npj | science of food

Brief communication

Published in partnership with Beijing Technology and Business University & International Union of Food Science and Technology

https://doi.org/10.1038/s41538-025-00545-1

# Consumer sensory preferences for processed meats with synthetic, conventional, organic, and deodorized curing ingredients



Siyuan Sheng[1] ✉, Erin M. Silva[2], Steven C. Ricke[1] & James R. Claus[1] ✉

The perceived environmental sustainability of organic food products is often offset by consumer sensory preferences, yet a quantitative understanding of these preferences remains elusive. We evaluated how consumer sensory perception of processed meats is influenced by different curing ingredient types. We found from a three-year longitudinal sensory panel analysis of non-incentivized consumers' opinions on widely consumed processed meats that retronasal aroma, specifically non-meat aftertastes, critically determines consumer purchase intent between organic and conventional formulations.

Organic agriculture, while widely advocated for its reduced environmental impact through the elimination of synthetic agrochemicals[1], faces a critical translational challenge: consumer acceptance. Despite documented nutritional enhancements and, paradoxically, reports of superior sensory profiles in raw organic fruits and vegetables produces[2–4], as well as increased consumer attraction to organic labeled products[5], the sensory impact of integrating organic vegetable ingredients into common processed foods as functional ingredients remains largely unexplored.

This gap is particularly salient in the area of processed meats, a staple food commodity where synthetic sodium nitrite is traditionally employed for curing and preservation, playing a critical role in inhibiting lipid oxidation and preventing bacterial growth, specifically *Clostridium botulinum*, and extending shelf life[6]. The burgeoning demand for 'clean label' products and proposed regulatory shifts[7], exemplified by the push towards organically sourced curing alternatives such as celery juice[8], raises a fundamental question: can organic processed meats achieve sensory parity with conventional formulations, thereby ensuring consumer acceptance?

Here, we address this question through a rigorous sensory panel analysis of processed meats cured with synthetic, conventional, or organic ingredients. The primary objective is to isolate the impact of the curing source on consumer sensory perception and purchase intent. A further aim is to identify potential sensory barriers to the wider adoption of organic processed meats, providing crucial insights for commercial innovation and policy development aimed at reconciling sustainability goals with consumer expectations.

To characterize the curing ingredients, we quantitatively analyzed the volatile and non-volatile phytochemical compounds in the organic and conventional plant-source powders using gas chromatography and ultrahigh-pressure liquid chromatography, respectively. As previously reported, organic plant-sourced curing ingredients exhibited significantly higher levels of volatile and aromatic plant compounds compared to conventional ingredients[9]. Furthermore, non-volatile phytochemicals were also significantly more abundant in organic ingredients (Supplementary Figs. 1, 2 and Supplementary Table 1). Synthetic ingredients traditionally used in industry, most notably sodium nitrites, which remain the most widely used curing agent in the meat industry, predictably lack detectable plant-associated compounds.

Complemented by chemical analysis, A large-scale consumer sensory panel, comprising 478 participants recruited from the University of Wisconsin and UW Health mass email communication to 246,143 individuals, was conducted. The demographic distribution of participants was as follows: 24.9% aged 18 to 24, 27.4% aged 25 to 34, 19.2% aged 35 to 44, 13.1% aged 45 to 54, and 16.8% aged 55 or above.

Despite visually distinct plant pigmentation across incorporated ingredient sources, Consumer preference on frankfurter color (Supplementary Fig. 3), non-meat aftertaste, and purchase intent did not differ significantly (Fig. 1). However, some significant sensory differences were observed in deli-turkey and boneless ham (Fig. 1). Notably, organic-cured products elicited significantly higher non-meat aftertaste perception compared to conventional counterparts (deli-turkey: $p < 0.001$; boneless ham: $p = 0.020$). This increased non-meat aftertaste correlated with significantly

[1]Department of Animal & Dairy Sciences, University of Wisconsin-Madison, Madison, WI, 53706, USA. [2]Department of Plant Pathology, University of Wisconsin-Madison, Madison, WI, 53706, USA. ✉e-mail: siyuan.sheng@outlook.com; jrclaus@wisc.edu

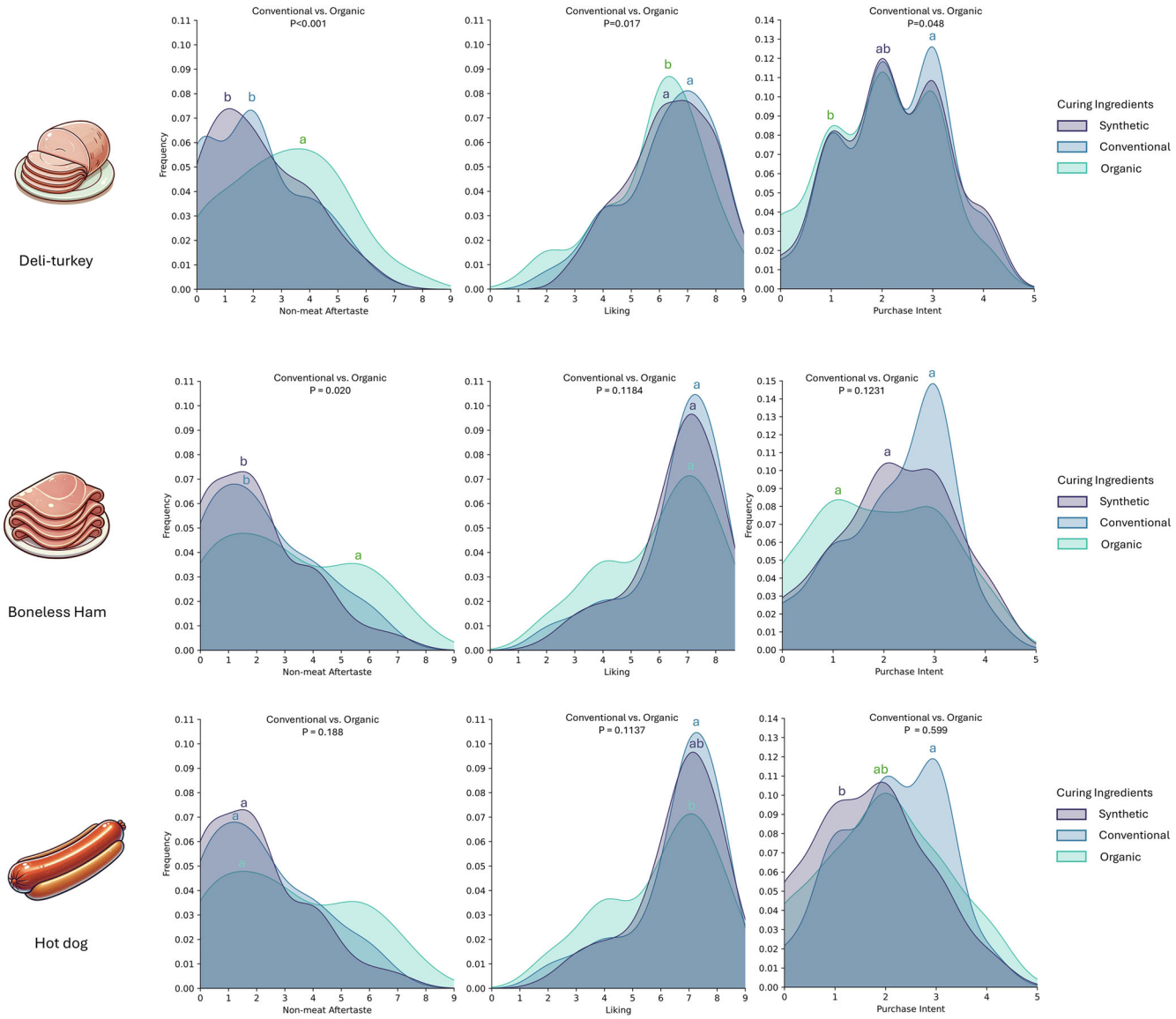


**Fig. 1 | Consumers' taste preference for traditional foods incorporated with synthetic, conventional, and organic function ingredients.** Unlike letters within a dependent variable denote a difference, with *p*-values provided in the figure panels.

reduced liking and purchase intent for organic-cured deli-turkey (liking: $p < 0.017$; purchase intent: $p = 0.048$), and a similar trend was observed for organic-cured boneless ham (liking: $p = 0.118$; purchase intent: $p = 0.123$). Principal component and correlation analyses further confirmed a robust negative association between non-meat aftertaste and purchase intent (Supplementary Fig. 4).

Analysis of consumption frequency (Fig. 2a) revealed that consumers consumed twice per month exhibited significant perceptual differences ($p < 0.05$) in non-meat aftertaste for organic-cured boneless ham. Specifically, disparities were observed between products cured with organic source ingredients and the remaining products. For deli-turkey, perception differences were observed between organic and the rest of products for consumers with once a month consumption frequency, and between organic ingredient cured products and the deodorized ingredient cured products for consumers with a higher consumption frequency. Age-stratified analysis unveiled distinct non-meat aftertaste perception patterns across different age cohorts (Fig. 2c, d). Specifically, age groups 25 to 34 and 35 to 44 reported significantly elevated non-meat aftertaste perception in organic boneless ham compared to products cured with conventional vegetables and chemically synthesized curing agents. Conversely, age groups 18 to 24, 35 to 44, and 45 to 54 reported significantly higher non-meat aftertaste intensity in organic deli-turkey compared to products incorporating deodorized plant source ingredients. Notably, the 45 to 54 age group reported significantly lower liking for organic products compared with products cured with conventional and deodorized vegetables. All other age groups did not report any significant differences among these products. Multilinear regression demonstrated a strong model fit for both boneless ham ($R^2 = 0.732$) and deli-turkey ($R^2 = 0.714$), indicating a significant association between age, non-meat aftertaste perception, and purchase intent (deli-turkey: $p = 0.0022$; boneless ham: $p = 0.033$) (Supplementary Fig. 5). These age and consumption frequency dependent differences were not identified in frankfurters.

This study investigated consumer perceptions of replacing conventional produce or synthetic chemical ingredients with organic produce as functional ingredients in processed foods. Using products manufactured to industry standards, it gathered first-hand insights from three series of consumer panels regarding consumers' perspectives on substituting synthetic and conventional ingredients with organic alternatives in commonly consumed processed foods.

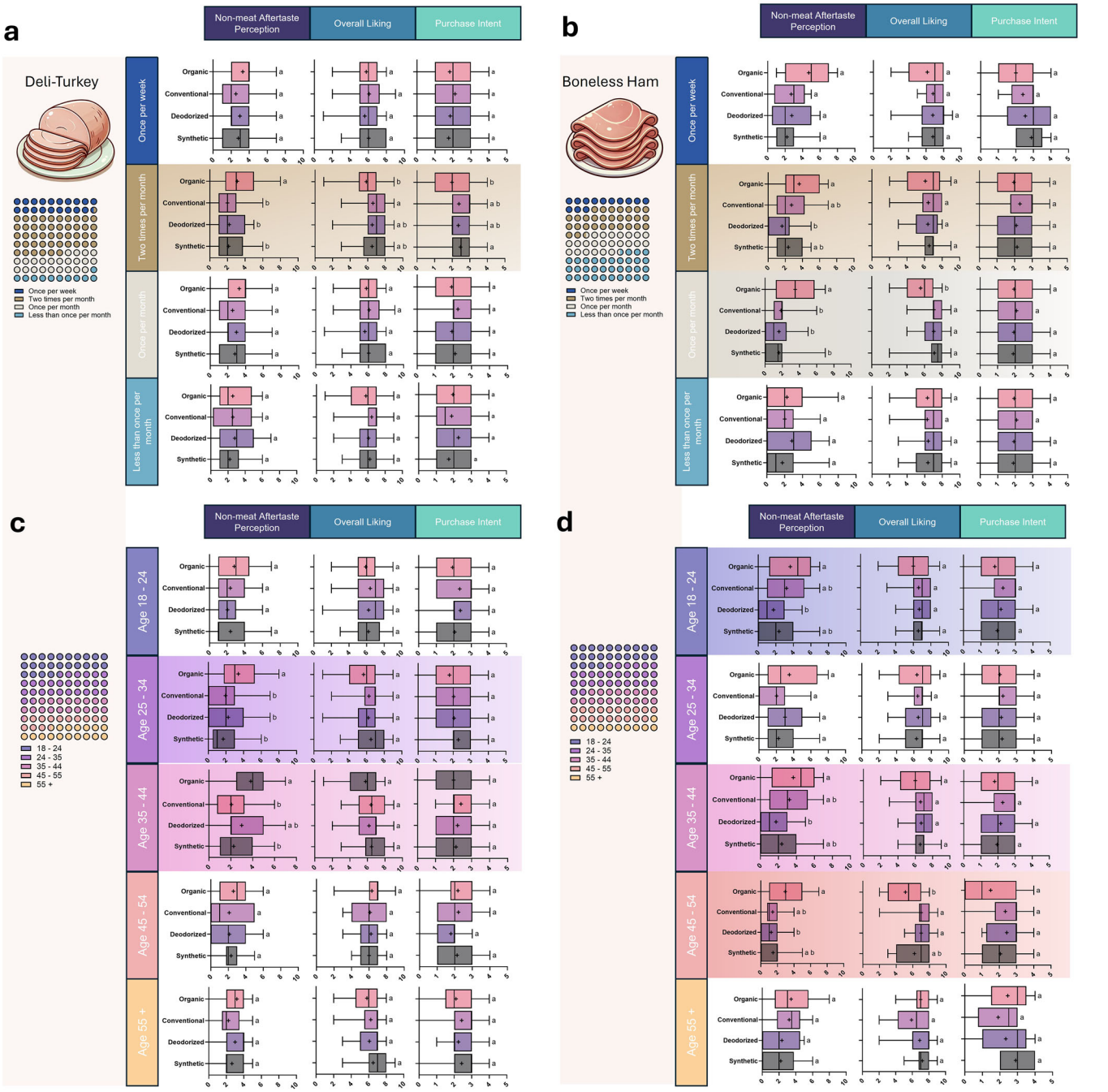


**Fig. 2 | Consumer sensory preferences categorized by age group and consumption frequency. a** Sensory preferences for deli-turkey based on consumption frequency. **b** Sensory preferences for boneless ham based on consumption frequency. **c** Sensory preferences for deli-turkey based on age group. **d** Sensory preferences for boneless ham based on age group. '+' in box chart represents the mean value. Statistical significance was determined using Tukey's Honest Significant Difference (HSD) test. Unlike letters within a dependent variable denote a difference ($p < 0.05$).

Organic produce generates more phytochemicals as one of the herbivore protection mechanisms[10]. Although these phytochemicals are usually antioxidants and beneficial to humans[11,12], they may exhibit a stronger herbal taste and aroma in organic ingredients. Our finding demonstrated that herbal retronasal aroma, described as non-meat aftertaste in meat products, is a critical determinant of reduced purchase intent across the studied processed meat products. While the results are evident in deli-turkey and boneless ham, non-meat aftertaste does not significantly influence liking and purchase intent in the frankfurter test, possibly due to the strong meat aroma in beef compared to pork and poultry products masking the non-meat aftertaste[13]. Beef and pork contain higher myoglobin levels than poultry, contributing more intensely to flavor development[14]. Additionally, fat content is more abundant in beef and pork than in poultry, further influencing aroma and taste perception[15]. Furthermore, unlike boneless ham and deli-turkey, frankfurters were served hot, which may have further enhanced the meat aroma and diminished the perception of the non-meat aftertaste. Given that retronasal olfaction constitutes a substantial portion of perceived flavor[16], and that odor perception is strongly linked to episodic memory[17], the perception of unfamiliar non-meat aftertastes likely diminished consumer liking by deviating from expected sensory profiles[18].

The observation of non-meat aftertaste perception within specific consumption frequency and age groups underscores the need for targeted marketing strategies for organic-ingredient-containing products (Fig. 2).

Our results indicated that age influences the perception of the non-meat aftertaste, but did not significantly affect liking or purchase intent. Age-related declines in olfactory sensitivity and the development of sensory-specific satiety, as documented in previous studies[19–21], may explain the observed differences in aftertaste perception among elderly individuals; these declines are potentially attributable to olfactory neuron degeneration, reduced olfactory bulb blood flow, and altered mucus production[22]. Notably, consumption frequency correlated with non-meat aftertaste perception in organic versus conventional products. The least and most frequent consumers exhibited reduced sensitivity to the atypical aftertastes associated with organic ingredients. This phenomenon is likely attributable to sensory-specific satiety, whereby repeated exposure diminishes perceived pleasantness and discriminative ability[23].

The strengths of this study lie in its rigorous methodology, which includes carefully controlled sample preparation, standardized ingredient usage, and a large longitudinal consumer sensory panel conducted over a three-year period. Our study enables a comprehensive examination of consumer perceptions regarding traditional processed meats cured with vegetable-sourced ingredients, providing critical insights to support a potential regulatory shift by the U.S. Department of Agriculture. Additionally, analyzing consumer demographic profiles, such as age and consumption frequency, provides valuable insights into the nuanced differences in perceptions between organic and conventional ingredients.

Building on these findings, Future research should expand on these findings by exploring a wider range of organic food ingredients, particularly those suitable for further processing, such as pepper, spinach, peas, carrots, beetroot, tomato, and onion powders, which are known for their food applications[24]. Additionally, future research should investigate the potential of organic ingredients to enhance the physicochemical properties and nutritional quality of these foods, ensuring their viability in both commercial applications and consumer acceptance.

In conclusion, this study reveals that sensory differences, particularly non-meat aftertastes, can significantly impede consumer acceptance of organic-ingredient-containing processed foods. The observed variations in aftertaste perception across consumption frequency and age groups highlight the importance of targeted sensory optimization and marketing strategies to promote organic food ingredients application. These findings highlight the importance of balancing sustainability goals with sensory preferences to drive the broader adoption of organic products. Additionally, the findings of this study support potential regulatory changes led by the National Organic Standards Board, advocating for all organic products to be cured using organic ingredients. Implementing such measures could further promote healthier diets and advance environmental sustainability.

## Methods

The study was conducted with human subjects and approved by the University of Wisconsin Institutional Review Board (IRB) (approvals 2022-1342, 2023-1195, and 2024-0540). Participants volunteered for the evaluation sessions and were informed that they would not be compensated, except for the opportunity to sample the test food during the test. Informed consent was obtained and documented from all participants, as required by the IRB data collection process.

### Sample manufacture and preparation

Frankfurters, boneless ham, and deli-turkey products were manufactured at the University of Wisconsin-Madison Meat Science and Animal Biologics Discovery (MSABD) processing facility, a U.S. Department of Agriculture (USDA) inspected establishment (Establishment Numbers M48465, P48465, and V48465). Manufacturing protocols and the quality attributes of the finished products closely adhered to industry standards for meat products distributed in the United States. The nitrite concentration within the vegetable-based curing ingredients was quantified using reverse-phase high-pressure liquid chromatography prior to incorporation into the raw meat matrix[25]. The finished products were vacuum-packaged and stored for a duration of two weeks at 3 °C in darkness before presentation to the consumer sensory panel, thereby simulating the typical timeframe for product delivery within the supply chain.

In this study, we selected four of the most prevalent commercially available meat curing ingredients within the United States market for incorporation into these processed and cured meats:

1. Synthetic: 6.25% sodium nitrite crystallized powder dispersed in sodium chloride, containing a pink dye as a restricted ingredient indicator (Does not contain any herbal ingredients).
2. Conventional: Pre-converted conventional Swiss chard powder with an approximate sodium nitrite equivalent of 22,000 ppm.
3. Organic: Pre-converted organic Swiss chard powder with an approximate sodium nitrite equivalent of 18,000 ppm.
4. Deodorized: Pre-converted celery powder that has undergone an odor removal process to eliminate plant-related flavors, with an approximate sodium nitrite equivalent of 17,000 ppm.

### Instrumental analysis

The proximate composition of the sample products, including moisture, fat, and protein content, was measured using procedures outlined by the Association of Official Analytical Chemists (AOAC) (moisture and fat: AOAC 2008.06; protein: AOAC 981.10). These analyses ensured adherence to industry-standard quality expectations and compliance with regulatory requirements for the standards of identity.

Color of the products were measured using a vertical spectrophotometer with a 2° standard observer (Konica Minolta CM-600d, Konica Minolta Inc., Tokyo, Japan), following the Commission Internationale de l'Eclairage (CIE) $L^*$ (Lightness), $a^*$ (redness), and $b^*$(yellowness) system. The colorimeter was calibrated using a white calibration cap (SM-A177, Konica Minolta CM-600d, Konica Minolta Inc., Tokyo, Japan). Measurements were taken on three randomly selected samples from each food type, with at least eight measurements conducted on different internal regions of each food sample.

The volatile aromatic compound profiles of conventional and organic vegetable ingredients were assessed using gas chromatography (GCMS-TQ 8040 NX, Shimadzu Inc. Kyoto, Japan) combined with tandem mass spectroscopy through steam distillation[9]. Non-volatizable ingredient analysis was performed using an ultra-high-pressure liquid chromatography system with tandem mass spectroscopy (Thermo Scientific Orbitrap Exploris 240, Waltham, MA, U.S.A.), applying a method for polyphenol content measurement[26].

### Consumer sensory evaluation

IRB-approved consumer sensory evaluation panels were conducted at MSABD for all products discussed in this study. Each panelist pre-registered for a scheduled time, with approximately 35 individuals participating in the sensory sessions per test day. Samples were served to panelists in individual booths that were isolated from the preparation area by a one-way glass window to prevent distraction or bias. The light intensity in each booth was carefully maintained at approximately 2000 lux to ensure consistent and optimal display lighting conditions. To replicate typical serving conditions, boneless ham and deli-turkey products were served cold at approximately 4 °C, while frankfurter samples were served hot, with an internal temperature of approximately 50 °C. No condiments were provided during serving to eliminate confounding factors. Water and a spit cup were supplied to enable panelists to cleanse their palates between samples. Panelists were asked to provide basic demographic information, including their age and the frequency of consumption within the test product's category. Each panelist evaluated four randomly pre-selected treatments. Sensory evaluations of the frankfurters were conducted using a 9-point hedonic liking scale (1 = extremely dislike, 9 = extremely like) to assess attributes such as color, aroma, purchase intent and overall liking. Purchase intent was measured using a 5-point scale (1 = definitely will not buy, 5 = definitely will buy).

### Statistical analysis

One-way Analysis of Variance (ANOVA) tests were employed to statistically assess significant differences in sensory attributes among treatments, which included color, aroma, aftertaste, liking, and purchase intent. Post hoc comparisons were performed using Tukey's Honest Significant Difference (HSD) test to identify pairwise differences among sample means. Data normality and homogeneity of variances were verified using the Shapiro-Wilk test prior to conducting the ANOVA. Statistical significance was determined using $p$-values, which were reported alongside mean values and standard deviations to ensure comprehensive representation of the findings.

To verify the correlation between individual variables and purchase intent, a multilinear regression analysis was performed shown in Eq. (1) below. This analysis investigated the combined and individual effects of independent variables such as color, aroma, aftertaste, liking, consumption frequency, and age on purchase intent based on the equation stated below. The coefficient of determination ($R^2$) was calculated to evaluate how well the model explains the variability in the dependent variable.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \beta_{n+1} x_1 x_2 + \ldots \frac{\beta_{n^2-n}}{2} + 1 x_{n-1} x_n + \varepsilon \quad (1)$$

Here $Y$ is the dependent variable (purchase intent), $\beta_0$ is the dependent variable intercept, $\beta_{1 \ldots} \frac{\beta_{n^2-n}}{2} + 1$ are coefficients for each sensory attributes, $x_1 \ldots x_n$ are sensory attributes (color, aroma, aftertaste, liking), $\varepsilon$ is the differences between the observed value and predicted value. The number of sensory attributes is represented by $n$.

All statistical analyses were conducted using GraphPad Prism 10.4.1. Besides the denoted $P$ value in overall consumer sensory evaluation, $P < 0.05$ was the criterion for statistical significance in all other tests.

## Data availability

All data has been presented in the supplemental material section.

Received: 16 April 2025; Accepted: 4 August 2025;
Published online: 25 August 2025

## References

1. Verma, B. C., Pramanik, P. & Bhaduri, D. In *Nutrient Dynamics for Sustainable Crop Production* (ed Meena R S.) 289-313 (Springer Singapore, 2020).
2. Czech, A., Szmigielski, M. & Sembratowicz, I. Nutritional value and antioxidant capacity of organic and conventional vegetables of the genus Allium. *Sci. Rep.* **12**, 18713 (2022).
3. Lima, G. P. P., Borges, C. V., Vianello, F., Cisneros-Zevallos, L. & Minatel, I. O. Phytochemicals in organic and conventional fruits and vegetables. *Fruit and Vegetable Phytochemicals: Chemistry and Human Health, 2nd Edition*, 1305-1322. https://doi.org/10.1002/9781119158042.ch70 (2017).
4. de Lima, D. P. et al. Chemical composition, minerals concentration, total phenolic compounds, flavonoids content and antioxidant capacity in organic and conventional vegetables. *Food Res. Int.* **175**, 113684 (2024).
5. Hemmerling, S. et al. Organic food labels as a signal of sensory quality—insights from a cross-cultural consumer survey. *Org. Agric.* **3**, 57–69 (2013).
6. Stoica, M. et al. New strategies for the total/partial replacement of conventional sodium nitrite in meat products: a review. *Food Bioprocess Technol.* **15**, 514–538 (2022).
7. Board, N. O. S. *National Organic Standards Board (NOSB) Meeting, Milwaukee, WI*, https://www.ams.usda.gov/event/national-organic-standards-board-nosb-meeting-milwaukee-wi (2024).
8. Yong, H. I. et al. Clean Label meat technology: pre-converted nitrite as a natural curing. *Food Sci. Anim. Resour.* **41**, 173–184 (2021).
9. Sheng, S., Silva, E. M., Ricke, S. C. & Claus, J. R. Characterization of volatilized compounds in conventional and organic vegetable-source alternative meat-curing ingredients. *Molecules* **30**, 835 (2025).
10. Richards, L. A. et al. Phytochemical diversity and synergistic effects on herbivores. *Phytochem. Rev.* **15**, 1153–1166 (2016).
11. Siyuan, S., Tong, L. & Liu, R. Corn phytochemicals and their health benefits. *Food Sci. Hum. Wellness* **7**, 185–195 (2018).
12. Chen, H. & Liu, R. H. Potential mechanisms of action of dietary phytochemicals for cancer prevention by targeting cellular signaling transduction pathways. *J. Agric. Food Chem.* **66**, 3260–3276 (2018).
13. Aaslyng, M. D. & Meinert, L. Meat flavour in pork and beef – From animal to meal. *Meat Sci.* **132**, 112–117 (2017).
14. Devaere, J. et al. Improving the aromatic profile of plant-based meat alternatives: effect of myoglobin addition on volatiles. *Foods* **11**, https://doi.org/10.3390/foods11131985 (2022).
15. Enser, M., Hallett, K., Hewitt, B., Fursey, G. & Wood, J. D. Fatty acid content and composition of English beef, lamb and pork at retail. *Meat Sci.* **42**, 443–456 (1996).
16. Spence, C. Multisensory Flavor Perception. *Cell* **161**, 24–35 (2015).
17. Chartier, F. *Taste buds and molecules: the art and science of food, wine, and flavor*. (John Wiley & Sons, 2012).
18. Morrin, M. & Ratneshwar, S. The impact of ambient scent on evaluation, attention, memory for familiar and unfamiliar brands. *J. Bus. Res.* **49**, 157–165 (2000).
19. Cavazzana, A. et al. Sensory-specific impairment among older people. An investigation using both sensory thresholds and subjective measures across the five senses. *PLoS One* **13**, e0202969 (2018).
20. Alia, S. et al. The influence of age and oral health on taste perception in older adults: a case-control study. *Nutrients* **13**, https://doi.org/10.3390/nu13114166 (2021).
21. Hollis, J. H. & Henry, C. J. K. Sensory-specific satiety and flavor amplification of foods. *J. Sens. Stud.* **22**, 367–376 (2007).
22. Fatuzzo, I. et al. Neurons, nose, and neurodegenerative diseases: olfactory function and cognitive impairment. *Int. J. Mol. Sci.* **24**, 2117 (2023).
23. Hetherington, M. & Havermans, R. C. In *Satiation, Satiety and the Control of Food Intake* (eds Blundell J. E. & Bellisle F.) 253-269 (Woodhead Publishing, 2013).
24. Neacsu, M. et al. Phytochemical profile of commercially available food plant powders: their potential role in healthier food reformulations. *Food Chem.* **179**, 159–169 (2015).
25. Sheng, S., Silva, E. M., Tarté, R. & Claus, J. R. Residual nitrite and nitrate in processed meats and meat analogues in the United States. *Sci. Rep.* **15**, 3269 (2025).
26. Liu, C., Lea Girard, A., William Hartel, R. & Warren Bolling, B. Improved analysis of grape seed extract by liquid chromatography–high resolution mass spectrometry (LC-HRMS) reveals that proanthocyanidin-protein interaction mechanisms in cream depend on degree of polymerization. *Food Chem.* **451**, 139432 (2024).

## Acknowledgements

We would like to extend our gratitude to all the panelists who generously volunteered to participate in this consumer sensory study. We also thank the faculty, staff, and students at the University of Wisconsin for their assistance with sample preparation, handling, and analysis. This research was funded by the Organic Research and Extension Initiative program of the U.S. Department of Agriculture, National Institute of Food and Agriculture (Award #2019-51300-30243).

## Author contributions

S.S., and J.C. designed the experiment, S.S. undertook the experiment, collected data, conducted the analyses, and wrote the manuscript. S.S. and

J.C. conducted the statistical analysis. All authors reviewed and revised the manuscript.

## Competing interests
The authors declare no competing interests.

## Additional information
**Supplementary information** The online version contains supplementary material available at https://doi.org/10.1038/s41538-025-00545-1.

**Correspondence** and requests for materials should be addressed to Siyuan Sheng or James R. Claus.