Meat and Muscle Biology™

Leveraging Understanding of Meat Flavor for Product Success[1]

Rodrigo Tarté[2,3]*

[2]Department of Animal Science, Iowa State University, Ames, IA 50011, USA
[3]Department of Food Science & Human Nutrition, Iowa State University, Ames, IA 50011, USA
*Corresponding author. Email: rtarte@iastate.edu (Rodrigo Tarté)
[1]This paper is a product of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, USA, Project No. IOW03721, which is sponsored by Hatch Act and State of Iowa funds.

Abstract: In order to get the most benefit out of the use of spices, seasonings, and flavors, an understanding of meat flavor and the factors that affect it is needed. This article discusses flavor and its sensory perception, the various factors that affect it, and how this understanding can be leveraged to achieve formulation objectives and product success.

Key words: meat flavor, taste, aroma, flavor precursors, product development
Meat and Muscle Biology 5(3): 7, 1–6 (2021) **doi:10.22175/mmb.13045**
Submitted 25 August 2021 Accepted 2 November 2021

This paper was accepted as a contribution to the 2021 AMSA Reciprocal Meat Conference.

Introduction and Background

From a consumer perspective, appearance, flavor, and texture are key food quality attributes (Civille, 1991). The relative contributions of each of these attributes to the acceptance of meat and meat products will depend on the chemical and physical states of the meat and its constituents, which are, in turn, the result of numerous complex interactions that take place as a result of intrinsic and extrinsic factors that act upon the meat. Of these attributes, flavor (term sometimes used interchangeably with *taste*) has, for many years, been at or near the top among drivers of food preference and purchase intent (Clark, 1998; International Food Information Council, 2021)

Flavor and its perception

Flavor is the sensation that results primarily from the chemical senses of taste, olfaction (or smell), and the trigeminal system (Spence, 2013). *Gustation*, or taste, is perceived when a taste-active compound binds to specific proteins known as taste receptors, which are found in the taste buds of papillae in the tongue, or in other parts of the oral cavity, including the soft palate (Gravina et al., 2013). This event leads to cell membrane depolarization, neurotransmitter release, and the eventual propagation of sensory information to the central nervous system via an action potential (Boughter Jr. and Munger, 2013). *Olfaction*, or smell, is initiated when volatile odorous molecules (or odorants) reach the olfactory epithelium located in the back of the nasal cavity and come into contact with the olfactory receptors located in the cilia of olfactory sensory neurons (Holley, 2006). There, membrane depolarization causes an action potential that is transmitted, via the olfactory and trigeminal nerves, to the brain. While it is known that humans possess between 10 and 20 million olfactory sensory neurons, each expressing one of more than 400 different olfactory receptors, the mechanisms by which their activity translates to sensory odor perception are not well understood (Trimmer et al., 2019). The *trigeminal system* is a chemical sense involved in the perception of somatosensory sensations, such as touch (e.g., itching, tickling), temperature (e.g., cooling, warming), and pain (e.g., burning, stinging) and involves activation of the trigeminal nerve endings (Brand, 2006). Because most odorants that stimulate the olfactory system also stimulate the trigeminal system, their trigeminal effects cannot be ignored.

Meat flavor

Meat flavor develops primarily during cooking. Though almost devoid of flavor, raw meat contains nonvolatile components that provide all 5 basic tastes (salty, sour, bitter, sweet, and umami) as well as the necessary flavor precursors that contribute to the characteristic flavor of cooked meat. These flavor precursors can be either water-soluble (amino acids, peptides, nucleotides, carbohydrates, etc.) or lipid components (Mottram, 1998). During thermal processing, very complex interactions between these precursors, as well as their thermal degradation, give rise to a large number of flavor compounds, which lead to a wide variety of different flavors. The types and concentrations of specific flavor compounds formed will depend on factors such as (i) the types and concentration of taste compounds and nonvolatile precursors of aroma components present in the meat, (ii) thermal processing conditions such as temperature, time, and humidity (in other words, the cooking method), and (iii) the presence of nonmeat ingredients, such as sugars, spices, flavorings, or smoke (Melton, 1999; Mottram, 1998). In order to have a better understanding of meat flavor, let us focus on its 2 primary determinants, taste and aroma.

Taste. The majority of taste compounds in meat are nonvolatile, low–molecular-weight components, typically amino acids, organic acids or their salts, and inorganic salts. Collectively, these components provide all 5 basic tastes: sweet, sour, bitter, salty, and umami (Tarté and Amundson, 2006). Hydrophilic peptides provide sweetness; hydrophobic peptides contribute sourness and bitterness; inorganic salts and salts of glutamate and aspartate are associated with saltiness; certain 5'-nucleotides (e.g., 5'-inosine monophosphate and 5'-guanosine monophosphate), amino acids and their salts (e.g., glutamic acid and monosodium glutamate), and certain peptides provide umami taste (MacLeod, 1998). Umami compounds do not possess unique characteristic flavors but can enhance, potentiate, or modify existing flavors. They have also been described as "savory," "beefy," or "brothy" (MacLeod, 1998; Maga, 1998).

Aroma. Over 1,000 volatile aroma compounds have previously been identified in beef, pork, chicken, and mutton. They include many types of organic compounds, such as hydrocarbons, alcohols, carboxylic acids, aldehydes, ketones, esters, lactones, ethers, furans, pyridines, pyrazines, pyrroles, oxazoles, oxazolines, thiazoles, thiazolines, thiopenes, and other sulfur- and halogen-containing compounds (Shahidi, 1998). These volatiles form during thermal processing by the interactions of nonvolatile, low–molecular-weight precursors, such as amino acids, peptides, reducing sugars, nucleotides, vitamins, and unsaturated fatty acids (Melton, 1999), through a series of many complex reactions. The most important of these reactions are the Maillard reaction; oxidation and degradation of lipids; thermal degradation of vitamins (primarily thiamin), sugars (including caramelization), and ribonucleotides; pyrolysis of amino acids and peptides; and interactions of Maillard reaction products with lipids (Kerth and Miller, 2015).

Although the number of identified volatile compounds in meats is very large (>1,000), only a relatively few have been shown to contribute "meaty" aromas (MacLeod, 1998; Kosowska et al., 2018). A few others contribute notes such as buttery, caramel, roast, burnt, sulfurous, green, fragrant, oily/fatty and nutty—and have thus been designated as "aroma modifiers"—and the majority are considered to be relatively unimportant. For instance, only 25 of 880 aroma compounds in cooked beef have been described as possessing a meaty aroma (MacLeod, 1998). The most important meat flavor volatiles are sulfur-containing compounds that occur at low concentrations but have odor detection thresholds that are very low and lipid-derived volatile compounds, which have higher aroma thresholds (Kerth and Miller, 2015). The former are predominant in meat cooked at temperatures greater than 149°C (300°F), whereas the latter predominate in meat cooked to lower temperatures (Dinh et al., 2021; Kerth and Miller, 2015). Therefore, both sulfur-containing flavor precursors (e.g., the amino acids cysteine, cystine, and methionine; the peptide glutathione; and thiamin) (Chen and Ho, 1998; Cerny and Davidek, 2003; Hou et al., 2017) and fatty acids are very important. It has been observed that most basic "meaty" aroma compounds are common to meat from various animal species, because flavor precursors from different animal species are roughly similar (Hornstein and Wasserman, 1987). Noteworthy among these are the thiol-substituted furans (furanthiols) and thiophenes (thiophenthiols), which form from the reaction of cysteine and ribose via the Maillard reaction (Farmer et al., 1989; Farmer and Mottram, 1990; Zhou et al., 2019) and the thermal degradation of thiamin (Güntert et al., 1993; Thomas et al., 2015) and that provide strong meaty and roast aromas and very low odor threshold values. As would be expected, there are flavor compounds that are responsible for flavor differences across animal species. These are believed to result primarily from degradation of the meat's phospholipid fraction, and from the interaction of this fraction with other meat components (van den Ouweland and Swaine, 1980; Hornstein and Wasserman, 1987; Mottram, 1998).

Flavor of cured meats. It has been thought for some time that nitrite's antioxidant properties are involved in cured meat flavor formation (Ramarathnam, 1998). It was first postulated in 1965 (Cross and Ziegler) that the flavor of cured meat is derived from non-lipid precursors, whereas the flavor of uncured cooked meat is heavily dependent on carbonyl compounds (hexanal and others) that result from lipid oxidation. In subsequent years, it was shown that cooked cured meat contains fewer volatiles than uncured cooked meat, due mostly to a significant reduction in the number and relative concentrations of the carbonyls and hydrocarbons that are normally found in cooked meat (Shahidi, 1992; Ramarathnam, 1998). Therefore, it was proposed that nitrite affects meat flavor by inhibiting lipid oxidation during cooking (and therefore formation of these carbonyls) (Shahidi, 1989) as well as warmed-over flavor (Sato and Hegarty, 1971). However, it has been pointed out that if cured meat flavor were the result of the antioxidant activity of nitrite alone, other commonly used antioxidants would also generate it, but they do not (Dumont et al., 1990; Jo et al., 2020), suggesting that it is due to more complex reactions of nitrite in the meat matrix. More recent research on ham confirms a nitrite-induced reduction in hexanal, in the highly odorous thiamin-derived sulfur-containing compound 2-methyl-3-(methyldithio) furan, and in overall odor intensity (attributed to fatty acid oxidation products) but not in perception of aroma compounds derived from degradation of sulfur-containing precursors (Thomas et al., 2013). These authors hypothesized that nitrite does not affect the production of specific flavor compounds, but rather that the higher levels of hexanal in nitrite-free ham mask the "cooked ham" flavor notes that would otherwise be present in hams without nitrite. This does not, however, rule out the possibility that intermediates formed by the reaction of nitrite with other flavor precursors are associated with cured meat flavor, as previously proposed (Dumont et al., 1990).

Factors That Affect Meat Flavor

Meat-specific factors

Besides species, other factors that can influence the flavor of meat include animal diet, age, breed, sex, muscle type, and pre-slaughter stress (Hornstein and Wasserman, 1987; Khan et al., 2015). These factors are generally outside a product developer's direct control, and are sometimes difficult to identify, so they are not discussed here in detail. However, it is important to be aware of them, because they are capable of affecting flavor in both positive and negative ways.

Product-specific factors

These are factors that are typically under the direct control or influence of food product developers and manufacturers. Their close control and monitoring are critical in order to guarantee consistent product quality. Therefore, as much information on these as possible should be included in product, process, and raw material/ingredient specifications; in-plant process controls; and handling/distribution guidelines and requirements, as applicable. These factors include the following:

1. **Added flavorings, spices, and seasonings.** These typically characterize the unique flavor profile of a product. Care must be taken in their selection, as well as storage. Their flavors can fade over time, so good inventory rotation is important.
2. **Other ingredients.** It is important to understand that many other "non-flavoring" ingredients can also affect product flavor, either positively or negatively (Guichard, 2002). Among these are ingredients such as binders (e.g., starches and proteins), antimicrobials (e.g., lactate, diacetate, vinegar, cultured sugar), and even water. Addition or removal of formula water can dilute or concentrate product flavor (as well as critically important antimicrobial additives), so it must be done very carefully.
3. **Thermal processing parameters.** As previously explained, cooking temperature, time, and humidity all play a role in the specific types and concentrations of flavor molecules that are found in meat products. Therefore, they must be tightly controlled,

which underscores the importance of ensuring that all sensors, steam and smoke injection ports, and exhaust dampers be in good working condition.

4. **Product consumption temperature.** How customers and/or consumers cook or heat a product before final consumption is also critical to flavor formation. Therefore, any cooking or re-heating instructions must be drafted carefully to guarantee consumer satisfaction.
5. **Product's expected shelf life.** Many products, especially those that are commercialized as ready-to-eat (generally pre-cooked, dried, or fermented) are usually expected to be stable over extended periods of storage and distribution, retail display, and in-home storage. Therefore, flavor stability should be monitored during shelf life studies. Microbial growth over time must also be considered, because microbial metabolites can affect product flavor, even in the absence of evident product spoilage. Consideration should also be given to potential abuse conditions that the product may encounter on its way from the packing or manufacturing plant to the end consumer.

Implications for Product Development

In order to ensure the production of a consistent-quality product that meets consumer expectations, all factors that could potentially affect flavor formation and stability (Table 1) must be identified and understood during the product development process and controlled through careful drafting of—and subsequent adherence to—product and production specifications. This involves an understanding of the following factors:

1. **The sources of flavor compounds and their precursors:** Consider the key contributions of the meat raw materials, the flavorings, seasonings and spices, and other ingredients.
2. **How and at what point flavor compounds are formed:** Consider the type of thermal process the product is subjected to and where it happens, whether in a manufacturing plant, in a customer's kitchen, or in the end-consumer's home (or cookout).
3. **How the flavor might change over time:** Consider how stable the product is and incorporate flavor stability assessments in product shelf life studies. Anticipate and address potential abuse conditions that the product may encounter (e.g., temperature abuse, light exposure) once it leaves the manufacturer's control and how these affect flavor.

Table 1. Factors affecting flavor formation and stability that should be considered during product development

Formula raw materials and ingredients
Thermal process
Temperature; humidity; time
Labeling/regulatory requirements or restrictions
Standards of identity; restricted-use ingredients; label claims, disclaimers, or qualifiers
Specific product attributes
Flavor; texture; color; chemical composition
Shelf life and shelf stability
Flavor stability over time; microbial growth; product abuse conditions
Handling requirements at all stages of product life cycle
Temperature; humidity; light exposure
Cooking and/or heating instructions

Conclusions

Flavor as a quality attribute is critical to meat and food product success. While the formation of flavor compounds involves a series of very complex reactions and interactions that are not fully understood, it is possible to identify the factors that affect flavor, and to control them. As with all product quality attributes, consistency in formulation, processing, handling, and distribution is critically important to ensuring consistent quality and, as a consequence, customer and consumer loyalty.

Literature Cited

Boughter Jr., J. D., and S. D. Munger. 2013. Taste receptors. In: W. J. Lennarz and M.D. Lane, editors, Encyclopedia of biological chemistry. 2nd ed. Academic Press, London. p. 366–368. https://doi.org/10.1016/B978-0-12-378630-2.00397-2.

Brand, G. 2006. Olfactory/trigeminal interactions in nasal chemoreception. Neurosci. Biobehav. R. 30:908–917. https://doi.org/10.1016/j.neubiorev.2006.01.002.

Cerny, C., and T. Davidek. 2003. Formation of aroma compounds from ribose and cysteine during the Maillard reaction. J. Agr. Food Chem. 51:2714–2721. https://doi.org/10.1021/jf026123f.

Chen, J., and C.-T. Ho. 1998. The flavour of pork. In: F. Shahidi, editor, Flavor of meat, meat products and seafoods. 2nd ed. Blackie Academic & Professional, London. p. 64–100.

Civille, G. V. 1991. Food quality: Consumer acceptance and sensory attributes. J. Food Quality. 14:1–8. https://doi.org/10.1111/j.1745-4557.1991.tb00044.x.

Clark, J. E. 1998. Taste and flavour: Their importance in food choice and acceptance. P. Nutr. Soc. 57:639–643. https://doi.org/10.1079/PNS19980093.

Cross, C. K., and P. Ziegler. 1965. A comparison of the volatile fractions from cured and uncured meats. J. Food Sci. 30:610–614. https://doi.org/10.1111/j.1365-2621.1965.tb01811.x.

Dinh, T. T. N., K. V. To, and M. W. Schilling. 2021. Fatty acid composition of meat animals as flavor precursors. Meat Muscle Biol. 5:34, 1–16. https://doi.org/10.22175/mmb.12251.

Dumont, J.-P. A., M. Mouloud, and R. Goutefongea. 1990. Contribution of nitrite-unsaturated fat reactions to flavor: The gordian knot revisited. In: Y. Bessière and A. F. Thomas, editors, Flavour science and technology. John Wiley & Sons, Chichester. p. 125–128.

Farmer, L. J., and D. S. Mottram. 1990. Recent studies on the formation of meat-like aroma compounds. In: Y. Bessière and A. F. Thomas, editors, Flavour science and technology. John Wiley & Sons, Chichester. p. 113–116.

Farmer, L. J., D. S. Mottram, and F. B. Whitefield. 1989. Volatile compounds produced in Maillard reactions involving cysteine, ribose and phospholipid. J. Sci. Food Agr. 49:347–368. https://doi.org/10.1002/jsfa.2740490311.

Gravina, S. A., G. Y. Yep, and M. Khan. 2013. Human biology of taste. Ann. Saudi Med. 33:217–222. https://doi.org/10.5144/0256-4947.2013.217.

Guichard, E. 2002. Interactions between flavor compounds and food ingredients and their influence on flavor perception. Food Rev. Int. 18:49–70. https://doi.org/10.1081/FRI-120003417.

Güntert, M., H.-J. Bertram, R. Hopp, W. Silberzahn, H. Sommer, and P. Werhoff. 1993. Thermal generation of flavor compounds from thiamin and various amino acids. In: R. Hopp and K. Mori, editors, Recent developments in flavor and fragrance chemistry: Proceedings of the 3rd International Haarmann & Reimer Symposium. VCH, Weinheim. p. 215–240.

Holley, A. 2006. Processing information about flavor. In: A. Voilley and P. Etiévant, editors, Flavour in food. Woodhead Publishing Limited, London. p. 36–61.

Hornstein, I., and A. Wasserman. 1987. Chemistry of meat flavor. In: J. F. Price and B. S. Schweigert, editors, The science of meat and meat products. 3rd ed. Food & Nutrition Press, Westport, CT. p. 329–384.

Hou, L., J. Xie, M. Zhao, M. Fan, Q. Xiao, J. Liang, and F. Chen. 2017. Roles of different initial Maillard intermediates and pathways in meat flavor formation for cysteine-xylose-glycine model reaction systems. Food Chem. 232:135–144. https://doi.org/10.1016/j.foodchem.2017.03.133.

International Food Information Council. 2021. 2021 Food & Health Survey. https://foodinsight.org/2021-food-health-survey/. (Accessed 19 May 2021).

Jo, K., S. Lee, H. I. Yong, Y.-S. Choi, and S. Jung. 2020. Nitrite sources for cured meat products. Lebensm.-Wiss. Technol. 129:109583. https://doi.org/10.1016/j.lwt.2020.109583.

Kerth, C. R., and R. K. Miller. 2015. Beef flavor: a review from chemistry to consumer. J. Sci. Food Agr. 95:2783–2798. https://doi.org/10.1002/jsfa.7204.

Khan, M. I., C. Jo, and M. R. Tariq. 2015. Meat flavor precursors and factors influencing flavor precursors—A systematic review. Meat Sci. 110:278–284. https://doi.org/10.1016/j.meatsci.2015.08.002.

Kosowska, M., M. A. Majcher, H. H. Jélen, and T. Fortuna. 2018. Key aroma compounds in smoked cooked loin. J. Agr. Food Chem. 666:3683–3690. https://doi.org/10.1021/acs.jafc.7b05996.

MacLeod, G. 1998. The flavour of beef. In: F. Shahidi, editor, Flavor of meat, meat products and seafoods. 2nd ed. Blackie Academic & Professional, London. p. 27–60.

Maga, J. A. 1998. Umami flavor of meat. In: F. Shahidi, editor, Flavor of meat, meat products and seafoods. 2nd ed. Blackie Academic & Professional, London. p. 197–216.

Melton, S. L. 1999. Current status of meat flavor. In: Y. L. Xiong, C.-T. Ho, and F. Shahidi, editors, Quality attributes of muscle foods. Kluwer Academic/Plenum Publishers, New York. p. 115–133.

Mottram, D. S. 1998. Flavour formation in meat and meat products: A review. Food Chem. 62:415–424. https://doi.org/10.1016/S0308-8146(98)00076-4.

Ramarathnam, N. 1998. Flavour of cured meat. In: F. Shahidi, editor, Flavor of meat, meat products and seafoods. 2nd ed. Blackie Academic & Professional, London. p. 290–319.

Sato, K., and G. R. Hegarty. 1971. Warmed-over flavor in cooked meats. J. Food Sci. 36:1098–1102. https://doi.org/10.1111/j.1365-2621.1971.tb03355.x.

Shahidi, F. 1989. Flavor of cooked meats. In: R. Teranishi, R. G. Buttery, and F. Shahidi, editors, Flavor chemistry: Trends and developments. American Chemical Society, Washington, DC. p. 188–201.

Shahidi, F. 1992. Prevention of lipid oxidation in muscle foods by nitrite and nitrite-free compositions. In: A. J. St. Angelo, editor, Lipid oxidation in food. American Chemical Society, ACS Symposium Series 500, Washington, D.C. p. 161–182. https:/doi.org/10.1021/bk-1992-0500.fw001.

Shahidi, F. 1998. Flavour of muscle foods—An overview. In: F. Shahidi, editor, Flavor of meat, meat products and seafoods. 2nd ed. Blackie Academic & Professional, London. p. 1–4.

Spence, C. 2013. Multisensory flavour perception. Curr. Biol. 23: R365–R369.

Tarté, R., and C. A. Amundson. 2006. Protein interactions in muscle foods. In: A. G. Gaonkar and A. McPherson, editors, Ingredient interactions: Effects on food quality. 2nd ed. CRC Press, Boca Raton, FL. p. 195–282. https://doi.org/10.1201/9781420028133.

Thomas, C., F. Mercier, P. Tournayre, J.-L. Martin, and J.-L. Berdagué. 2013. Effect of nitrite on the odourant volatile fraction of cooked ham. Food Chem. 139:432–438. https://doi.org/10.1016/j.foodchem.2013.01.033.

Thomas, C., F. Mercier, P. Tournayre, J.-L. Martin, and J.-L. Berdagué. 2015. Effect of added thiamine on the key odorant compounds and aroma of cooked ham. Food Chem. 173:790–795. https://doi.org/10.1016/j.foodchem.2014.10.078.

Trimmer, C., A. Keller, N. R. Murphy, L. L. Snyder, J. R. Willer, M. H. Nagai, N. Katsanis, L. B. Vosshall, H. Matsunami, and J. D. Mainland. 2019. Genetic variation across the human olfactory receptor repertoire alters odor perception. P. Natl.

Acad. Sci.-Biol. 116:9475–9480. https://doi.org/10.1073/pnas.1804106115.

van den Ouweland, G. A. M., and R. L. Swaine. 1980. Investigation of the species specific flavor of meat. Perfumer & Flavorist. 5(October):15–16, 19–20.

Zhou, R., J. Grant, E. M. Goldberg, D. Ryland, and M. Aliani. 2019. Investigation of low molecular weight peptides (<1 kDa) in chicken meat and their contribution to meat flavor formation. J. Sci. Food Agr. 99:1728–1739. https://doi.org/10.1002/jsfa.9362.