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REVIEW

Consumer Acceptability of Intramuscular Fat

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Abstract

Fat in meat greatly improves eating quality, yet many consumers avoid visible fat, mainly because of health concerns. Generations of consumers, especially in the English-speaking world, have been convinced by health authorities that animal fat, particularly saturated or solid fat, should be reduced or avoided to maintain a healthy diet. Decades of negative messages regarding animal fats has resulted in general avoidance of fatty cuts of meat. Paradoxically, low fat or lean meat tends to have poor eating quality and flavor and low consumer acceptability. The failure of low-fat high-carbohydrate diets to curb "globesity" has prompted many experts to re-evaluate of the place of fat in human diets, including animal fat. Attitudes towards fat vary dramatically between and within cultures. Previous generations of humans sought out fatty cuts of meat for their superior sensory properties. Many consumers in East and Southeast Asia have traditionally valued more fatty meat cuts. As nutritional messages around dietary fat change, there is evidence that attitudes towards animal fat are changing and many consumers are rediscovering and embracing fattier cuts of meat, including marbled beef. The present work provides a short overview of the unique sensory characteristics of marbled beef and changing consumer preferences for fat in meat in general.

Keywords: intramuscular fat, animal fat, fatty meat cuts, marbling, marbled beef, meat quality

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Introduction

The fat in meat plays an important role in overall meat palatability. Intramuscular fat (IMF) positively influences sensory quality traits of meat including flavor, juiciness and tenderness, whereas a low amount of fat induces a less positive response (Hocquette *et al*., 2010; Van Elswyk and McNeill, 2014). The amount of visible fat, both subcutaneous and intramuscular, is used as a visual cue by consumers to judge meat quality. Many Asian consumers prefer moderate amounts of IMF in the meat they purchase, whereas visible fat is unpopular with Western (e.g., Europe, Australia) consumers. The amount of IMF within beef muscle varies widely depending on animal breed or genetics (Barendse, 2014; Hocquette *et al*., 2014; Widmann *et al*., 2011), the nutrition system (pasture or grain) (Duckett *et al*., 2013; Sithyphone *et al*., 2011; Van Elswyk and McNeill, 2014), animal maturity and weight (Duckett *et al*., 2014; Frank *et al*., 2016), primal (Pavan and Duckett, 2013) and other factors. Marbling describes the small flecks of visible fat deposited between individual muscle fiber bundles. Increases in IMF are generally accompanied by improvements in tenderness, juiciness and mouthfeel (Thompson, 2004). Therefore, this review addresses the importance of fat in beef for sensory palatability and consumer satisfaction.

The Importance of Fat in Meat for Consumer Satisfaction

Grilled beef flavor is due to a combination of heat generated aroma volatiles and non-volatile taste compounds (mainly free amino acids, peptides and organic acids) delivered in a unique matrix of muscle fiber, collagen, warmed-meat juices and partly dissolved fat (Frank *et al*., 2016). The positive relationship between IMF and overall palatability (tenderness and juiciness) and liking has been firmly established, mainly by untrained or naive consumer panels (Corbin *et al*., 2015; Emerson *et al*, 2013; Hunt *et al*., 2014; O'Quinn *et al*., 2012; Thompson, 2004). There have been fewer studies regarding the impacts of IMF on

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beef flavor using trained sensory panels (Frank *et al*., 2016; Legako *et al*., 2016). Trained panels learn to objectively rate the intensity of defined sensory attributes using validated quantitative scales. Consumers are generally asked to provide hedonic information about liking of products, whereas trained panels are used to provide objective quantitative information. The quality of data obtained using trained panels is more accurate than data obtained from untrained consumers. In one recent study comparing low and high fat Wagyu, a trained sensory panel found no difference in either tenderness or flavor, although the high fat samples were rated higher for juiciness (Okumura *et al*., 2007). In contrast, a positive curvilinear relationship between IMF and beef flavor scores was reported over a range of 0.3% to 15% fat, that plateaued at higher IMF content (Thompson, 2004). More recent studies confirm a strong correlation between marbling level and flavor (Corbin *et al*., 2015; Frank *et al*., 2016; Jung *et al*., 2016; Legako *et al*., 2015; Mateescu *et al*., 2015; O'Quinn *et al*., 2012).

Some Reasons Why We Like Fatty Meat

Fat is an essential macronutrient and a vehicle for fat soluble vitamins. Fat also plays a critical role in defining the sensory properties of complex foods, such as marbled beef. Apart from making food softer, fat facilitates "oral processing", lubrication of food particles, increases saliva viscosity and acts as a binder or glue assisting in formation of a solid bolus in preparation for swallowing (Almiron-Roig, 2010; de Lavergne *et al*., 2015; Foster *et al*., 2011; Frank *et al*., 2015; Salles *et al*., 2011). There is increasing evidence for the existence of a long chain fatty acid taste receptor mechanism (Galindo *et al*., 2012; Tucker *et al*., 2014; Voigt *et al*., 2014) and human preferences for fat have been linked to variations in saliva flow and composition (Méjean *et al*., 2015; Mennella *et al*., 2014; Running *et al*., 2013). Fat may also increase parasympathetic saliva production, perhaps through the influence of free fatty acids, increasing perceived juiciness, although supporting data is lacking (Hodson and Linden, 2004).

Fat produces "mouth-coating" sensations, where a film of fat remains on oral membranes; this may result in greater persistence of fat soluble flavors in the mouth (Frank *et al*., 2011). As the level of marbling increases in meat, the bulk density decreases; there is less muscle fiber and collagen per unit volume of meat, potentially requiring less oral processing (Foster *et al*., 2011; Frank, 2015; Salles *et al*., 2011). Increasing levels of IMF may also contribute to meat tenderization by disrupting the organization of intramuscular connective tissue (Li *et al*., 2006). Fat plays an important functional role in meat; fat conducts heat more slowly than water, meat with a high fat content takes longer to reach a desired internal temperature, compared to meat with a low fat content (Baghekhandan *et al*., 1982). In practical terms this means that when cooking to the same endpoint temperature, meat of high fat content will have longer exposure to grilling surfaces and greater potential for generation of aroma volatiles and taste compounds (Frank *et al*., 2016). It should be noted that it is well-known that other factors make a contribution to meat tenderness such as the amount of collagen, and protein, cross-linking (Archile-Contreras *et al*., 2010; Purslow, 2014; Starkey *et al*., 2015).

Fat and Beef Flavor

Fat acts both as a substrate and a reservoir for flavor compounds and also affects the temporal flavor release. The role of unsaturated lipids and phospholipids in the formation of volatile compounds is well known (Elmore *et al*., 2000; Elmore *et al*., 2002). Different types of lipids have been shown to either promote or suppress the formation of different classes of volatiles in the presence of various amino acids (Farmer and Mottram, 1990; Farmer and Mottram, 1992; Farmer *et al*., 1989). Highly reactive radical intermediates from lipid oxidation can interact with other molecules to produce an array of potent aroma molecules formed through the Strecker degradation and other complex reactions (Frankel, 1980; Hidalgo *et al*., 2013; Zamora *et al*., 2015). There are many inconsistencies in the literature, past and present, regarding which lipid substrates contribute to volatile formation in meat, though it is widely believed that unsaturated free fatty acids and phospholipids contribute the most. Under the extreme temperature conditions of grilling and frying, many complex reactions take place leading not only to generation of aroma volatiles, but also reactions on the meat surface where taste-active polymeric condensation products, known as melonoidin, formed - Melonoidin is also responsible for the desirable browned surface of grilled meat (Adams *et al*., 2009; Obretenov *et al*., 1993). Unfortunately, mutagenic heterocyclic aromatic amines (HAAs) are also generated at high grilling temperatures. Paradoxically, the level of HAAs is positively correlated to flavor and liking (Gibis *et al*., 2015). Recent studies show that beef with higher fat content produces lower levels of HAAs, especially fat from grass fed animals (Szterk *et al*., 2014).

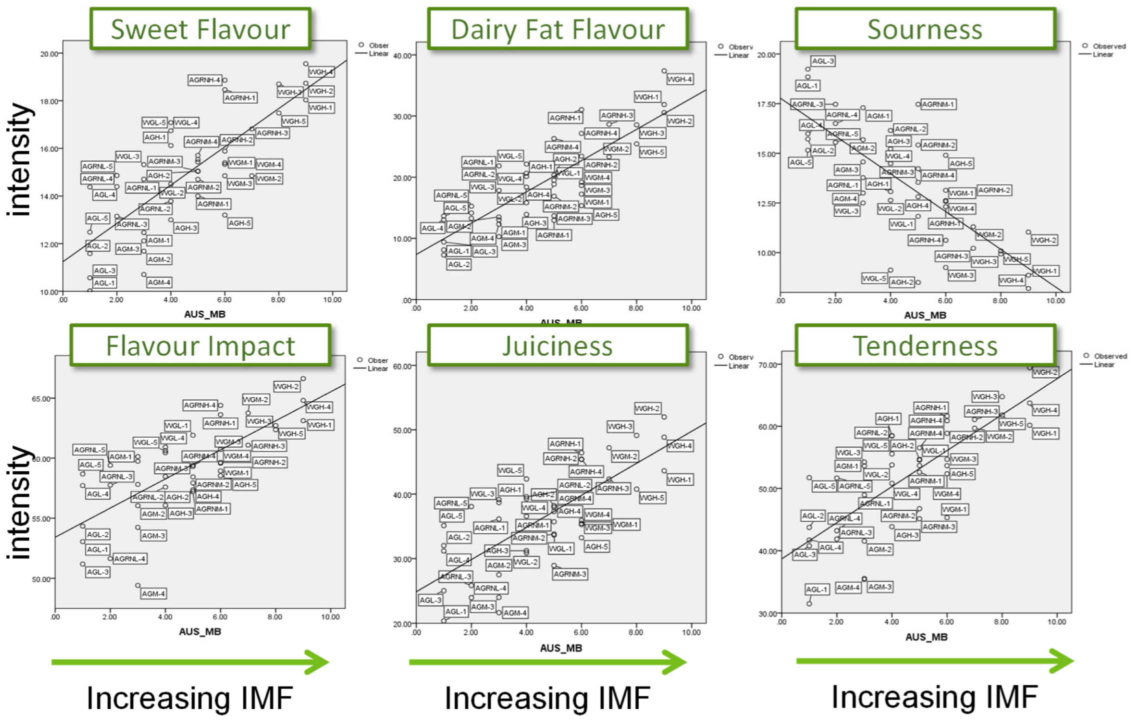

Fig. 1. Effect of increasing intramuscular fat (IMF) on trained panel sensory scores for various attributes for various attributes (Damian Frank, unpublished results).

In a recent study on grilled beef from three different production types, grass-fed Wagyu, grass-fed Angus and grain-fed Angus, a trained sensory panel showed that most flavor-related attributes were significantly correlated with the level of IMF (Frank *et al*., 2016). For example, apart from the expected improvements in juiciness and tenderness, as the level of marbling increased the meat became sweeter and saltier and the acidity, astringency and aftertaste decreased. The odor and flavor impact, grilled beef, bloody, dairy fat and grassy flavors increased with marbling level, whereas hay/grainy and livery flavors decreased. Some of these relationships are shown in Fig. 1. These trends were consistent regardless of the breed or feed, implying a degree of generalization can be used for describing sensory properties of marbled beef. In the same study, it was shown that the concentration of most aroma-active volatiles increased with the marbling level (Table 1). The greatest amount of volatiles was measured in grass-fed Wagyu compared to grain-fed Angus, corresponding with higher flavor scores in the Wagyu samples. The concentration of non-volatile flavor compounds, such as free amino acids and carnosine also increased in beef after grilling, especially in high IMF Wagyu. Organic acids such as succinic and α-ketoglutarate, positively associated with meat flavor, increased with IMF, and lactic acid, associated with sourness, decreased (Table 1). In an other recent study on Hanwoo beef, the significant correlation between high IMF and positive sensory palatability attributes was confirmed (Jung *et al*., 2015; Jung *et al*., 2016). It was suggested that the palatability of Hanwoo beef can be improved by increasing IMF content, as increased IMF content leads to an increase in sensory tenderness, flavor, and juiciness.

Once formed, fat-soluble flavors naturally partition into the fat phase (e.g., melted fat) affecting their flavor release during eating and subsequent perception (Frank *et al*., 2011, 2012; Martuscelli *et al*., 2008). The fat solubility of aroma volatiles can be described by octanol water partitioning coefficients - LogP values; higher values indicate greater fat solubility. It was shown that aroma volatiles with high LogP values, such as nonanal and (*E*)-2-nonenal were less released into the headspace as IMF increased, whereas less fat soluble aroma volatiles increased, e.g.; 3-methylbutanal, 2,3-butanedione and 2-ethyl-3,5-dimethylpyrazine (Frank *et al*., 2016). The difference in ratios of aroma molecules at different IMF contents may explain some of the clear sensory changes perceived by consumers as the IMF increases. Fat also has a concentrating effect on water-soluble flavor molecules. For example sodium ions and many free amino acids do not read-

Table 1. Effect of different levels of intramuscular fat (low, medium, high) in beef on water-holding capacity characteristics, content of amino acids important for flavor and trained panel assessments. The average IMF (%) for the group is shown in brackets for each trait and level of IMF

	Low IMF	Medium IMF	High IMF
Flavor - chemical and sensory			
Total umami/ sweet amino acids (mg/kg)[1]	70^{a} (7.63)	94^{b} (12.65)	
Aspartic acid (mg/kg)[1] (an amino acid contributing to umami)	0.80^{a} (7.63)	1.14^{b} (12.65)	
Trained panel - overall flavor impact (scale 0=100)[1]	60.39^{a} (7.8)	60.87^{a} (10.9)	63.95^{b} (17.5)
Juiciness/water - chemical and sensory aspects			
Moisture (%)[3]	73.68^{a} (6.6)	69.45^{b} (11.02)	60.93^{c} (21.48)
Drip loss (%)[2]	6.26^{a} (6.13)	4.53^{b} (9.87)	
Cook loss (%)[1]	27.0^{b} (5.2)	25.8^{b} (10.2)	23.6^{a} (17.5)
Trained panel juiciness after 3 chews (scale 0=100)[1]	41.12^{b} (7.8)	43.5^{b} (10.9)	53.08^{a} (17.5)
Trained panel juiciness after 10 chews (scale 0=100)[1]	36.24^{b} (7.8)	38.4^{b} (10.9)	46.82^{a} (17.5)

^{a,b}Means with different superscripts within a row are significantly different (p<0.05).
[1]Frank *et al*., 2016; [2]Kim and Lee, 2003; [3]Jo *et al*., 2012.

ily dissolve in fat. By increasing the amount of fat in a food matrix, hydrophilic water soluble molecules are "pushed" into the aqueous phase increasing their relative concentration. This may increase the perceived intensity of the flavor (Chabanet *et al*., 2013; Lawrence *et al*., 2012). Similarly volatiles with low fat solubility (lipophobic molecules) may be released faster in the presence of significant levels of fat (Frank, 2015). Finally, fat has been shown to affect the rate of volatile release during eating in meat (Carrapiso, 2007; Lorido *et al*., 2015). In an unpublished study, we showed that the rate of release of an important water soluble beef aroma volatile (3-methylbutanal) was released faster, and at a higher concentration, in high fat Wagyu beef compared to low fat Wagyu beef (see Fig. 2) and was linked to positive differences in sensory perception (Fig. 1).

Quality Characteristics of High IMF Beef

Meat Standards Australia (MSA) uses a marbling score system (MSA-MB), based on the scheme developed by the United States Department of Agriculture (USDA). The MSA-MB system provides a fine scale for accurate measurement of beef marbling; the scoring system ranges from 100 to 1190 in increments of 10. Highly marbled meat is considered a premium product in Japan and Korea (Cho *et al*., 2010; Thompson, 2004). In Europe and Australia, increasing levels of marbling correspond to more acceptable flavor, juiciness and overall liking (Fig. 1).

The water-holding capacity and chemical composition

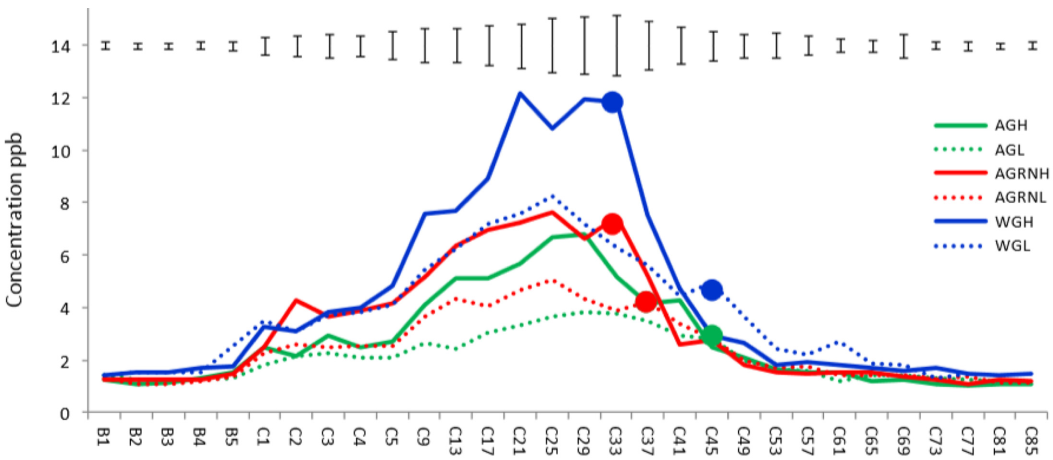

Fig. 2. *In vivo* measurement, using PTR-MS, of grilled beef volatiles during eating and swallowing of beef from two breeds (Angus, A; Wagyu, W), two feeding systems (Grass, G; Grain, GRN) and from two levels of marbling (High, H; L Low) respectively, for the acronyms in the legend. Each line is the average of 30 replicates. The black bars indicate the least significant difference at a time point. B = background breath, C1 = chew 1, etc. Extracted from Frank *et al.* (2014), Final report to MLA.

Table 2. Effect of finishing system (pasture vs feedlot) and level of marbling on trained panel scores for flavor and 'blind' and 'informed' consumer scores for acceptability (n=8 loins per treatment). From Morales *et al.* (2013)

	Pasture		Feedlot		*p*-value
	Low marbling	High marbling	Low marbling	High marbling	
Trained panel Flavor[1]	4.5[b]	4.9[a]	4.4[b]	5.4[a]	0.031
Consumer - Blind accceptability[2]	4.9[ab]	4.9[ab]	4.6[b]	5.2[a]	<0.001
Consumer - Informed acceptability[3]	5.4[a]	5.3[a]	5.0[b]	5.2[ab]	0.003

[1]Flavor; 0 = absence to 10 = maximum intensity.
[2]Each consumer received the four beef samples from each treatment, asked to evaluate acceptability; 1 = dislike extremely, 7 = like extremely.
[3]Each consumer received the four beef samples for each treatment, except each sample was accompanied by cards showing a photo corresponding to how the animal was raised (pasture vs feedlot) and the level of marbling in the raw meat (low vs high). The consumer gave an acceptability score as per the 'blind' acceptability.

of meat are influenced by intramuscular fat (Table 1). As the intramuscular fat increases from 5% to 22%, the moisture content declines (Jo *et al.*, 2012). Consequently the drip loss and water lost during cooking are lower in meat with high IMF (Frank *et al.*, 2016; Kim and Lee, 2003). As shown in Table 1 and in Fig. 1, a higher fat content in the meat also results in higher initial, and sustained, juiciness scores given by consumers and trained panelists. The reduced loss in water during storage and cooking is an advantage, as there is lower weight loss, improved yields, reduced loss of nutrients and greater returns to the wholesaler, retailer and food service industry.

The taste of meat is derived from a variety of compounds, including amino acids which can impart sweet, umami, salty, sour and other tastes (Frank *et al.*, 2016). The amino acids contributing to sweet and umami taste have been found to be higher in beef striploin of higher IMF (Table 1). It is likely that these amino acids, in part, contribute to the increased consumer 'like flavor' scores (Fig. 3) and increased trained panel scores for 'overall flavor impact' (Table 2).

Cultural Differences in Liking of Meat Characteristics

Many consumers prefer the appearance of beef with low or zero levels of marbling (Morales *et al.*, 2013). But as shown in Table 1, when these same consumers are given cooked beef "blind", without knowledge of the marbling level, they prefer the flavor of highly marbled beef and find it more acceptable (Morales *et al.*, 2013). Consumers from Asian countries (Korea, Taiwan, Japan) generally prefer raw meat with a moderate amount of marbling (Ngapo *et al.*, 2007).

In trials conducted in Japan, Korea and Australia using Meat Standards Australia (MSA) protocols, with beef ranging from low to high marbling, it was found that consumers from all three countries clearly identify eating quality differences and the grade cut-off scores given by Japanese and Korean consumers (fail, 3-star, 4-star, 5-star; corresponding to unsatisfactory, everyday, good everyday, premium, respectively) were very similar to the cut-offs given by Australian consumers (Park *et al.*, 2008; Thompson *et al.*, 2008). The weightings given in the meat quality score by Japanese and Korean consumers were more influenced by flavour and juiciness, than for Australian consumers. Korean consumers rated juiciness and flavor lower than Australian consumers across a range of beef muscles (Fig. 4). This may suggest that while tenderness

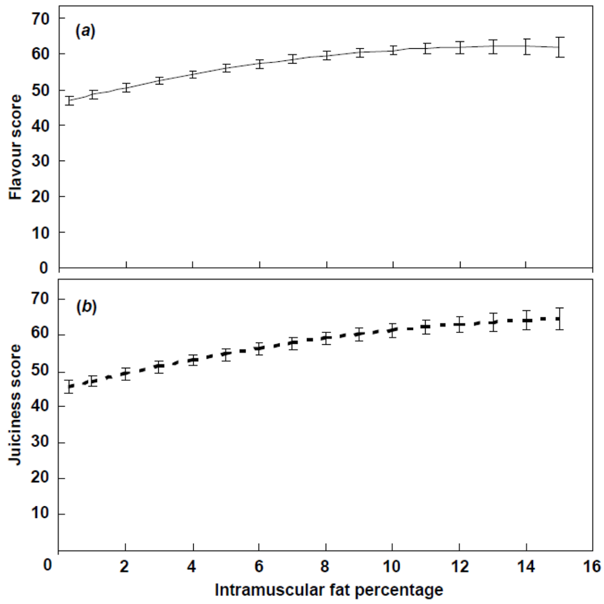

Fig. 3. Effect of muscle intramuscular fat (%) on predicted consumer scores for (a) flavor and (b) juiciness of grilled striploins, adjusted to a standard peak shear force (5.0 kg) and standard animal age (716 d). Vertical bars indicate standard error. From Thompson (2004).

is universally well understood, other attributes such as juiciness and flavor, may have specific cultural contexts.

Changes in Attitudes towards Animal Fat

It is very clear that consumer attitudes toward animal fats, especially the saturated fat in meat has been overwhelmingly negative in the US, Australia and other English speaking countries for the last 50 years (Ngapo and Dransfield, 2006; Williams and Droulez, 2010; Williams and Mummery, 2013). The per capita decline in beef consumption in the US and other Western countries has been attributed in large part to animal fat phobia (Higgs, 2000). Most public health authorities, continue to recommend reduction of saturated fat in the diet, including avoiding fatty cuts of meat. These health recommendations are obviously in conflict with the hedonic reality of a high fat product, such as marbled beef. A growing body of research questions the validity of the so called “diet-heart hypothesis” (Ramsden *et al*., 2016; Siri-Tarino *et al*., 2010; Smith *et al*., 2015; Willett, 2003) and calls for a re-evaluation of role of animal fats in the diet (Barendse, 2014; Klurfeld, 2015). Although a nutritional consensus on saturated fat is unlikely to be found soon, the overall position of fat in the modern diet appears to be changing. The failure of low fat, high carbohydrate diets to curb obesity is being acknowledged by health experts and in popular media (Drewnowski, 2015; Teicholz, 2014). Hence, inclusion of high fat foods with superior sensory properties in a balanced diet, is likely to gain wider acceptance in the near future.

Opportunities for Improving Meat Quality

An unfavorable balance of omega-6/omega-3 fatty acids in the Western diet has been associated with negative health impacts (Lawrence, 2013; Simopoulos, 2008). The balance has been shifting towards omega-6 fats partly as a consequence of industrial animal production (Barendse, 2014; Yu *et al*., 2013). Ruminants raised on less intensive pasture based systems generally have a more favorable ratio than animals raised on grain or concentrate. Beef can be a good source of mono-unsaturated oleic acid as well as short and long chain omega-3 fatty acids, with proven health benefits. Ruminants also produce a number of unique unsaturated fatty acids (vaccenic and rumenic) which probably have positive human health effects (Bjorklund *et al*., 2014; Daley *et al*., 2010; Pavan and Duckett, 2013). Importantly, unsaturated fat has been shown to significantly increase satiety compared to saturated fats (Maljaars *et al*., 2009). Smaller, more satiating portions of marbled beef high in “healthy” unsaturated fat, can play an important role in sustainable beef production.

Previous studies showed lower consumer acceptance of grass-fed beef compared to beef raised on concentrate (Bjorklund *et al*., 2014; Hunt *et al*., 2014; Legako *et al*., 2015; Maughan *et al*., 2012). Most comparisons are typically between very low fat grass-fed beef with much higher

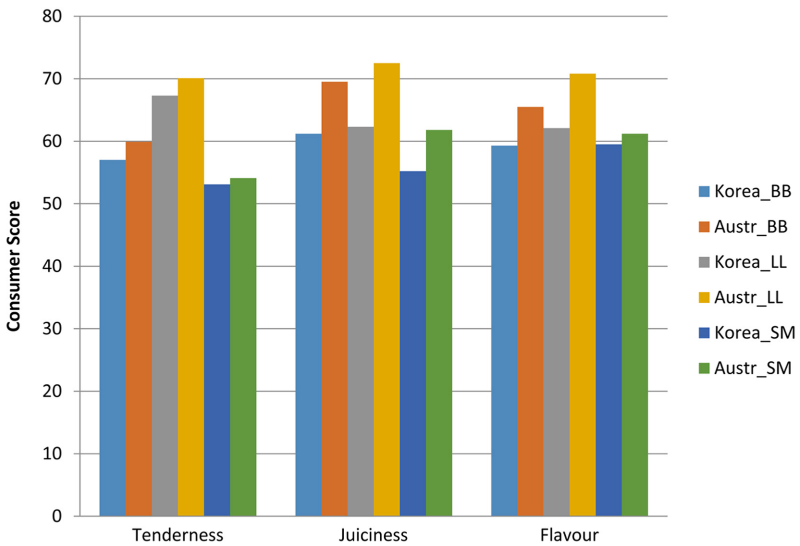

Fig. 4. Effect of consumer (Korea vs Australia) and muscle (BB, *Biceps brachii*; LL, *Longissimus lumborum*; SM, semimembranosus) on the consumer scores for tenderness, juiciness and flavor (scale; 0 = lowest liking to 100 = highest liking). Standard error = 1.4, 1.1, 1.0 for tenderness, juiciness and flavor respectively. From Park *et al.*, 2008.

fat grain-fed produce (Van Elswyk and McNeill, 2014). The lower preference for low fat grass-fed meat is expected, given the clear impacts of IMF on beef sensory properties. Yet, when grass and grain fed marbled beef with the same IMF was compared, few distinctive grass-fed flavors were apparent, especially at levels of IMF above 5%. The data strongly suggested that differences in the flavor of grass and grain fed beef is mainly due to differences in fat level rather than due to inherent grass or grain flavors (Frank *et al*., 2016). Refinement of animal production and feeding strategies to optimize the composition of IMF and enhance sensory properties of beef will present new opportunities for producers of marbled beef (Barendse, 2014; Scollan *et al*., 2014; Widmann *et al*., 2011).

Conclusion

Fat in meat positively influences sensory quality traits of meat, and the positive relationship between IMF and overall palatability has been firmly established by both untrained and consumer panels. IMF plays an important functional role in meat and acts both as a substrate and a reservoir for flavor compounds. Research has shown that most flavor-related attributes are significantly correlated with the level of IMF. In this regard, consumers from Asian countries including Korea, Japan and Taiwan generally prefer meat with a moderate amount of marbling. Also, the overall position of fat in the modern diet appears to be changing, although a nutritional consensus on saturated fat is unlikely to be found soon. The failure of low fat, high carbohydrate diets to curb obesity is being acknowledged by health experts and in popular media. Beef can be a good source of oleic acid and short and long chain omega-3 fatty acids, with proven health benefits. Consequently, refinement of animal production and feeding strategies to optimize the composition of IMF and enhance sensory properties of beef will present new opportunities for producers of marbled beef.

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