The most important attributes of beef sensory quality and production variables that can affect it: a review

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Abstract

This work aimed to study and unveil the factors that define the quality of beef from a consumer perspective as well as the production variables affecting it. Price, the designation of origin/brands/certification, appearance/meat colour, presentation, and visible fat are the most valorised factors used by consumers to predict quality. Flavour, tenderness, and juiciness are the most valorised beef quality attributes. It is common worldwide that consumers use price to predict quality and would rather choose meat from its region or country. However, for meat colour, there are countries where consumers generally prefer bright red and others where consumers choose a dark red colour. Regarding marbling, some cultures seek for a high amount of intramuscular fat and countries

where health concerned consumers prefer leaner meat. It is consensual worldwide that tender and more juicy meat is largely preferred. The preferences about flavour vary among cultures.

Breed, feeding and production system, post-mortem conditions and handling can strongly affect those factors that consumers use to predict quality as well as those quality attributes valorised by the consumers. Pasture-fed animals result in leaner meat with healthier fatty acids profile; however, it can also result in less tender (depending on the muscle) with less juicy meat than an intensively grown one.

1. Introduction

Worldwide, beef market corresponds to a production of bovine meat of 63 million tons and it has increased by 0.9% p.a. between 1991 and 2007 (Alexandratos and Bruinsma, 2012). For the coming years (from 2005/2007 to 2030) it is expected to continue increasing by 1.3% p.a. According to FAO (2018) on Food Supply, beef consumption approximates 9.32 kg/capita/year in the world.

For the consumer, beef consumption is related to food concepts as “It is good for sharing with family” (scored with 5.8 of agreement in a scale from 1 to 7), “It is nutritious” (5.6), “It makes me feel satiated” (5.5), “It gives me energy” (5.3), “It gives me pleasure” (5.3), “It makes me feel satisfied” (5.3), “It is good for wellbeing” (5.2) and “It makes me feel good” (5.0) (Ares et al., 2016). The consumer is increasingly conscious and concerned about animal welfare and demands higher quality of meat (Jorquera-Chavez et al., 2019). The definition of quality is not universal. However, in a satisfaction-based definition of quality Wicks and Roethlein (2009) defined quality “as the summation of the affective evaluations by each customer of each attitude object that creates customer satisfaction”. Accordingly, the present work emphasizes the current knowledge on the most important attributes of beef quality in a consumer’s perspective as well as production variables that affect them, giving an overview of how consumers perceive and analyse the sensory quality of beef and how it can be managed during production.

This literature review is divided into two main parts. First is the compilation of the most important quality attributes for consumers, divided into a) *quality cues* that consumers use (at the store) to *predict* quality and, b) *quality attributes* that consumers give importance during *consumption*. The second part of this literature review is related to the production and post-production handling variables that affect those quality cues and quality attributes specifically pointed in the first part of the review. The literature search was conducted on ISI Web of Science with the following topics: *beef quality*, *beef sensory quality/preferences/analysis*, *consumer preferences*, *beef production*, *intensive production*, *extensive production*, *semi-intensive or semi-extensive production*. Studies comprising dairy cattle were not included, as well as studies not comprising sensory analysis, consumer preferences or production effects on beef quality attributes.

2. Quality attributes - a consumer point of view

Beef quality is assessed by the consumer in two points: the moment of purchase (at the store) and the moment of consumption. Different factors are used to predict and assess the quality of beef. Previous purchases and experienced quality will influence the quality perception in the next purchases (Bello Acebrón and Calvo Dopico, 2000). Table 1 summarizes how consumer predicts beef quality at the store as well as the quality attributes assessed during the beef consumption.

2.1. What affects consumer perception of beef quality at the store?

Several studies have investigated how consumer evaluate meat quality at store. It has been proposed that consumer relies on both intrinsic and extrinsic cues (Bello Acebrón and Calvo Dopico, 2000; Font i Furnols et al., 2011) and several studies rely on that to evaluate how the consumer evaluates meat (Font i Furnols et al., 2011; Xu et al., 2019; Arenas de Moreno et al., 2020).

Among the intrinsic quality cues (such as texture, freshness, colour, visible fat, which in turn are affected by age, cut, conservation, maturating, hygienic-sanitary conditions), consumers can mainly perceive meat colour, freshness and visible fat at the store, mainly because generally there is a lack of information. Among the extrinsic quality cues, consumers perceive or give importance to the store image, price, origin, presentation and promotion (Bello Acebrón and Calvo Dopico, 2000; Font i Furnols et al., 2011). In agreement, a recent study on the consumer's attitude on meat revealed that 22 attributes can influence the choice of the meat (Henchion et al., 2017). The top two are extrinsic: price and certification/label/brands/information, which shows how the purchase behaviour is largely influenced by extrinsic cues in quality perception (Grunert, 2006). The next three are intrinsic features: visible fat, which includes both internal fat (marbling) and external fat, meat colour and appearance. The last two are very important for consumers with high familiarity with meat, because this kind of consumers may rely only on appearance for purchase choice once they present more product involvement and higher pleasure and symbolic value to fresh meat, regardless of the storage or animal effects (Borgogno et al., 2015). High familiarity consumers use meat colour to predict quality and low familiarity consumers are more likely to use the brand as a confidant cue to predict quality (Banović et al., 2009). However, also low familiarity consumers use appearance as one of the most important perceived intrinsic quality cues, influencing the purchase (Borgogno et al., 2015).

All these perceived extrinsic and intrinsic cues have been highlighted as the ones that will define a visual impression to the consumer that makes him expect a certain quality and determines the purchase choice. The consumers' perception of these main intrinsic (appearance/meat colour/freshness and visible fat) and extrinsic (price, origin/brands/information, and presentation) quality cues vary between regions, educational level, occupation and other sociodemographic characteristics (Arenas de Moreno et al., 2020). Thus, segmentation is a very important issue in beef quality. In this way, next, it will be explored the different preferences for these quality cues.

2.1.1. Appearance, meat colour, and freshness

Although eating satisfaction was not always related to colour (Carpenter et al., 2001; Meat & Livestock Australia, 2016-17), meat colour is used as a selection criterion (Killinger et al., 2004b). Previous experiences and habits of the consumer are probably influencing the meat colour preferences. Meat colour is used by consumers to predict freshness, taste, and texture (Henchion et al., 2017). In general, red-purple colour is associated with freshness and the opposite brown colour is associated with lower freshness (Henchion et al., 2017). Red is the preferred colour, before purple, and brown is the last (Carpenter et al., 2001) since brown meat is considered not fresh (Corcoran et al., 2001) or spoiled.

Within red colours, bright or light red is considered better than pale red or dark red, in Spain (Bello Acebrón and Calvo Dopico, 2000; Realini et al., 2014), Italy (Borgogno et al., 2015), Australia and Japan (Egan et al., 2001); cherry red could be the preferred colour in the US (Killinger et al., 2004b; Grebitus et al., 2013a) and Germany (Grebitus et al., 2013a). Conversely, in Scotland bright red may be considered a false colour suggesting the presence of additives or lack of maturation (Corcoran et al., 2001). Some US consumers would pay more for dark red meat (Killinger et al., 2004b). Irish male consumers only seek intensely red meat, preferring thicker steaks in opposition to thin strips (McCarthy et al., 2017), as in this culture, expression of masculinity was (once) related to meat consumption (Newcombe et al., 2012).

About fat colour, it seems to have lower importance, as only a very few studies are pointing this feature. A study in Australia concluded that the preferred colour of beef fat was white over yellow (Egan et al., 2001).

2.1.2. Marbling

Fat content can strongly and positively affect the sensory attributes of steak such as tenderness, juiciness, and flavour (O'Quinn et al., 2012), however, consumers could be avoiding high-fat meat because of health concerns (Frank et al., 2016). In fact, the concerns related to fat and cholesterol content resulted in a 6% reduction of beef consumption per capita per quarter in the USA between 1987 and 2000 and increased consumption of poultry (Boetel and Liu, 2003).

In Spain, lean beef is preferred over a fatty beef (Bello Acebrón and Calvo Dopico, 2000; Realini et al., 2014), as well as in Australia, where consumers would pay more for a lean steak (Egan et al., 2001). Nevertheless, British and French people would prefer a marbled appearance, relating fat to flavour (Corcoran et al., 2001). In the US some consumers would choose a moderately marbled steak over a slightly marbled one (Killinger et al., 2004a; Yong et al., 2010). But, there are also US consumers that found low marbling more acceptable or even those who found the marbling degree indifferent (Killinger et al., 2004a). And, US consumers who prefer lean beef would pay more for the preferred beef than those who prefer high marbling (Killinger et al., 2004b), which shows the economic importance of consumer's health-related concerns. In Japan, several consumer segments are found. Some consumers would rather choose a slightly marbled meat over moderately or not marbled meat (Egan et al., 2001), as well as consumers who would prefer high-fat steaks with at least 30% intramuscular fat (Gotoh et al., 2018) and consumers that prefer moderate marbling. Keisuke et al. (2017) found that some consumers would choose beef for its taste independently of the visible fat amount. Consumers of Asian countries such as Korea and Taiwan, in general, prefer moderately marbled meat (Frank et al., 2016).

A recent study that evaluated the consumer knowledge about fatty acids of beef verified that consumer may have some difficulty in categorizing fatty acids (monounsaturated, polyunsaturated, saturated and trans fat) as healthy or unhealthy, but after they receive an educational excerpt they were willing to pay a premium for beef with improved fatty acids composition (Flowers et al., 2019). This study shows

that segmentation can be done regarding fatty acids profile towards health-conscious consumers, but some education about fatty acids may be necessary.

2.1.3. Price

Price, being the most important search attribute, highlights the importance of economic factors (Henchion et al., 2017). Several studies show the importance of price at the moment of purchase, however this is a very difficult feature to summarize as consumers with different economic possibilities will have different threshold regarding price, not only among countries but even in the same country, thus the choice of beef will be differently conditioned by this. Bello Acebrón and Calvo Dopico (2000) concluded that price has a very positive influence on the expected quality and other studies showed that consumers from South Africa (Makweya and Oluwatayo, 2019), Scotland, Spain, France, and Holland would pay more for better quality or graded beef (SteenKamp and van Trijp, 1989; Corcoran et al., 2001). However, Italians and Englishes would value a low price (Corcoran et al., 2001) and in some studies, also Spanish people seem to prefer medium-low price beef. Health-conscious consumers would pay more (up to 15%) for meat enriched with CLA and/or *n*-3 fatty acids (Realini et al., 2014). Other studies showed that, when comparing the origin of the beef, the designation of origin and the production system, price is the attribute with the least importance in Spain (Mesías et al., 2005). In Australia and Japan, price is used to predict quality as well, and mid-range prices are preferred over high or low prices (Egan et al., 2001). In general, it can be concluded that the price is a very important factor in the purchase. However, it is always combined with other information and quality cues, for which some consumers could be willing to pay more (Polkinghorne and Thompson, 2010; Yong et al., 2010) as explained forward in this review. The price will depend on feeding and production systems (Berton et al., 2018; Swain et al., 2018), as well as supply chain costs. However, it can also be defined by the market for which it is intended, as consumers are willing to pay more for increased beef quality.

A study by Lyford et al. (2010) including Japan, the US, Australia, and Ireland has demonstrated that consumers, especially in the Japanese market, are willing to pay more for higher quality meat (scored as 4 star - “better than everyday” – and 5 star - “premium” - quality compared to to a 3 star “good everyday” quality meat). Whereas, consumers would pay half the price for a lower (2 stars graded as "unsatisfactory") quality meat (Lyford et al., 2010).

2.1.4. Designation of origin/brands/information

Origin is always present as a credence attribute in consumer’s beef preference studies. Even though the price is a very important attribute, the origin information, can be a more valorised attribute, followed by animal feed (Realini et al., 2013). Which may be linked to familiarity with the meat and animal welfare concerns (Viegas et al., 2011). Some studies have found that consumers are willing to pay more for animal welfare or environmentally-friendly labels (Schnettler M et al., 2008; Tonsor et al., 2015; Sonoda et al., 2018).

Consumer considers “very important” that meat labels include information about nutrition, health claim, and production system and, the preferences for nutrition information is positively related with meat consumption frequency (Rimal, 2005). Information about the production system may affect the consumer purchase choice regarding both health and animal welfare concerns, in contrast, sensory attributes lead to an opposite preference. In studies where consumers were asked to rank between grass, grass plus concentrate and concentrate-fed meat, Spanish, British, and French consumers preferred the grass-fed and free-range meat over intensively produced meat, however, when blind sensory tests are performed the concentrate-fed meat was preferred (Font i Furnols et al., 2011; García-Torres et al., 2016). History shows that information about the production system greatly affects beef preferences. Meat-related scandals, such as Bovine Spongiform Encephalopathy, abuse of antibiotics, etc. which are related to traditional production and low animal welfare, lead to an

increased interest in organic meat (García-Torres et al., 2016), which is perceived by the consumer as beneficial for human health (Magnusson et al., 2003). Nevertheless, recent studies found that consumers would prefer "extensive suckler cow husbandry" before "organic production" when informed about the production conditions through films (documentary or image films) or an informative leaflet (Risius and Hamm, 2017).

Portuguese consumers use brand as the strongest extrinsic quality cue to predict quality (Banović et al., 2009). For US students, origin and "tenderness guarantee" are almost as important as the price (Yong et al., 2010). Spanish people as well, seem to strongly valorise the origin of the meat they eat, as various studies have demonstrated an intention to prefer "designation of origin" meat (Bello Acebrón and Calvo Dopico, 2000; Realini et al., 2013). In South America, origin and animal feed information was two of the most important extrinsic cues besides ageing, hygiene and breed (Arenas de Moreno et al., 2020). Spanish, French and British consumers, when presented Uruguayan beef versus local beef, all preferred local beef, grass-fed and with the lowest price (Realini et al., 2013). In Japan, there is a strong preference for Japanese meat over others as this is the attribute with the highest importance for Japanese people besides the freshness of the meat at the moment of purchase (Egan et al., 2001). Thus, information on the origin, production system, tenderness guarantee or brand that provides the guarantee can determine purchase choice. Globally the opinion is consensual, consumers would rather choose a known quality local beef mainly because they are used to its sensory attributes and trust the local producers regarding both health and animal welfare concerns.

2.1.5. Presentation and packaging

The presentation was found as one of the most important perceived extrinsic quality cues. There are markets where the fresh cut meat from the slab is preferred because consumers do not trust in handling and conservation process of packed meat in trays (Bello Acebrón and Calvo Dopico, 2000). In

contrast, in other markets, consumers preferred packaged meat in trays over non-packaged meat (Schnettler et al., 2015). Nevertheless, it is important to emphasize that despite presentation is an important extrinsic quality cue, it had less importance than origin and price (Schnettler et al., 2015). For example, consumers that prefer fresh cut meat from the slab may choose a packaged meat for its origin or brand.

Package preference is related to the package effect on beef colour and appearance. Packaging can give red, purple or brown colour depending on modified atmosphere used: e.g., 0.5% CO gives a red colour, 100% N_2 promotes purple colour and 1% O_2 leads to brown colour. As well, the type of packaging material also affects beef appearance: beef overwrapped with conventional polyvinyl chloride (PVC) was better scored for appearance and purchase intention than beef packaged with MAP and vacuum skin package. This is related to colour as more panellists considered that meat was red for the conventional PVC overwrap (Carpenter et al., 2001) and red colour is the preferred as referred previously. Additionally, vacuum packaging leads to a dark-purplish colour because of deoxymyoglobin oxygenation (Mancini and Hunt, 2005). Van Wezemael et al. (2011) study indicated that packaging acceptance in beef is influenced by consumer's previous experiences. Thus, despite the colour given by vacuum packaging, the familiarity of the consumer with it, gives a high acceptance (73% of the inquired consumers) of this type of packaging. Another study demonstrated that despite the preferred colour given by CO-MAP, when the consumer is informed about the package system, the willingness to pay decreases (Grebitus et al., 2013b).

As high drip loss is an indicator of less tender and less juicy meat, the consumer usually prefers the absence of drip loss in the package (Font-i-Furnols and Guerrero, 2014). Some strategies can be used to avoid drip loss, such as avoiding temperature changes, the use of specific packaging films with antifog properties and using extra absorbent pads (Troy and Kerry, 2010).

Among the following packaging technologies, “Packaging (general)”, “vacuum packaging”, “modified atmosphere”, “with natural agents”, “with protective bacteria” and “releasing additives”, releasing additives, addition of protective bacteria and the addition of natural agents were the three technologies for beef packaging that were less accepted by the consumer comparing with the packaging that consumer is more familiarised with (Van Wezemael et al., 2011).

2.2. Quality attributes during consumption

It is consensual among the literature that, during the consumption of beef (and meat in general), the main quality attributes are tenderness, flavour/taste and juiciness (King et al., 2009). However, other features were pointed such as freshness/wholesomeness/shelf-life and convenience (Bello Acebrón and Calvo Dopico, 2000; Henchion et al., 2017). Studies on literature aiming to analyse the eating quality of beef use always tenderness, flavour/taste and juiciness to evaluate it (Huffman et al., 1996; Moreno-Indias et al., 2011; Ellies-Oury et al., 2016; Huuskonen et al., 2017). Additionally, the Meat Standards Australia (MSA) grade score, which is the most extensive modelling of beef palatability, is a composite of tenderness, juiciness, flavour and overall liking (Meat & Livestock Australia, 2013; O’Quinn et al., 2018).

Other features may be analysed or not, which indicates their minor importance. In this section, it will be explored how these three main quality attributes are preferred by the consumers.

2.2.1. Flavour

Meat flavour is getting the highest importance in quality attributes (Bello Acebrón and Calvo Dopico, 2000), which highlights the importance of fat content. Fat is a flavour carrier and a tenderness and juiciness influencer (O'Quinn et al., 2012) positively correlated with meat flavour (Corbin et al., 2015). This explains the importance that consumers give to visible fat or marbling when they are buying the

meat. The sensory attribute, which is more correlated with the overall liking of steak, for US consumers, is the flavour liking (Hunt et al., 2014; Corbin et al., 2015), even before tenderness and juiciness (O'Quinn et al., 2012). Nevertheless, other studies verified that global acceptance has a higher correlation with tenderness and juiciness and a low correlation with flavour (Costa et al., 2016). These contradictory results found in the literature are comprehensible as both factors have such importance such as 'if the flavour is not acceptable, beef is rejected regardless of the other attributes', and the same happens to tenderness 'if tenderness is not acceptable, beef is rejected regardless the other attributes'. Additionally, a recent study concluded that "flavour linking in the main driver of variability in overall liking"(Liu et al., 2020). So, in beef with stronger flavour intensity or high flavour variability and low tenderness variability, the global acceptance may have a higher correlation with this attribute than with tenderness. Especially in consumers that prefer beef with low flavour intensity such as US consumers. These consumers, which are more familiarized with the taste of corn-fed beef, prefer this kind of meat; they consider that the flavour of the grass-fed meat is less acceptable and richer in off-flavours (Priolo et al., 2001; Sitz et al., 2005). European consumers consider that pasture-fed beef or less intensively produced meat has a better flavour than only concentrate-fed beef (Realini et al., 2009; Realini et al., 2013).

Flavour is a combination of aroma and taste developed during cooking as a result of Maillard reaction and lipid degradation. The most common flavour descriptors for meat are "flavour intensity", "sweet", "acidic", "metallic", "liver", "gamy", "bitter" and "umami" (Rødbotten et al., 2004). Maughan et al. (2012) developed and beef lexicon and used it to compare the beef flavour of grain and grass-fed cows. Attributes "livery", "bitter", "sour", "grassy" and "metallic" were attributed to the grass-fed animals and descriptors such as "juicy", "fatty", "sweet" and "umami" were more related to the grain-fed animals. "Pastoral" or "grassy" are descriptors of an off-flavour detected in pasture-fed animals. Skatole, indole, (*Z*)-4-heptenal and other breakdown products of linolenic acid C18:3 *n*–3, as well as 4-

285 methylphenol, have been suggested as the compounds possibly responsible for these off-flavours
286 (Elmore and Mottram, 2009). Several other compounds can be responsible for off-flavours, such as 2,3-
287 butanedione, allyl methyl sulphide, 1-(methylthio)-1-propene and 1-(methylthio)propane. Corral and
288 Flores (2017) verified that the last - 1-(methylthio)propane - was the most potent odorant and
289 panellists attributed the off-flavour described as garlic, cabbage, oxidized iron, solvent, and rancid
290 odour, to this molecule.
291
292 **2.2.2. Tenderness**
293 Tenderness has been reported as one of the most important sensory attributes for meat, being the
294 only quality attribute analysed for several beef quality studies (Maltin et al., 2007). A tough steak has
295 not consumer acceptability (Sensory Market Analysis and Research Technology, 1994; Huffman et al.,
296 1996; Bello Acebrón and Calvo Dopico, 2000; Polkinghorne and Thompson, 2010; O'Quinn et al., 2012),
297 but as tenderness improves, the contribution of flavour liking on overall liking increases (Liu et al.,
298 2020), which explains why it has been difficult to define which one of the attributes, flavour and
299 tenderness, contributes more to overall liking in meat. Overall liking is commonly correlated with
300 tenderness independently of the animal type, although it is not systematic and for some breeds this
301 correlation was not there (Gagaoua et al., 2016b). However, it is not easy to answer the question “what
302 is a tough or a tender beef?”. A study with US consumers determined that 98% of acceptability is
303 achieved when the Warner-Bratzler shear force value was less or equal to 4.1 kg (Huffman et al., 1996).
304 To know the analytical value that corresponds to the desired tenderness could help in market
305 segmentation and consequently increase the economic value of beef products. However, to be able to
306 use this tool, more studies are necessary to assess the quantitative tenderness desired in different
307 markets. Recently, an innovative approach for the prediction of beef tenderness was presented by
308 Gagaoua et al. (2019). The proposed technique is a combination of statistical methods that are

309 “chemometrics” and “supervised learning” to integrate and manage data of the continuum from the
310 farm to fork, thus selecting the potential predictors of beef tenderness (Gagaoua and Picard, 2020).
311 A study performed at the store provided a taste test and information about the tenderness of steaks
312 and verified that consumers prefer, as expected, tender steaks and that fifty-one per cent of the
313 consumers were willing to pay more for tender steaks (Lusk et al., 2001). Tenderness is closely related
314 to intramuscular fat content. Fatter meat is more tender than leaner meat, because of the adipose
315 tissue deposits in the perimysium, reducing the mechanical strength of the intramuscular connective
316 tissue resulting in a tender beef (Takanori, 2010; Choi et al., 2019).
317
318 **2.2.3. Juiciness**
319 Juiciness can be described as the amount of moisture/juice released in the mouth in the first 3 or 4
320 chews (Rødbotten et al., 2004). It can also be divided into initial juiciness and overall juiciness. This
321 sensory descriptor is scored from “not juicy” to “very juicy” (Peachey et al., 2002).
322 Juiciness plays an important role in the overall liking of beef and show strong positive correlation with
323 fat content. For US consumers (O'Quinn et al., 2012; Hunt et al., 2014; Corbin et al., 2015; Costa et al.,
324 2016) and Australian consumers, a maximum juiciness score is reached at 20% of intramuscular fat (M.
325 Thompson, 2004). Nevertheless, a recent study verified that juiciness liking can be easily compensated
326 or influenced by the other attributes (flavour and tenderness) especially for medium cuts steaks,
327 meaning that juiciness is the attribute that contributes less to the overall liking (Liu et al., 2020). As
328 well, a recent study concluded that juiciness is highly correlated with tenderness, and when tenderness
329 is within the consumer liking range, the flavour is the most important attribute contributing to the
330 overall liking of beef (Miller, 2020).
331 This quality attribute is evaluated through sensory analysis with trained panel or consumers depending
332 on the aim of the study (Moreno-Indias et al., 2011; Ellies-Oury et al., 2016). However, given the lack

of knowledge about what kind of juiciness is preferred, studies with both trained panel and consumer sensory analysis would be interesting as it would allow assessing the juiciness levels that are preferred by the consumers. As well as for the other attributes, for juiciness, it would be necessary to perform these studies in different market segments.

2.3. Food safety

Modern consumers are highly concerned and critical about food safety even though some evidence suggests that, at least in developed countries, the food supply chain may be safer than it ever has been (EUFIC; Martin and Harris, 2009). Nevertheless, the widespread food scandals such as Bovine Spongiform Encephalopathy (mad cow disease) and more recently the horsemeat scandal may have contributed to increasing awareness and search for safer alternatives. In addition to safety concerns, animal welfare has become a major concern among consumers (Yunes et al., 2017; Regan et al., 2018). Despite labelling as "natural", "organic", "GM-free", "free-range" and "grass-fed" are thought to be increasingly important in determining consumer purchasing preferences (Council, 2010), the impact of different production systems in beef meat safety remains unclear because of the limited and conflicting data (Young et al., 2009; Zhang et al., 2010; Loo et al., 2012; Garcia and Teixeira, 2017), mainly due to the lack of systematic longitudinal studies that quantify the risks imposed by microbial and chemical hazards from farm-to-fork. Dervilly-Pinel et al. (2017) detected environmental contaminants at higher levels in organic than in conventional meats. However, these chemicals were under the maximum accepted limits and do not represent any major health concern for the general population.

3. Production and handling variables that influence the beef quality

Around the world, beef is produced under extensive, semi-extensive or intensive production systems. The production system and the consequent meat obtained may be conditioned by the environment

where the producer is settled. Local breeds for example already have their preferred kind of ecosystem to grow and usually, the producer is limited to its ecosystem (Jordana et al., 2003). The economic capacity of the producer can also influence the choice of the production system. Land rents remain low and intensification of the production implies high levels of the initial investment. Expansion is often more economic than intensification (Swain et al., 2018).

In the US, corn-fed young animals are the most common beef found, since corn is largely produced in this country. For Canada, barley is more commonly produced, so meat production includes cattle finishing with a barley-based grain diet (Sitz et al., 2005). In Australia, 55% of MSA (Meat Standards Australia) is grass-fed meat, and grain-fed represents 45% of MSA meat (Meat & Livestock Australia, 2016-17). US consumers scored the US corn-fed meat higher for flavour, juiciness, tenderness and overall acceptability, compared to Australian grass-fed meat and Canadian barley-fed meat. This could be because they are used to US meat (Sitz et al., 2005). In Argentine, beef is produced traditionally on pasture, but it has been upgraded for a semi-intensive production system with grain finishing to fulfil market requirements (Descalzo et al., 2005). Ireland produces Limousin crosses and Charolais crosses breeds (McCarthy et al., 2017), as well as Belgian-Blue×Friesian, Angus×Friesian breeds and other Angus crosses (Gagaoua et al., 2016b) with several production systems, either pasture fed or pasture-fed followed by finishing with concentrate (Teagasc, 2015). France is characterized by the production of pure breeds such as Charolais, Limousin and Blond d'Aquitaine (Gagaoua et al., 2016b). The UK produces, for example, Belgian-Blue×Holstein and Charolais×Friesian (Gagaoua et al., 2016b). In Denmark, beef production is a result of young bulls of dairy-dual purpose breeds, slaughtered 11 to 12 months old at 425 to 475 kg live weight (Vestergaard, Therkildsen, et al., 2000). Italian production systems include semi-intensive and intensive models with specialized beef cattle such as native Podolian breed (Berton et al., 2018; Bragaglio et al., 2018). Likewise, in Spain beef is produced under semi-intensive and intensive systems with pure local breeds such as Asturiana de los Valles (double-

muscled breed from the North of Spain), Pirenaica and Rubia Gallega (Northern Spanish meat purpose breeds from the Pyrenees and Galicia, respectively), Brown Swiss (dual-purpose breed) and Avileña-Negra Ibérica, Morucha and Retinta (rustic breeds from the Centre and East of Spain) (Campo et al., 1999); as well as crosses with Limousin and Charolais breeds (Moreno-Indias et al., 2011). Beef production in Portugal is mainly based on semi-intensive systems with the local breeds (Viegas et al., 2011) Alentejana (in the southern region of Alentejo) (Costa et al., 2016), Mertolenga (in Low Alentejo and Ribatejo), Barrosã (from Gerês), Arouquesa (from Arouca), Maronesa (from Serra do Marão), Mirandesa (from Northeast Transmontano) and also crosses with Limousin and Charolais breeds (Jordana et al., 2003).

In this section, it will be analysed the influence of the production systems (directly related to feeding systems) on beef sensory quality. Table 2 summarizes the effects of the mentioned production systems on beef quality, for each quality attributes previously identified. As well, some insights about breed and post-production handling conditions that also affect beef quality will be pointed out.

3.1. Extensive production

Extensive production includes grazing with pasture and animals having a large area to grow, usually green landscapes and are fed on the available pasture in that large land area. The extensive production system is sought for improved animal welfare (Vestergaard et al., 2000b; Teixeira et al., 2015; Swain et al., 2018), increased environmental quality, such as landscape quality and attractiveness, and enriched biodiversity of agro-eco-systems compared to intensive practices (Giupponi et al., 2006; Sturaro et al., 2009). However, it has its limitations as the grassland productivity is low which limits feed quality (Teixeira et al., 2015). It also requires a large land area per kilogram of product (Swain et al., 2018). Other production systems allow to increase the lipid concentration and/or the inclusion of nitrate in

404 the feeding system, which can reduce the methane emissions of livestock production (Richardson et
405 al., 2019).
406 This production system provides darker-red meat. The influence of production and feeding systems on
407 meat colour is related to glycogen content and muscle pH. A lower amount of glycogen generates lower
408 acidification of the muscles, higher pHu and meat will be darker (Jorquera-Chavez et al., 2019).
409 Extensively grown bulls (grass-fed and free) can have darker meat colour with higher pigmentation
410 than intensively grown bulls (Priolo et al., 2001). This could be related to the higher physical activity in
411 extensive conditions resulting in muscle's higher oxidative capacity. Grazing-based diets, with no
412 concentrate finishing, have lower glycogen content, generating lower acidification of the muscles and
413 consequently a darker colour during post-mortem (Vestergaard et al., 2000a; Baublits et al., 2004;
414 Mancini, 2009). Grass-finished Angus cattle provided darker meat with lower L* and more red meat
415 with higher a* than legume-finished and grain-finished Angus (Legako et al., 2018). Similarly, other
416 studies comparing concentrate-based system and pasture-based system showed that the last resulted
417 in lower L* and higher a* and C* (Mezgebo et al., 2017a; Mezgebo et al., 2019). Other studies verified
418 no colour differences between grazing plus concentrate and only concentrate feeding (Moran et al.,
419 2017). However, in this study, cattle production had similarities such as both groups were maintained
420 indoors for a season (winter) before feeding groups differently for 98 days. Finally, both groups had
421 similar finishing on a barley-based concentrate diet for 76 days (Moran et al., 2017). Thus, this
422 production system provides meat colour more indicated for markets such as Scotland where darker
423 red beef is preferred (Table 2).
424 The extensively grown beef have been demonstrated as leaner meat and with a better fatty acids
425 profile, which is one of the most important features in beef for health-conscious consumers that seek
426 equilibrium between flavour and health. For health issues, it is important to accomplish meat with a
427 lower *n*−6/*n*−3 fatty acids ratio and a low amount of saturated fatty acids (Garcia et al., 2008;

428 Simopoulos, 2016). Conjugated linoleic acid (CLA) is also a good marker because beef and dairy
429 products are the main sources of CLA for humans. Its importance is related to its anticarcinogenic and
430 antiatherogenic properties as well as the ability to reduce body fat while enhancing lean body mass
431 (Azain et al., 2000; Tsuboyama-Kasaoka et al., 2000; Dhiman et al., 2005). Animals fed on grass have
432 higher amounts of 18:3 and long-chain *n*-3 polyunsaturated fatty acids (PUFA) (Wood et al., 2004). A
433 diet richer in grass and lower in grain or concentrate generates leaner meat, with lower intramuscular
434 fat content, and a lower *n*−6/*n*−3 fatty acids ratio (French et al., 2000; Nuernberg et al., 2005; Menezes
435 et al., 2013), as grass-feeding generates a higher percentage of *n*-3 fatty acids and grain feeding gives
436 muscle with a higher *n*-6 fatty acids amount (Elmore and Mottram, 2009), nevertheless, as the grass-
437 feeding provides leaner meat the total intake of C18:3 fatty acids is low.
438 Vitamin E reduces lipid oxidation and increases colour stability. A good amount of α-tocopherol can be
439 achieved with a grass-feed system that generates a higher amount of this compound than a grain-feed
440 system with vitamin E supplementation (Wood et al., 2004; Descalzo et al., 2005). Furthermore, the
441 grass-feeding system has been demonstrated to prevent lipid oxidation in other studies, regardless of
442 the breed (Nuernberg et al., 2005).
443 The flavour of the extensively produced meat (Irish and Argentine breeds) has been scored with higher
444 flavour intensity compared to intensively produced meat. However, these differences could have been
445 affected by different ageing time (Raes et al., 2003). Additionally, this production system can also
446 generate more off-flavours for the consumer that is more familiarized with intensively grown beef (Sitz
447 et al., 2005). Webb and Erasmus (2013) stated that the pasture flavour found in beef is due to the
448 presence of branched-chain fatty-acids, 3-methhylindole and other oxidation products thus generating
449 the common off-flavours. Resconi et al. (2010) found that the higher the energy content of the diet,
450 the lower the flavour intensity of the beef. Animals fed on concentrate plus hay *ad libitum* produced
451 meat with lower beef odour and flavour intensity that animal fed only on pasture. Beef flavour is

affected by intramuscular fat content as well. Within three different breeds produced under extensive systems in Spain, one of them presented significantly higher flavour scores than the other two and authors indicated that the higher intramuscular fat content was responsible for the specific flavour of that breed (Serra et al., 2008).

3.2. Intensive production

Intensive production is characterized by reduced grazing and confinement of the cattle along with the production. The available space per animal decreases with the intensification of the production. This production system is more environmentally sustainable with lower greenhouse gas emissions per kilogram of meat, once animals grow faster, but have higher localized pollution from manure lagoons. For the consumer, the main disadvantage of this production is the constant use of antibiotics as well as the low animal welfare this production system provides (Swain et al., 2018).

Markets with a preference for bright red beef colour should be supplied with intensively grown beef, as this production gives the brighter red colour (Priolo et al., 2001). Nevertheless, breed and genetics also play a significant role in beef colour, see section 3.4.1. As well, the age of the animal at slaughter, older animals' meat has lower *L** and higher a*, b* and *C** (Gagaoua et al., 2018).

As previously seen, consumer evaluates both external and intramuscular fat content. The external fat may be easily handled during the whole supply chain (Henchion et al., 2017), but the internal must be controlled during animal growth through the production system, feed system, breed and other variables. The feeding regime determines the marbling level present on meat. A higher energetic diet, as the diet provided by the intensive production system, produces a higher amount of subcutaneous fat and intramuscular fat. When the time of fattening increases, the intramuscular fat accumulation increases as well (Gotoh et al., 2018; Couvreur et al., 2019). Animals fed on grass-silage *ad libitum* plus 1.5 kg of concentrate for 120 days, followed by 100 days of grazing at pasture and finished with

concentrate *ad libitum* until slaughter, had a lower intramuscular fat content than animals fed with concentrates *ad libitum* plus 1.5 kg of grass silage until slaughter and animals fed with grass silage *ad libitum* plus 1.5 kg of concentrate for 120 days followed by concentrate *ad libitum* until slaughter (Mezgebo et al., 2017b). Extensively grown beef has a better fatty acids profile, nevertheless, the fatty acids profile of intensively grown beef can be improved with supplements. Grain-fed animals when supplemented with oils (e.g. sunflower and linseed oil) have greater amounts of CLA (0.48 – 1.35 % of fat) than animals fed only on simple grain or concentrate (Mir et al., 2004; Dhiman et al., 2005). Steers fed with grass silage plus barley/sugar beet feed concentrate containing fish oil (high C20:5 *n*-3, eicosapentenoic acid (EPA) and C22:6 *n*-3, docosahexaenoic acid (DHA)) and linseed (high C18:3) had higher deposition of CLA. But the animals supplemented with linseed oil generate a higher concentration of total *n*-3 polyunsaturated fatty acids (Enser et al., 2016). Finishing of 95 days with microalgae high in C22:6 *n*-3, increases eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) levels and decreases *n*−6/*n*−3 fatty acids ratio in beef (Rodriguez-Herrera et al., 2018).

As tenderness and juiciness are positively correlated with intramuscular fat, frequently intensive production provides tender and more juicy beef when comparing within the same animal type and breed (Corbin et al., 2015; Pogorzelska-Przybyłek et al., 2018; Choi et al., 2019). Grain-fed animals grown in feedlots provide more tender meat than forage-fed animals (King et al., 2009), which is related to the increased growth rate (Koohmaraie et al., 2002), higher post-mortem proteolysis, the number of grain feeding days (Aberle et al., 1981; Koohmaraie et al., 2002) and collagen solubility (Aberle et al., 1981), rather than reduced chilling rate and sarcomere shortening (Bowling et al., 1977). Nevertheless, some studies found that after 14 days of ageing, there was no correlation between crude fat content and Warner-Bratzler Shear Force (Puente et al., 2016; Puente et al., 2019). Discontinuous growth (hay-feed until 15 months of age and then concentrate plus hay until 24 months age) provides more tender meat than continuous growth meat (with concentrate plus hay until 18 months of age),

500 even though the animal were older in the first production system (Costa et al., 2016). Being tenderness
501 one of the most important quality attribute, it has been strongly studied, reviews by Maltin et al. (2007)
502 and Koohmaraie et al. (2002), as well as, the book chapter by King et al. (2009) can be consulted for
503 more detailed information about how production system can affect it.
504
505 **3.3. Semi-intensive production**
506 Semi-intensive, semi-extensive production system or discontinuous growth are terms that are used to
507 refer to a production system that combines both extensive and intensive systems. For example, beef
508 production that combines pasture feeding in the first stage of animal growth followed by a fattening
509 period where animals are confined and fed on concentrate. The same happens to production that
510 combines grazing plus concentrate feeding along the lifetime of the animal. This is probably the most
511 common production system used in beef, for several reasons, namely for the seasonality of pasture,
512 which implies the use of concentrate to supply the feeding needs. Thus, summarizing, with the
513 intensification of the beef production (which mainly means, increase the caloric content of the diet and
514 decrease of the available space per animal), the meat will have lighter-red colour, lower flavour
515 intensity and more likely to be free of off-flavours, fatter and, consequently, tender and more juicy
516 (see Table 2).
517 The fattening period, which is characteristic of this production system, has a great influence on fatness
518 and conformation scores and consequently on beef quality. Recently, Soulat et al. (2019) proposed
519 four models that identify the rearing factors (such as, initial and final weights, duration of the fattening
520 period, concentrate, forage and net energy intake, weight daily gain, slaughter age, among others)
521 influencing fatness and conformation scores, thus allowing to adapt the rearing practices during
522 fattening to the desired carcass conformation.

Reduced maintenance during pasture followed by finishing a period with a higher energetic diet gives the advantages of the compensatory growth of the animals (Costa et al., 2016). Compensatory growth is characterized by an acceleration of animal growth after a period of restricted development, usually due to reduced feed intake (Hornick et al., 2000), which results in an increased protein deposition, reduced maintenance of the body and greater feed intake during the fattening period (Ryan et al., 1993). However, according to the review by Hornick et al. (2000) a catch-up growth near 100% when compared to animals whose feed was not reduced is "scarcely observed", and usually the recovery is between 50 and 100%.

This compensatory growth can affect negatively the tenderness and overall liking of beef, but it is usually a very low effect that is unlikely to be detected by the untrained consumer (Keady et al., 2017) and also it is dependent of the muscle (Hansen et al., 2006).

3.4. Animal breed

3.4.1. Effects on meat colour

The breed can play a role in meat colour. Nuernberg et al. (2005) verified that German Simmental breed was influenced by a feeding system regarding meat colour stability, in comparison to the German Holstein breed. German Simmental breed concentrate-fed presented a faster colour deterioration than German Simmental grass-fed or German Holstein in both feeding systems. Furthermore, Angus, Charolais, Limousin, and Simmental breeds were all fattened on forage until a desired and equal marbling levels, but the resulting meat colour was different: Angus and Charolais created pale meat, in contrast to Limousin and Simmental breeds (Chambaz et al., 2003). A study performed with fifteen European breeds showed that several breeds can be grouped regarding beef colour (instrumental measure according to CIELAB): the most specialised beef breeds such as Limousin, Charolais, Piemontese, and Marchigiana have 'bright and pale-red' colour; South Devon, Danish Red, Asturiana

de los Valles, Pirenaica, Aberdeen Angus and Holstein provide 'bright and pale' colour; Simmental, Avileña-Negra Ibérica, Highland and Casina deliver 'red' colour and Jersey (a small dairy cattle) breed offers dark and dull red colour. The authors concluded that the variation in colour was related to body size, fat content and muscle development and structure (Ripoll et al., 2018).

3.4.2. Effects on visible fat

Breeds produced under a similar production system present different fat content; thus, genetics plays an important role in visible fat in beef. For instance, in Portugal, Mertolenga breed presented a significantly lower intramuscular fat content than the large breeds (Alentejana, Mirandesa and Marinhoa) but not significantly lower than the other small breeds (Arouquesa, Barrosã, and Maronesa) (Simões and Mira, 2002). For subcutaneous fat, there was no significant difference between these all breeds (Simões and Mira, 2002). Black Wagyu Japanese breed produces fat richer in monounsaturated fatty acids than other breeds of Wagyu cattle and has been developed to produce meat with at least 30% of intramuscular fat (Gotoh et al., 2018). To do so, farmers provide as much concentrate as possible and rice straw *ad libitum* during the finishing of these animals.

The breed can also influence fatty acids profile but in a lower extension than diet (see book chapter by (Nuernberg, 2009)). Limousin breed and Limousin and Wagyu crossbred produced a higher amount of CLA than European and British crossbred and Wagyu breed (Mir et al., 2000; S Mir et al., 2002). More local studies are necessary to determine each breed's influence on fatty acids profile.

3.4.3. Effects on tenderness

Genetics plays an important role in tenderness. In a study comprising Piedmontese breed, it was verified how genetics affect tenderness (Wheeler et al., 2002). Animals with two normal alleles at the myostatin *locus* create less tender steaks than animals with one or two inactive myostatin alleles

571 (Wheeler et al., 2002). During the post-mortem storage of fresh meat, muscle proteolysis occurs, which
572 is responsible for the tenderization of aged meat. It is believed that the primary proteolytic enzyme
573 system involved in this muscle proteolysis is the calpain system, which comprises two calcium-requiring
574 enzymes, calpain-1 and calpain-2, and an inhibitor – calpastatin (O'Connor, Tatum, Wulf, Green, &
575 Smith, 1997). *Bos indicus* cattle, especially Brahman breed produces less tender meat than *Bos Taurus*
576 cattle (Koch et al., 1982; M. Peacock et al., 1982; Crouse et al., 1989; Wheeler et al., 1990), as a result
577 of high calpastatin amounts, resulting in less protein degradation. Ageing can help increase the
578 tenderness in these breeds, as there are studies that showed a slowly ageing from 1 to 7 days, but
579 higher tenderness in *Bos indicus* cattle after an ageing time of 21 days (Wheeler et al., 1990; O'Connor
580 et al., 1997; Pringle et al., 1997). Angus, Limousin, Charolais and Simmental breeds were forage-fed
581 until an equal marbling level (thus fixing this factor that affects tenderness) and Angus and Limousin
582 provided more tender meat than Charolais and Simmental breeds (Chambaz et al., 2003). This
583 demonstrates the importance of breed on tenderness despite the marbling content.
584
585 **3.4.4. Effects on flavour**
586 Belgian Blue double-muscled meat develops a wider range of odour compounds than Limousin and
587 Aberdeen Angus breeds (Machiels et al., 2004). Belgian Blue cooked meat presents higher levels of 5-
588 methyl-2,3-diethylpyrazine (sulfury, chemical, fruity and meaty) and nine compounds that were only
589 found in this breed, which could contribute to a different flavour profile. On the other hand, 2-
590 methylpropanal (burnt, nutty, oily) was only found on both Limousin and Aberdeen Angus breeds,
591 which remarks the breed's effect on flavour. Despite these results, Belgium Blue, is considered beef
592 meat with low flavour intensity, which could be related to the lower amount of fat comparing to the
593 other breeds, as well as, the double-muscle conformation (Machiels et al., 2004). A recent study
594 corroborates this belief that the lower fat content of Belgian Blue breed is related to its lower flavour

595 intensity (Keady et al., 2017). This study comparing Aberdeen Angus × Holstein-Friesian and Belgian
596 Blue × Holstein-Friesian, reported the first with higher intramuscular fat content and higher scores for
597 some of the flavour characteristics (greasy, sweet and dairy) (Keady et al., 2017).
598 Nevertheless, other studies concluded that flavour intensity, as well as, juiciness or fibrosity is not
599 affected by breed (Campo et al., 1999). When the marbling level would be equal between several
600 breeds (Limousin, Charolais, Simmental, and Angus), the flavour will be similar (Chambaz et al., 2003).
601 A study comparing the water-soluble precursors of beef flavour in the *M. longissimus lumborum* of
602 Aberdeen Angus × Holstein-Friesian and Holstein-Friesian breeds with the same age, verified small
603 differences between the beef breeds (Koutsidis et al., 2008).
604
605 **3.4.5. Effects on juiciness**
606 Literature studies have been demonstrating that juiciness is influenced by breed. Limousin breed
607 provided meat with higher juiciness than Simmental, Charolais, and Angus breeds although all breeds
608 were fed until the same marbling level was achieved in a semi-intensive European-type of fattening
609 (Chambaz et al., 2003). However, for several Spanish breeds, intensively grown in a feedlot, differences
610 in juiciness are only significant at one day of ageing between double-muscled breeds (Asturiana de los
611 Valles) and fast growth rate breeds (Pirenaica and Rubia Gallega). After seven days there are no longer
612 significant differences and there are no differences between these breeds and dual-purpose (Brown
613 Swiss) and rustic breeds (Avileña-Negra Ibérica, Morucha, and Retina) (Campo et al., 1999). Hereford
614 breed may provide more juicer meat, as Hereford x Holstein-Friesian crosses had better juiciness after
615 cooking than meat from Limousin x Holstein-Friesian crosses (Bogdanowicz et al., 2018). The age of the
616 animal can also influence the juiciness. Although more studies are necessary to corroborate this
617 information, a study suggests that the initial impression of juiciness decreases with the higher animal
618 age but sustained juiciness increases with increased age (Schönfeldt and Strydom, 2011).

619

620 **3.5. Post-production handling effects on beef quality**

621 There are few studies analysing the various post handling variables, but they are enough to point that
622 there are possibilities to overcome disadvantages of the production systems or to improve the sensory
623 quality of beef.

624 a) Pre-slaughter stress control

625 It is well known that pre-slaughter stress reduces the glycogen amount in muscles, leading to higher
626 pHu and consequently, darker meat as well as lower quality meat regarding tenderness, juiciness,
627 flavour, liking, and shelf-life (Warner et al., 2007; Ponnampalam et al., 2017; Jorquera-Chavez et al.,
628 2019).

629 b) Pre-rigour temperature control

630 Pre-rigour temperature affects sarcomere shortening. Temperature between 15 and 20 °C has been
631 detected for minimal muscle shortening and better beef quality (Warner et al., 2014). After pre-rigour,
632 along the next stages of post-mortem, it is important to assure a cold supply chain to maximize meat
633 colour stability, appearance, and shelf-life. Myoglobin oxidation, as well as lipid oxidation and microbial
634 growth, will accelerate with increased temperature, which will decrease the shelf-life of meat (Mancini,
635 2009).

636 c) Electrical stimulation

637 It is possible to increase the tenderness of beef by electrical stimulation applied to pre-rigour carcasses
638 (King et al., 2009), to fresh and frozen-thawed muscles (Kantono et al., 2019), nevertheless, for frozen-
639 thawed muscles, the application of pulsed electric field also increases fat oxidation and saturated fatty
640 acids content. The tenderness improvement promoted by electrical stimulation may be equivalent to
641 days of ageing (Savell et al., 1981). Nonetheless, the amount of energy that is applied during electrical

642 stimulation is critical to achieving the desired effect on tenderness. A review work verified that “under
643 or over stimulation can result in no or a detrimental effect on meat tenderness” (Hwang et al., 2003).

644 d) Ageing and ageing time

645 Ageing increases the tenderness of beef as a result of the endogenous proteolytic enzymes activity and
646 consequently changes in the myofibrillar structure. A longer ageing time seems to have a great
647 influence on increased tenderness (Brewer and Novakofski, 2008). However, for meat with high
648 tenderness scores at an early post-mortem period (double-muscled breeds and fast growth rate
649 breeds), the increase in texture score with ageing time is lower comparing to dual-purpose condition
650 breeds (Campo et al., 1999). Moreover, other authors have found that double-muscled breeds are
651 tender because of the reduced collagen concentration (King et al., 2009). The needed ageing time for
652 a given tenderness may be affected by the feeding system. In a study where it was assessed the
653 influence of ageing on *longissimus lumborum* of Polish Holstein-Friesian bulls, animals were fed with
654 different dietary treatments containing none, one or two herbal preparations (Optirum and Stresomix),
655 and it was concluded that using two herbal preparations in the animal diet reduced the time of ageing
656 from 14 to 9 days to obtain similar tenderness, compared to animals fed without the herbal
657 supplements (Modzelewska-Kapituła et al., 2019). Authors suggested that this faster tenderization of
658 meat from animals fed with two herbal preparations could be due to the higher antioxidants in meat
659 that can inhibit the oxidation of protein resulting in tender meat (Modzelewska-Kapituła et al., 2019).
660 Ageing time can also play an important effect on flavour. Jeremiah and Gibson (2003) verified that
661 ageing time increased the flavour intensity positively, as well as tenderness and desirability of beef.
662 The juiciness of steaks can also be improved by 14 and 21 days of dry ageing time rather than 7 days.
663 Ageing improving juiciness may be related to loss of water-holding capacity allowing for more juice
664 release during chewing (Campbell et al., 2001). Wet ageing of 3 days after conventional ageing of 4
665 days improves juiciness in comparison to just conventional ageing of 4 days (Bogdanowicz et al., 2018).

Freezing before ageing increases proteolysis so it can also improve tenderness by reducing calpastatin activity, but it will depend on the breed. Between Aberdeen Angus and Nellore breeds only for Aberdeen Angus the shear force decreased with freezing prior to ageing, even though proteolysis has increased for both breeds (Aroeira et al., 2016). These results may be related to the higher amount of calpastatin present in the muscle of Nellore (a *B. indicus* breed) that inhibits the calpains activity on proteolysis during ageing.

e) Types of freezing

When freezing is intended, fast freezing (Kim et al., 2015) or cryogenic freezing with liquid nitrogen (Bogdanowicz et al., 2018) decreases purge and drip loss and consequently promotes better juiciness levels.

f) Types of packaging system

The packaging system can also influence the colour, tenderness, juiciness, flavour and overall acceptability of beef. Oxygen permeable film and vacuum skin packaging provide better sensory scores than modified atmosphere packaging with 80% O_2 and 20% CO_2 (Polkinghorne et al., 2018). Skin packaging is a relatively recent technique that has been demonstrated as advantageous for both maintaining a good appearance and meat colour of raw meat and promoting the sensory quality of meat, as well as increasing shelf-life and stability of products (Stella et al., 2018). Edible chitosan-gelatine coatings may extend the shelf-life of beef steaks during retail display, decreasing weight loss, lipid oxidation and microbial growth (Cardoso et al., 2019).

g) Retail display control

Retail display influences the appearance of the meat decreasing redness of grass-, grain- and legume-finished Angus animals, after 3 days, especially for *triceps brachii* muscle (Legako et al., 2018). Using a conduction cooling gravity assist service display case extends the shelf-life of beef steaks as a result of

689 the lower overall tissue temperatures as well as lower water loss during retail display (Vorst et al.,
690 2018).

691 h) Muscle cut

692 Muscle cut can strongly influence the quality attributes and overall liking of beef (McCarthy et al.,
693 2017). Bonanza cut of M. *infraspinatus* provides better tenderness, juiciness and lower off-flavour
694 intensity than traditional steak cuts of M. *gluteus medius* and M. *rectus femoris* (Yeh et al., 2018).
695 Nonetheless, the muscle itself also affects tenderness due to the different proteins in it (Picard et al.,
696 2018).

697 i) Cooking method and cooking temperature

698 The way the meat is prepared or cooked can also influence quality attributes (Gomes et al., 2014)
699 including the degree of doneness (extra-rare to well-done) achieved (Lucherk et al., 2017). Different
700 muscle cuts from the same animal may need to be prepared in different ways to achieve their
701 maximum sensory quality (McCarthy et al., 2017). Dry heat cooked steaks, from aged meat of electrical
702 stimulated carcasses, were juicier than those cooked by moist heat. Dry cooking was accomplished by
703 roasting steaks at 160 °C, on a rack in an open oven pan until an internal temperature of 70 °C. Moist
704 cooking was achieved by broiling the steaks at 160 °C on a rack in a covered stainless steel casserole
705 dish with distilled water, the heating was kept until an internal temperature of 70 °C (Schönfeldt and
706 Strydom, 2011). Gagaoua et al. (2016a) had found that the cooking temperature affects the perception
707 of tenderness and for both the UK and French panellists lower cooking temperature (55 °C) resulted in
708 higher tenderness (and juiciness) when compared to higher cooking temperature (74 °C).

709

710 **4. Conclusions**

711 Consistently, the literature studies on consumers' preferences for a given beef product, evaluate the
712 meat colour/appearance, visible fat, price, origin/brands/information, and presentation preferences.

Thus, it could be concluded that these are the main variables that consumer use to predict the sensory quality of beef at the store. The lack of importance given to other variables such as breed that also influences the beef quality, could be justified by the lack of information that consumer has about these variables. An informed consumer about all the variables that can affect quality could change his preferences. During consumption, tenderness, flavour, and juiciness are the main quality attributes that consumers use to describe the quality of the beef. In general, juiciness is correlated with tenderness and when tenderness is meeting consumers liking, the flavour is the attribute contributing more to the overall liking of beef. Despite the use of common factors to predict sensory quality and to define the quality during consumption across many cultures, the preferred traits vary. A different population has different quality definitions e.g. Europe and Australia prefer leaner, grass-fed or grass plus concentrate-fed meat rather than only concentrate-fed meat. Contrastingly the US considers grass-fed meat having an inferior flavour and it is a market more familiarized with grain-fed beef. Designation of origin, brand or tenderness guarantee (US) is very valorised by the consumers. Meat from consumers' own country is normally preferred over foreign meat. Pasture-fed animals result in leaner meat with a healthier fatty acids profile; however, it is also less tender with lower juiciness meat than an intensively grown one. Nevertheless, other production variables, such as breed, post-mortem conditions, ageing, and handling affect beef quality. Thus, an optimization to achieve the best combination of quality attributes might be necessary for a given producer, regarding its production system and breeds. The consumer is willing to pay more for higher-quality beef. Thus, segmentation is a very important issue in the beef market to increase the economic power of the producers and benefit both producers and retailers.

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742 **Table 1. Summarized information about quality perception and quality attributes for consumers.**

Beef quality for consumer	Preferred characteristics	References
Intrinsic quality cues		
Meat colour/ appearance	▪ It is preferred red (a* values > b* values) over purple (proximal values of a* and b*) or brown (a* values < b* values) colour. ▪ Bright or light cherry red over pale or dark red in Spain, Italy, US, German, Australia and Japan. However, there are consumers who prefer dark colour in US as well. ▪ Oppositely, Scotland finds bright red a sign of additives presence or lack of maturation. ▪ More dark red meat in Ireland.	Vestergaard et al. (2000a); Priolo et al. (2001); Chambaz et al. (2003); Baublits et al. (2004); Nuernberg et al. (2005); Mancini (2009); Legako et al. (2018); Polkinghorne et al. (2018); Resconi et al. (2018); Stella et al. (2018)
Visible fat	▪ Lean meat: intramuscular fat < 10% (in Spain, Australia, Italy, UK). ▪ Moderately marbled (in UK, France, US). ▪ High fat: intramuscular fat ≥ 30% (in Japan).	Simões and Mira (2002); Mezgebo et al. (2017b); Gotoh et al. (2018); Listrat et al. (2020)
Extrinsic quality cues		
Price	▪ Price is positively related to quality. ▪ Some consumers seek for medium-low price meat and others would pay more for higher quality (e.g. health conscious consumers would pay up to 15% for *n*-3 and CLA enriched meat).	Koohmaraie et al. (2002); Nijdam et al. (2012); Swain et al. (2018)
Designation of origin/ certification/ label/brands/ information	▪ Designation of origin is strongly valorised. ▪ “Tenderness guarantee” in US. ▪ Brand is used to predict quality.	Bello Acebrón and Calvo Dopico (2000); Egan et al. (2001); Mesías et al. (2005); Banović et al. (2009); Yong et al. (2010); Realini et al. (2013); Meat & Livestock Australia (2016-17)
Presentation/ Packaging	▪ Fresh cut meat from the slab over packed meat in trays in some markets and other way around for other markets. ▪ Simple package systems with no additives are preferred. ▪ Absence of drip loss.	Mancini (2009); Polkinghorne et al. (2018); Stella et al. (2018)

Quality attributes		
Flavour	▪ Absence of off-flavours such as “pastoral”, “garlic”, “oxidized iron”, “solvent”, “rancid”. ▪ Grass/pasture-fed animals which have higher flavour intensity are the most preferred in Europe and Australia. ▪ Corn-fed animals in US. ▪ Cooking temperatures affect flavour and preferences varies on considered countries.	Chambaz et al. (2003); Jeremiah and Gibson (2003); Raes et al. (2003); Machiels et al. (2004); Resconi et al. (2018); Yeh et al. (2018); Gagaoua et al. (2016a)
Tenderness	▪ The higher the tenderness the higher the global acceptance of meat.	Bowling et al. (1977); Aberle et al. (1981); Savell et al. (1981); Koch et al. (1982); M. Peacock et al. (1982); Crouse et al. (1989); Wheeler et al. (1990); O'Connor et al. (1997); Pringle et al. (1997); Koohmaraie et al. (2002); Wheeler et al. (2002); Chambaz et al. (2003); Brewer and Novakofski (2008); King et al. (2009); Schönfeldt and Strydom (2011); Aroeira et al. (2016); Costa et al. (2016); Polkinghorne et al. (2018); Stella et al. (2018)
Juiciness	▪ The higher the juiciness the higher the global acceptance of meat.	Campo et al. (1999); Campbell et al. (2001); Chambaz et al. (2003); Schönfeldt and Strydom (2011); O'Quinn et al. (2012); Pordomingo et al. (2012); Corbin et al. (2015); Kim et al. (2015); Bogdanowicz et al. (2018); Polkinghorne et al. (2018); Stella et al. (2018); Yeh et al. (2018)

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744 **Table 2. Most common influence of production system on beef quality.**

	Quality cues	Extensive system	Semi-intensive system	Intensive system
Intrinsic quality cues	Meat colour/ appearance	Darker red		Lighter red
	Visible fat	Lean (< 10% fat)		Fat (≥ 30% fat)
	Health, nutrition, body weight[1]	Healthier and more nutritive meat. Better fatty acids content.		Lower protein content and higher fat content. Considered less healthy by health-conscious consumers. Quality of fatty acids profile is dependent of the concentrate (supplemented with oils or not).
	Safety (antibiotics residues, hormones, health risk)[1]	Antibiotics are rarely used.		Uses antibiotics, hormones content will depend on type of the given concentrate; higher pollution from manure lagoons.
Extrinsic quality cues	Price	Consumers who prefer lean, darker meat and have animal welfare concerns would pay more for extensive meat.		Consumers who prefer fatter meat would pay more for intensive meat.
	Designation of origin/ certification/ label/ brands/ information	In general, more valorised. There are more brands to emphasize extensive meat than the contrary.		Valorised by consumers who seek fat meat.
	Presentation/Packaging	Not influenced by production system.		
	Animal welfare[1]	Good animal welfare depending on animal husbandry.		Confined animals.
Quality attributes	Flavour	Higher flavour intensity but possibly higher amount of off-flavours.		Lower flavour intensity.
	Tenderness	Less tender meat.		More tender meat.[2]
	Juiciness (related to fat content)	Lower juiciness.		Higher juiciness.

745 [1] Other quality cues (Henchion et al., 2017)
746 [2] This is a general tendency, the differences between extensive and intensive are not always the same in the different studies, it depends on fat content, animal mobility and muscle studied.

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