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Review Paper

Key parameters affecting the sensory quality of beef: a review

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ABSTRACT

The sensory quality of beef is one of the most important factors by which consumers assess their satisfaction, and it plays a crucial role in influencing future purchasing decisions. Color, tenderness, juiciness and flavor are the most valorized sensory attributes of beef. The sensory characteristics of beef are influenced by various factors related to the animal, such as breed, sex, age, and growth potential, as well as technological factors, including feeding systems, rearing methods, transport, and slaughter procedure. Consumer preferences regarding sensory quality parameters are shaped by geographic regions, cultural norms and individual differences. Consumers in some regions favor a bright red color, while others associate a darker red color with higher quality of beef. European consumers tend to prefer the more intense flavor of grass-fed beef, while U.S. consumers favor the flavor of grain-fed beef. This review focuses on the key parameters for the sensory quality of beef from a consumer perspective, as well as the main variables that affect these parameters.

1. Introduction

Sensory attributes, perceived through the senses, play a central role in shaping consumer food preferences and satisfaction. The principal sensory quality parameters of beef that define satisfaction in consumers include color, tenderness, juiciness, and flavor. However, consumer perception of these sensory attributes is not uniform and can vary significantly based on geographic region, cultural norms, educational background, and other sociodemographic factors (*Clinquart et al.*, 2022). The sensory characteristics of beef are influenced by a complex combination of different factors, including breed, age, sex, and rearing systems, as well as technological factors. Moreover, diet, growth strategy, and technological procedures ranging from transport to slaughterhouse and meat preparation are critical in determining the final sensory quality of beef (*Pogorzelski et al.*, 2022).

The objective of this review is to describe the sensory attributes of beef that are most valued by consumers, and outline the main factors that influence these attributes.

2. Beef color

Color is commonly regarded as a critical visual indicator of freshness, taste, texture, and overall quality

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(*Smith et al*., 2000). A bright, cherry-red hue is typically associated with freshness and superior eating quality, whereas a brown discoloration is often interpreted as a sign of spoilage or lower quality (*Lukić et al*., 2013). Meat color is predominantly determined by the concentration of myoglobin and its chemical state, particularly its level of oxygenation or oxidation. The main chemical forms of myoglobin responsible for the appearance of beef are: Oxymyoglobin (OMb; Fe^{2+}in the presence of O_2), which imparts a bright cherry-red color and positively influences consumer acceptance; Metmyoglobin (MMb; Fe^{3+} in the oxidized state), associated with a brown coloration and commonly regarded as a primary indicator of freshness loss, often resulting in product rejection; Deoxymyoglobin (DMb; Fe^{2+} in the absence of O_2), which gives the meat a purplish-red appearance. The susceptibility of myoglobin to oxidation is affected by several interrelated factors, including breed, sex, nutrition, muscle type, pre-slaughter stress, and postmortem metabolic changes. Female animals tend to accumulate pigment more rapidly with age compared to males. Nonetheless, meat from intact males generally appears darker than that from females or castrated males, which is attributed to higher physical activity levels and greater myoglobin concentrations (*Liu et al*., 2022). Variations in beef color are significantly affected by the production system and feeding regime. It is well established that grass-fed, particularly pasture-raised, cattle produce meat with a darker color. This effect is primarily attributed to increased physical activity, which induces a shift in muscle fiber composition toward oxidative metabolism. Such a physiological adaptation is characterized by enhanced capillarity, a higher proportion of slow oxidative (red) muscle fibers, and elevated myoglobin concentrations (*Scollan et al*., 2014). The visible portion of intramuscular fat (IMF), commonly referred to as marbling, is widely recognized as a key indicator of beef quality. Marbling is influenced by several factors, including diet, age at slaughter, muscle type, and particularly differences among cattle breeds. *Park et al.* (2018) reported a wide range in IMF content, from as low as 1.9% in Brahman cattle to as high as 37.8% in Japanese Wagyu beef. Generally, grain-fed cattle reared in feedlot systems accumulate greater amounts of IMF, which contributes to a lighter meat appearance due to increased fat dispersion. A comparative study involving fifteen European cattle breeds revealed significant breed-dependent variation in beef color, allowing classification into four distinct groups. Highly specialized beef breeds, such as Limousin, Charolais, Piemontese, and Marchigiana, tend to produce meat with a bright, pale-red color. South Devon, Danish Red, Asturiana de los Valles, Pirenaica, Aberdeen Angus, and Holstein are associated with meat of a similarly bright but pale appearance. Simmental, Avileña-Negra Ibérica, Highland, and Casina produce beef with a more intense red color, while the Jersey breed (a dairy breed) yields meat with a darker and dull red hue (*Ripoll et al*., 2018). European consumers generally prefer beef with a bright or light red color, a preference that is also observed among consumers in Australia and Japan. U.S. consumers tend to favor a cherry-red color. In contrast, consumers in Scotland and Ireland perceive bright red beef as less acceptable, exhibiting a clear preference for darker red meat (*Santos et al*., 2021).

3. Beef tenderness

Consumer satisfaction with meat tenderness is primarily determined on the basis of the interaction between the physical and textural properties of the meat and the perceived oral sensations during mastication, commonly referred to as mouthfeel (*Liu et al*., 2022). Beef tenderness is strongly influenced by genetic factors. It is well established that meat from *Bos indicus* cattle tends to be less tender than that from *Bos taurus* breeds. This difference is primarily attributed to elevated levels of calpastatin enzyme in *Bos indicus*, which inhibits postmortem proteolysis (*Wright et al*., 2018). Breed-specific differences in tenderness can occur independently of intramuscular fat content. *Chambaz et al.* (2003) demonstrated that cattle from the Angus and Limousin breeds consistently produced more tender meat compared to Charolais and Simmental, even when marbling levels were equivalent. Post-slaughter carcass cooling is a critical factor influencing the meat tenderization process, and it can negatively impact final meat quality. Elevated carcass temperatures with insufficient or delayed carcass cooling, combined with a rapid postmortem pH decline can lead to a condition known as heat-induced toughening, which significantly compromises tenderness. Conversely, if the carcass is chilled too rapidly before the completion of rigor mortis, excessive muscle contraction can occur, resulting in irreversible toughness—a phenomenon referred to as cold shortening. Compared with other meats, beef is particularly susceptible to cold shortening due to its relatively high proportion of oxidative red muscle fibers, which are more reactive to sudden temperature drops postmortem

(*Thomson et al*., 2008). Beef tenderness is inversely related to the age of the animal, with tenderness decreasing as age increases. This decline is primarily attributed to age-related changes in connective tissue. The impact of age on tenderness becomes especially pronounced when the age differences among animals are substantial. Sex category also influences meat tenderness. Heifers generally produce more tender meat than bulls and steers, due to the females' lower intramuscular connective tissue content and smaller muscle fiber diameters (*Duarte et al*., 2022). Feeding strategy is another critical determinant of tenderness. High-energy diets in intensive beef production systems promote greater deposition of intramuscular fat, which reduces the mechanical strength of intramuscular connective tissue and improves tenderness (*Santos et al*., 2021).

4. Beef juiciness

The primary determinants of juiciness are the meat's water-holding capacity and its intramuscular fat content. Accordingly, sensory perception of juiciness is typically divided into two phases: initial juiciness, which is primarily affected by the water content of the meat and perceived during the first few chews; and sustained juiciness, which is associated with the fat content and its effect of stimulation of salivary flow during continued mastication (*Winger and Hagyard*, 1994). Previous research has demonstrated that significant differences in meat juiciness exist among cattle breeds. *Chambaz et al.* (2003) evaluated the meat quality of four European breeds—Limousin, Angus, Simmental, and Charolais—raised under semi-intensive fattening systems and slaughtered at comparable levels of marbling. The study found that the Limousin breed produced meat with superior juiciness relative to the other breeds. Further evidence of the relationship between intramuscular fat and juiciness was provided by a study involving U.S. and Australian consumers, which identified a strong positive correlation between fat content and perceived juiciness. Maximum juiciness scores were observed when IMF content reached approximately 20% (*Thompson*, 2004).

5. Beef flavor

Flavor results from a complex integration of olfactory and gustatory sensations, encompassing both basic taste and aroma perceptions. As a complex sensation, flavor develops primarily during cooking, and it is affected by the chemical composition of the meat. Both lipids and water-soluble compounds undergo degradation during cooking, producing numerous volatile aromatic components (VACs) that contribute to the development of meat flavor. The quantity and composition of intramuscular lipids, the oxidative status of these lipids, and their fatty acid profiles are critical factors in determining the extent of lipid oxidation and the diversity of VACs produced. These variables collectively affect the overall flavor balance (*Fu et al.*, 2022). Seven major classes of VACs have been identified as key contributors to lipid-derived flavor development in cooked beef: aldehydes, alcohols, carboxylic acids, furans, hydrocarbons, pyrazines, and sulfur-containing compounds (*Lee et al*., 2025). In addition to lipid-derived VACs, water-soluble compounds such as peptides, amino acids, reducing sugars, and nucleotides, formed after slaughter through the breakdown of proteins and glycogen, enhance the flavor development. The Maillard reaction, which involves interactions between reducing sugars (e.g., ribose, glucose) and free amino compounds (e.g., amino acids and peptides), is a critical pathway for the generation of flavor-enhancing heterocyclic compounds (*Kosowska et al*., 2017). Flavor is predominantly an inherent attribute of fresh meat that is not substantially modifiable through postmortem handling. Instead, it is primarily determined by pre-slaughter factors such as feeding regime, breed, sex, and age at slaughter. Early research has demonstrated that the feeding strategy plays a pivotal role in influencing the intramuscular fat content and fatty acid composition. Beef from grass-fed animals contains higher levels of polyunsaturated fatty acids (PUFAs), such as linoleic acid (C18:2n-6) and α-linolenic acid (C18:3n-3), compared to beef from grain-fed animals. The high oxidative susceptibility of PUFAs is essential in development of off-flavors, commonly described as grassy or pastoral. These undesirable flavor notes are largely attributed to degradation products of C18:3n-3, including compounds such as skatole, indole, (Z)-4-heptenal, and 4-methylphenol. Conversely, in most studies, beef from grain-fed cattle, which is typically richer in saturated fatty acids (SFAs), has been consistently associated with more favorable flavor characteristics, such as juicy, fatty, sweet, and umami (*O'Quinn et al*., 2016; *Piao et al*., 2019).

However, European consumers tend to prefer the more intense flavor of grass-fed beef over that of concentrate-fed cattle. This preference is likely

influenced by traditions, cultural norms, and individual taste perceptions. In contrast, U.S. consumers generally perceive grass-fed beef as less acceptable, favoring the flavor of grain-fed beef, which is typically associated with higher IMF content and characterized by buttery/beef fat flavor notes (Realini et al., 2013). Differences in flavor intensity among cattle breeds can be explained by variations in fat content and marbling. For instance, beef from Wagyu cattle is reported to exhibit more intense flavor and greater juiciness compared to Angus beef, primarily due to its significantly higher IMF content and marbling score (*Frank et al*., 2016).

Meat from the Hereford breed has been reported to exhibit a more rancid flavor profile compared to that of Aberdeen Angus cattle. This difference is primarily attributed to the higher PUFA content in Hereford meat, making it more susceptible to oxidative degradation (*Warren et al.*, 2008). Heifers and steers generally receive higher flavor scores than bulls, largely due to their higher IMF content. Furthermore, flavor quality has been shown to improve with the animal's age, a trend that could be associated with increased fat deposition and greater physiological maturity (*Therkildsen et al*., 2017).

6. Conclusion

Studies evaluating beef eating quality have consistently identified color, tenderness, flavor, and juiciness as the primary sensory attributes affecting consumer satisfaction. Consumer experiences with these sensory characteristics during consumption play a critical role in shaping future beef purchasing behavior. Importantly, consistency in eating quality has been recognized as a pivotal factor in promoting increased beef consumption.

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