vide						
Day 0	40.9 ± 15.1	31.3 ± 20.5	2.9 ± 1.2	0.7 ± 0.2	1.4 ± 0.3	0.4 ± 0.1
Day 21	53.1 ± 13.5	37.9 ± 8.5	3.4 ± 0.9	0.7 ± 0.1	1.4 ± 0.2	0.3 ± 0.1
Day 42	41.4 ± 23.3	31.2 ± 20.2	2.8 ± 1.1	0.7 ± 0.1	1.4 ± 0.2	0.4 ± 0.2

Testing was performed in two replicates. Data are mean values ± standard deviation.

4. Conclusion

Three weeks of dry ageing resulted in partly improved oral processing of beef, but only in terms of the increased total number of particles and percentage of area occupied by particles of smaller size, which might have an indirect positive effect on meats' texture, digestion and nutrient absorption. In the same terms, sous-vide was not perceived as a favourable culinary method compared to grilling. Dry ageing for a prolonged period of time, i.e., an additional three weeks, had no effect on beef oral processing. However, a limitation of this study was the food oral processing panel that was not tested for reliability, repeatability, or consistency. Also, further research is needed where the difference between dry ageing periods would be smaller, which could lead to more statistically robust and reliable results; instrumental textural analysis is also needed to confirm the sensory findings. The results of these studies could also be compared with the results of sensory evaluation and textural characteristics.

Uticaj perioda suvog zrenja i naknadnih kulinarskih metoda na parametre oralne obrade govedine

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INFORMACIJE O RADU

Ključne reči:
Suvo zrenje
Roštilj
Sous-vide
Veličina čestica
Brzina žvakanja
Brzina jedenja
Oralna obrada
Tekstura go

APSTRAKT

Ova studija istražuje uticaj trajanja suvog zrenja i naknadnih metoda termičke obrade na parametre oralne obrade govedine. Suvo zrenje je tradicionalna tehnika koja poboljšava cenzorni kvalitet govedine u kontrolisanim uslovima usled dejstva enzima. Dva perioda suvog zrenja (21 i 42 dana) kombinovana su sa dve metode termičke obrade (roštilj i suvid). Senzorni panel je ocenio uzorke govedine, procenjujući parametre kao što su veličina čestica, brzina žvakanja i brzina jedenja. Razgradnja strukture hrane tokom oralne obrade utiče na senzornu percepciju teksture, ukusa i arome, čime određuje ukupnu prihvatljivost i ukus mesa. Rezultati su pokazali da kraće trajanje suvog zrenja i metod termičke obrade značajno utiču samo na neke od parametara oralne obrade. Kraći period suvog zrenja (21 dan) generalno je doveo do povećanja ukupnog broja i udela čestica manjih veličina. U tom smislu, su-vid kuvanje je rezultiralo poboljšanim profilima oralne obrade u poređenju sa roštiljanjem. Duži period (42 dana) suvog zrenja nije imao uticaja na oralnu obradu govedine, bez obzira na primenjeni kulinarski metod. Ovi nalazi doprinose boljem razumevanju kako suvo starenje i metode termičke obrade utiču na senzorno iskustvo govedine, što potencijalno pomaže u razvoju proizvoda prilagođenih željama potrošača.

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References

Aguayo-Mendoza, M. G., Ketel, E. C., van der Linden, E., Forde, C. G., Piqueras-Fiszman, B., & Stieger, M. (2019). Oral processing behavior of drinkable, spoonable and chewable foods is primarily determined by rheological and mechanical food properties. *Food Quality and Preference*, 71, 87–95. https://doi.org/https://doi.org/10.1016/j.foodqual.2018.06.006

Campbell, C. L., Wagoner, T. B., & Foegeding, E. A. (2017). Designing foods for satiety: The roles of food structure and oral processing in satiation and satiety. *Food Structure*, 13, 1–12. https://doi.org/https://doi.org/10.1016/j.foostr.2016.08.002

Cenci-Goga, B. T., Iulietto, M. F., Sechi, P., Borgogni, E., Karama, M., & Grispoldi, L. (2020). New Trends in Meat Packaging. *Microbiology Research*, 11(2), 56–67.

Devezeaux De Lavergne, M., Young, A. K., Engmann, J., & Hartmann, C. (2021). Food Oral Processing—An Industry Perspective [Perspective]. *Frontiers in Nutrition*, *vol.* 8 - 2021. https://doi.org/10.3389/fnut.2021.634410

Djekic, I., Ilic, J., Lorenzo, J. M., & Tomasevic, I. (2021). How do culinary methods affect quality and oral processing characteristics of pork ham? *Journal of Texture Studies*, 52(1), 36–44. https://doi.org/https://doi.org/10.1111/jtxs.12557

Djekic, I., Ilić, J., Chen, J., Djekic, R., Sołowiej, B. G., Vujadinović, D., & Tomasevic, I. (2021). Analysis of Pungency Sensation Effects from an Oral Processing, Sensorial and Emotions Detection Perspective—Case Study with Grilled Pork Meat. *Applied Sciences*, 11(21), 10459.

Foegeding, E. A., Vinyard, C. J., Essick, G., Guest, S., & Campbell, C. (2015). Transforming Structural Breakdown into Sensory Perception of Texture. *Journal of Texture Studies*, 46(3), 152–170. https://doi.org/https://doi.org/10.1111/jtxs.12105

Forde, C. G., van Kuijk, N., Thaler, T., de Graaf, C., & Martin, N. (2013). Oral processing characteristics of solid savoury meal components, and relationship with food composition, sensory attributes and expected satiation. *Appetite*, 60, 208–219. https://doi.org/https://doi.org/10.1016/j.appet.2012.09.015

Goh, A. T., Chatonidi, G., Choy, M., Ponnalagu, S., Stieger, M., & Forde, C. G. (2021). Impact of Individual Differences in Eating Rate on Oral Processing, Bolus Properties and Post-Meal Glucose Responses. *Physiology & Behavior*, 238, 113495. https://doi.org/https://doi.org/10.1016/j.physbeh.2021.113495

Gómez, I., C., I. F., & Beriain, M. J. (2019). Physicochemical and sensory properties of sous vide meat and meat analog products marinated and cooked at different temperature-time combinations. *International Journal of Food Properties*, 22(1), 1693–1708. https://doi.org/10.1080/10942912.2019.1666869

Guo, Q. (2021). Understanding the oral processing of solid foods: Insights from food structure. *Comprehensive Reviews in Food Science and Food Safety*, 20(3), 2941–2967. https://doi.org/https://doi.org/10.1111/1541-4337.12745

Hennequin, M., Allison, P. J., Veyrune, J. L., Faye, M., & Peyron, M. (2005). Clinical evaluation of mastication: validation of video versus electromyography. *Clinical Nutrition*, 24(2), 314–320. https://doi.org/10.1016/j.clnu.2004.11.010

Jadhav, H. B., Annapure, U. S., & Deshmukh, R. R. (2021). Non-thermal Technologies for Food Processing [Review]. *Frontiers in Nutrition*, vol. 8 - 2021. https://doi.org/10.3389/fnut.2021.657090

Khan Muhammad, I., Jung, S., Nam Ki, C., & Jo, C. (2016). Postmortem Aging of Beef with a Special Reference to the Dry Aging. 한국축산식품학회지, 36(2), 159–169. https://doi.org/10.5851/KOSFA.2016.36.2.159

Koç, H., Vinyard, C. J., Essick, G. K., & Foegeding, E. A. (2013). Food Oral Processing: Conversion of Food Structure to Textural Perception. *Annual Review of Food Science and Technology*, 4(2013), 237–266. https://doi.org/https://doi.org/10.1146/annurev-food-030212-182637

O'Quinn, T. G., Legako, J. F., Brooks, J. C., & Miller, M. F. (2018). Evaluation of the contribution of tenderness, juiciness, and flavor to the overall consumer beef eating experience1. *Translational Animal Science*, 2(1), 26–36. https://doi.org/10.1093/tas/txx008

Przybylski, W., Jaworska, D., Kajak-Siemaszko, K., Sałek, P., & Pakuła, K. (2021). Effect of Heat Treatment by the Sous-Vide Method on the Quality of Poultry Meat. *Foods*, 10(7), 1610. https://doi.org/https://doi.org/10.3390/foods10071610

Ramírez, C., Millón, C., Nuñez, H., del Campo, V., Almonacid, S., & Simpson, R. (2019). Effect of particle size distribution on the in vitro digestion of calcium alginate-starchy model foods. *Journal of Food Process Engineering*, 42(5), e13097. https://doi.org/https://doi.org/10.1111/jfpe.13097

Rizo, A., Peña, E., Alarcon-Rojo, A. D., Fiszman, S., & Tarrega, A. (2019). Relating texture perception of cooked ham to the bolus evolution in the mouth. *Food Research International*, 118, 4–12. https://doi.org/https://doi.org/10.1016/j.foodres.2018.02.073

Sánchez-Ayala, A., Arcelino, F.-N., Nara, H. C., & and Matheus Rodrigues Garcia, R. C. (2013). Relationship Between Chewing Rate and Masticatory Performance. *CRANIO®*, 31(2), 118–122. https://doi.org/10.1179/crn.2013.019

Tyle, P., Cary, K., Lauri, G., & and Jarosz, P. (1990). Effect of Size, Shape and Hardness of Particles in Suspension on Oral Palatability. *Drug Development and Industrial Pharmacy*, 16(8), 1339–1364. https://doi.org/10.3109/03639049009115965

van der Bilt, A. (2009). 1 - Oral physiology, mastication and food perception. In D. J. McClements & E. A. Decker (Eds.), *Designing Functional Foods* (pp. 3–37). Woodhead Publishing. https://doi.org/https://doi.org/10.1533/9781845696603.1.3

Wee, M. S. M., Goh, A. T., Stieger, M., & Forde, C. G. (2018). Correlation of instrumental texture properties from textural profile analysis (TPA) with eating behaviours and macronutrient composition for a wide range of solid foods [10.1039/C8FO00791H]. *Food & Function*, 9(10), 5301–5312. https://doi.org/10.1039/C8FO00791H

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