Consumer liking of *M. longissimus lumborum* from New Zealand pasture-finished lamb is influenced by intramuscular fat

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Abstract

Palatability of meat is known to be affected by intramuscular fat (IMF), but the effect in relatively low-fat New Zealand lamb is unknown. This study evaluated the eating quality of 108 loins (*M. longissimus lumborum*) from a single flock of ewe-lambs. Loins ranged from 1.09-5.68% IMF and were stratified into 6 groups: 1.65, 2.12, 2.65, 3.20, 3.58 and 4.40%. Consumers' (n=165) overall liking of lamb increased significantly at around 3% IMF, achieving maximum scores at 4% IMF. One consumer cluster (n=111) showed a linear increase in overall liking with increasing IMF%, regarded as 'IMF lovers: the more the better', while a second cluster (n=54) preferred 2.5-3.5% IMF, described as 'IMF optimizers: just the right amount'. IMF% was modestly correlated (~+0.25) with all sensory attributes except juiciness.

Liking scores were modestly correlated with monounsaturated (~+0.25) and polyunsaturated (~-0.20) fatty acids. Results suggest aiming for IMF% levels in New Zealand lamb beyond 3% to maximize eating quality for premium markets in particular.

Keywords: marbling, fatty acids, sensory, flavour, tenderness, juiciness

1. Introduction

While consumers consider a range of attributes in their meat purchasing decisions, eating quality is ultimately a major determinant of satisfaction, re-purchase and willingness to pay for lamb (Grunert, Bredahl, & Brunsø, 2004; Henchion, McCarthy, Resconi, & Troy, 2014). Many factors such as animal welfare, country of origin, sustainability and authenticity are becoming increasingly important, but consumers do not seem to be willing to compromise on taste for other potential benefits (Verbeke, 2006). Thus, consistently producing meat with highly desirable eating quality characteristics is a key goal of the New Zealand lamb industry (Craigie, Agnew, Stuart, Shorten, et al., 2017).

Eating quality of cooked meat is determined by the combined acceptance of flavour, tenderness and juiciness (Miller, 2020). Many factors along the meat value chain affect the sensory quality of lamb, including its fat content. Intramuscular fat (IMF) has been reported to have a positive effect on eating quality as increasing levels in meat are associated with increasing tenderness, flavour, and juiciness (Lambe, McLean, Gordon, Evans, Clelland, & Bunger, 2017; Pannier, Gardner, Pearce, McDonagh, et al., 2014; Phelps, Garmyn, Brooks, Mafi, et al., 2018). Early work in the USA with beef, pork and lamb indicated that a certain degree of marbling is essential for optimum palatability (Savell & Cross, 1988). Miller (2014) indicated that fat values lower than 3% are outside the window of acceptability and that palatability increases at the highest rate as fat increases from 1-3%. More recent consumer studies with cooked lamb have confirmed that marbling improves eating quality and have suggested IMF values in the range of 3 to 5% to ensure an acceptable eating experience (Lambe et al., 2017; Pannier et al., 2014; Phelps et al., 2018). Thus, it has been proposed that intramuscular fat or the ability of an animal to marble, be included in animal selection programmes for genetic improvement as a key indicator of meat quality. There are suggestions that consistent selection for lean meat yield is reducing IMF across the lamb carcass, with negative impact on the eating quality of meat (Anderson, Williams, Pannier, Pethick, & Gardner, 2015; Pannier et al., 2014).

Intramuscular fat is considered a late maturing tissue with increasing levels as the animal develops and matures (Hausman et al., 2009). Most lambs in New Zealand are typically slaughtered between 3 and 8 months of age resulting in IMF values around 2.7% (Craigie et al., 2017), and it is considered that higher levels would be desirable to increase the likelihood of consumer satisfaction. A broad range of IMF% (1-6%) has been reported in New Zealand for a narrow range of industry target lamb carcass weights (17-19 kg), indicating potential for animal selection to improve marbling levels (Craigie et al., 2017). However, no data are available for New Zealand lamb to understand the relationship between increasing levels of IMF and meat palatability assessed by consumers. Such information is needed in order to provide reliable recommendations to New Zealand farmers based on local information.

Some studies looking at the relationship between IMF in lamb and meat sensory traits have evaluated lamb with few defined levels (e.g. Low vs High) instead of linear concentrations of IMF within a range (Phelps et al., 2018; Young, Bain, McLean, Campbell & Johnson, 2009). Moreover, when meat samples are sourced from carcasses with unknown background at commercial abattoirs (Lambe et al., 2017; Phelps et al., 2018), the impact of IMF on eating quality of meat can be confounded with other animal and production factors if they are not accounted for. The objective of this study was to evaluate the role of IMF level and fatty acid composition in New Zealand lamb on the eating quality of meat from animals with a similar background. The relationships between IMF% and individual fatty acid composition in *M. longissimus lumborum* for these animals will be reported in a separate paper.

2. Materials and methods

2.1. Loin sample collection

Meat sampling aimed to obtain loins (*M. longissimus lumborum*) with increasing intramuscular fat values within a representative range of New Zealand lamb (approximately 1 to 6% IMF; Craigie et al., 2017). To avoid confounding factors and ensure that consumer-perceived differences, if any, were primarily the result of different IMF% levels, a flock of 530 female lambs out of Romney ewes crossed with mixed-breed rams (mainly Texel and Poll Dorset genetics) was identified from the Pāmu Meringa farm near Taumaranui, New Zealand. Animals met the criteria for antibiotic-free lambs, and before and after weaning at an age of about 12 weeks, had been grazing on pastures of predominantly perennial ryegrass (*Lolium perenne*) and white clover (*Trifoloum repens*) until slaughter at 8 to 9 months old. Lambs were transported 310 km for processing at the Takapau meat plant of Silver Fern Farms Ltd. on 21 May, 2019.

On the day after slaughter, shortloin samples from 217 lambs were selected visually by experienced personnel to provide a range of IMF% levels in the *M. longissimus lumborum* (LL) at a cross-sectional cut between ribs 12th and 13th. A slice of ~2 cm thickness was taken from the cranial end of the LL samples for assessment of IMF% levels by near-infrared spectroscopy (NIRS) and chemical analysis. The remaining LL portion was vacuum packed, aged at the meat plant for 14 d at -1.5ºC and frozen at -20 ºC for 5 months until sensory analyses were performed.

2.2. Loin intramuscular fat and fatty acid analyses

Meat samples were freeze-dried, ground (Breville spice/coffee grinder, model BCG200, 220-240V, ~ 50Hz 200W; Palmerston North, New Zealand) and measured using NIRS (Labspec4 spectrophotometer, spectral range: 350-2500 nm, spectral resolution: 3 nm @700 nm 6 nm @ 1400/2100 nm, Hi-Brite Contact Probe Model A122320; ASD Inc., Boulder, CO, USA) to predict IMF% (R_{CV}^2=0.89, coefficient of determination in cross-validation for prediction of IMF%; Dixit, Pham, Realini, Agnew, Craigie, & Reis, 2020). Based on the NIRS predicted IMF% values, 108 samples were selected for chemical determination of total IMF% and fatty acid profile. Total and individual fatty acid content of the samples were determined using trans-methylation gas chromatography (GC) method according to Agnew, Craigie, Weralupitiya, Reis, Johnson, and Reis (2019). Freeze-dried ground meat (300 mg), 4 mL of toluene, 0.3 mL of internal standard (C11 triglyceride in toluene), and 4 mL of 5% of sulphuric acid in methanol were mixed thoroughly by vortex and incubated at 70°C for 2 h, with mixing every 30 min during the incubation time. Every 10 samples, a random allocated duplicate sample was analysed to verify consistency. After 25 min of equilibration at room temperature, 5 mL of saturated NaCl was added, mixed and then centrifuged at 1065 g speed for 2 min to separate solvent layers. The top layer containing the fatty acid methyl esters (FAME) was transferred into 1.5 mL GC autosampler vial (Hewlett Packard, model 6890). The GC was a Shimadzu GC-2010 plus (Shimadzu Corporation, Kyoto, Japan) with a flame ionization detector (FID). The column was Restek RTX 2330 of 105 m length, 0.25 mm i.d., and 0.20µm film thickness (Restek Corporation, Bellefonte, PA, USA). The thermal program used an initial temperature of 175°C for 17 min, which was increased to 220°C at a rate of 6°C per min and held for 10 min. The carrier gas was hydrogen with a linear velocity of 50 cm/s. The injection volume was 1 µL, with a split ratio of 80:1. The injector temperature was 260°C and the detector temperature was 300°C. The peak areas were integrated using the Shimadzu Labsolution software (version 4.20) in post-run analysis and were averaged for duplicate samples. Peaks were identified by comparison of their retention times with those of commercial standard mixtures (FAME mix 37 components from Supelco Inc., Bellefont, PA, USA) and quantified by using an internal standard (C11:0) and theoretical FID response factors. The equations for generating the response and conversion factors to quantify individual fatty acids from FAME were obtained from American Oil Chemists' Society 6th edition (AOCS Ce1f-96, Ce 1 h-05 and Ce 1i-07). Intramuscular fat content was calculated from the sum of fatty acids and expressed as triacylglycerides (percentage in fresh tissue). Finally, the 108 loin sections were ranked by IMF% and then stratified into 6 groups of 18 loins each with increasing IMF% levels that defined the six experimental treatments for consumer sensory evaluation denoted as G1 to G6.

2.3. Consumer sensory evaluation

One hundred and eighty consumers were recruited in November 2019 using Qualtrics (Qualtrics, Provo, UT, USA) to evaluate the eating quality of six lamb samples with increasing levels of IMF at a session. Participants were preselected according to the following criteria: age (18-65 years old) and consumption profile (consume meat including lamb at least once a fortnight). Eighteen sessions were run over 3 days with 6 sessions per day and aiming for 10 consumers per session, at the Food Experience and Sensory Testing Lab, Massey University, Palmerston North, New Zealand. There were 10 incomplete sessions (5 sessions with 9 consumers and 5 sessions with 8 consumers) resulting in a total of 165 consumers. Loins were assigned to each session so that the difference in IMF% among the 6 IMF groups were similar for all sessions. Consumers were selected following a stratified random sampling to balance for gender and age to represent the population distribution of New Zealand.

Vacuum-packed loin sections (approximately 12 cm) were thawed at 4°C for 48 h. Six loins per session corresponding to the six IMF% groups were sous vide cooked at 58°C for 1 hour. After cooking, the loins were removed from the sous vide bag, dried using paper towels and rested for 4 minutes. Loins were subsequently grilled in a clamshell hot plate (Roband Aluminium Grill Station 8 Slice Smooth Plates WGSA815S, Nisbets, Auckland) pre-heated at 150°C for 3 minutes with core temperature recorded at 65°C (medium degree of doneness). Cooked loin sections were then cut into five 1-cm-thick slices and each slice cut in half obtaining 10 samples (about 1-cm^3 each) per loin section. Meat samples were individually wrapped with aluminium foil pre-coded with 3 random digit codes and kept in a sample warmer at 50°C until serving. Samples were served monadically in pre-heated (40°C) ceramic cups. To avoid first order and carryover effects, samples were presented to panellists in different orders according to a Williams square design. The evaluation of the samples was performed in individual sensory booths that had controlled environmental conditions under red light. Consumers were provided unsalted gluten-free crackers and filtered water to cleanse their palate between samples. Each consumer rated liking of flavour, juiciness, tenderness and overall liking of six lamb samples using a 100 mm non-structured line scale anchored at each end (0: dislike extremely to 100: like extremely). Consumers also rated the quality of each lamb sample as 'Unsatisfactory', 'Good every day', 'Better than every day' or 'Premium' (Watson, Gee, Polkinghorne, & Porter, 2008). After sample scoring, consumers answered a sociodemographic and frequency of meat consumption survey (Table 1).

2.4. Statistical Analysis

A total of 108 loins (n=18 for each IMF% group: G1-G6) were evaluated by 165 consumers, however, one loin sample was removed for data analysis due to incorrect allocation to G4 (n=17). Consumer demographic and frequency of meat consumption data were summarized for all consumers and by consumer cluster (Table 1) using the FREQ procedure and differences between clusters were obtained with the Chi-square test using SAS (Version 9.4; SAS Inst. Inc., Cary, NC). Individual consumer scores were used for the analysis of sensory variables (Table 2 and 3), while the mean of 10 consumer scores was used for the combined analysis of sensory and chemical data (IMF and fatty acid composition, Tables 4 and 5). Overall, flavour, tenderness and juiciness liking scores were analysed using the GLIMMIX procedure of SAS. The statistical model included IMF% group (G1-G6) as a fixed effect and session and consumer within session as random effects. Since flavour, tenderness and juiciness liking scores were highly correlated with overall liking, cluster analysis was conducted using the CLUSTER procedure of XLSTAT (2019.4.1 version, Addinsoft, UK) on the consumer overall liking scores only. Overall liking scores for each consumer cluster were analysed using the same model and procedure run for all consumers. Consumer data for eating quality levels (Unsatisfactory, Good every day, Better than every day, and Premium) were analysed using a binomial error distribution. For all analyses, the Kenward-Roger adjustment was used to estimate the denominator degree of freedom. Least-square mean separation was carried out using the Tukey's test for all variables. GLIMMIX models of SAS were used to estimate the relationships between consumer liking scores with IMF% for all consumers and by cluster (Table 4, Figure 1), after adjustment for random effects (session). A quadratic regression equation was fitted in each case, but the quadratic term was retained only for those equations where that term was significant at $P \leq 0.10$. When $P > 0.10$, a simple linear regression equation is reported. For the quadratic equations, the inflexion point was calculated as values when dy/dx was equal to zero. Pearson correlation coefficients between IMF%, lipid composition (selected groups of fatty acids) and meat consumer liking scores (overall, flavour, tenderness and juiciness) were calculated (XLSTAT) for all consumers (Table 5). Principal component analysis (PCA) was performed using XLSTAT to evaluate the relationships between consumer liking scores and proportions of selected groups of fatty acids of the six IMF% groups (G1-G6).

3. Results

3.1. Consumer liking of lamb loins with different intramuscular fat percentage

The IMF% of the lamb loins selected for this study ranged from about 1-6%. Consumer liking scores for tenderness, juiciness, flavour and overall liking showed a similar pattern across the six IMF% groups (Table 2). Liking scores increased with increasing IMF% until G4, with no further improvements in eating quality with G5 and G6. Juiciness and overall liking scores for G5 were lower ($P<0.05$) than G4 and similar ($P>0.05$) to all other groups. Three loin sections were identified as odd samples in G5, resulting in lower liking scores than the rest of the samples in the group or any loin section from the other IMF% levels (Figure 1). When these samples were removed from the data set, the average consumer liking scores for G5 became similar ($P>0.05$) to G4 and G6. However, these samples were kept in the data set as the IMF% and fatty acid composition did not differ ($P<0.05$) from the other samples in G5.

Cluster analysis revealed two segments of consumers with differential liking response pattern to increasing IMF% levels in meat. Overall liking consumer scores in Cluster 1 (n=111) showed a linear response to IMF%, while scores in Cluster 2 (n=54) showed an inverted-U shape response to IMF% reaching an optimum at G3-G4 (Figure 2a). The proportion of lamb loins rated by all consumers as 'Unsatisfactory' or 'Better than everyday' quality did not differ ($P>0.05$) across the six IMF% levels in meat (Table 3). However, a higher proportion of loins in G2 than G3 and G4 were categorized as 'Good everyday', while the 'Premium' quality was dominated by loins with higher levels of IMF%, particularly G4 than G1 and G2 ($P<0.05$). Consumers in Cluster 1 categorized the highest proportion of loins in G5 as 'Premium', while this quality level was dominated by loins in G3-G4 for consumers in Cluster 2.

Table 4 and Figure 2 show the relationships between overall, flavour, tenderness and juiciness consumer liking scores with IMF% in meat for all consumers and for consumers in Cluster 1 and 2 by fitting regression models. The best fit for data from all consumers (n=165) was represented by a quadratic model with maximum liking scores around 67-70/100 at 3.6-4.1% IMF for overall, flavour and juiciness liking; while a linear model was the best fit for tenderness liking scores and IMF%. For consumers in Cluster 1 (n=111), linear models were the best fit for overall, flavour, tenderness and juiciness liking scores and IMF%, although the linear term was not significant for juiciness. Data from Cluster 2 (n=54) showed a quadratic fit for overall liking scores with a maximum of 70/100 at 3.5% IMF, and a linear response for tenderness, flavour and juiciness liking scores to increasing IMF% in meat, although the linear terms were not significant for flavour and juiciness.

3.2. Relationships among intramuscular fat, fatty acid composition and consumer liking

Meat overall liking was highly correlated with all sensory traits, mainly tenderness and flavour followed by juiciness (0.83 to 0.90, $P<0.001$) (Table 5). Overall, flavour and tenderness liking scores were low to modestly correlated ($P<0.05$) with IMF% in meat with positive values around 0.25, while juiciness scores were not correlated ($P>0.05$) with IMF%. Liking scores were weakly correlated with the selected major fatty acid groups, showing positive coefficients ($P<0.05$) for overall, flavour and tenderness liking scores with monounsaturated fatty acids (MUFA); and negative coefficients for overall, flavour and tenderness liking scores with polyunsaturated (PUFA), n-3 and n-6 fatty acids ($P<0.05$), although the correlation between flavour and n-6 fatty acids was not significant ($P>0.05$). Correlations between consumer overall liking scores and individual fatty acids in meat were low or not significant (data not shown in Table 5). Consumer overall liking scores were positively correlated ($P<0.05$) with 16:0 (+0.24), 14:1 (+0.22), 18:1 *trans*9 (+0.22) and 18:1 *cis*9 (+0.25) and negatively correlated with 18:1

*cis*11 (-0.25). Correlations between liking scores and individual PUFA were significant for the longer chain fatty acids (-0.26 for 20:3 n-6, -0.24 for 20:4 n-6, -0.26 for 20:5 n-3, -0.28 for 22:5 n-3 and -0.22 for 22:6 n-3; $P<0.05$), but not ($P>0.05$) for 18:2 *cis*9*trans*11, 18:2 or 18:3.

An overall view of these correlations is presented in Figure 1 by means of the PC biplots showing a superimposed representation of the meat-sample groups with different IMF% levels and the fatty acid composition and sensory variables. The first two principal components accounted for 76.87% of the total variation in the data (PC1: 42.04%, PC2: 34.83%). The six IMF% groups were separated mainly by PC1 with G1 and G2 and some samples from G3 having positive PC1 values and samples from G4, G5 and G6 having mainly negative PC1 values. However, there is considerable overlap among samples from the different IMF% groups. PUFA, n-6 and n-3 fatty acids have positive values on the PC1 axis (Figure 1), while BCFA, SFA, and MUFA had negative values on the same axis. Consumer overall liking of meat and its main sensory attributes flavour, tenderness and juiciness are located with positive values on PC2 far from the origin, explaining an independent cause of variation. Although the level of loin IMF% is not clearly separated by PC2, samples with higher levels of IMF% are closer to consumer liking variables than those from G1 and G2. It is noticeable that 7 samples in G5 had negative values for PC2 located opposite to consumer liking variables and particularly the separation of three odd samples from the rest of the meat samples.

4. Discussion

4.1. Consumer liking of lamb loins with different intramuscular fat percentage

The range of IMF% (mean=2.93±0.9%, minimum=1.09%, maximum=5.68%) in the loins selected for this study was similar to previously reported values (n=1,705) for New Zealand lamb (mean=2.69±0.8%, min=0.91%, max=6.42%; Craigie et al., 2017), with slight differences due to having mainly rams and wethers and only a few ewes in the published data set. The higher average loin IMF% in female than male lambs is well documented (Craigie et al., 2012; Pannier, Pethick, Geesink, Ball, Jacob, & Gardner, 2014). Loin IMF% values for New Zealand lamb are significantly lower than those reported in other studies that have investigated the relationship between IMF% and eating quality of lamb, mainly from Australia and the USA (Pannier et al., 2014; Phelps, Garmyn, Brooks, Martin, et al., 2018); mostly because New Zealand lamb is typically raised on pasture alone and carcass weights are significantly lower (about 18-19 kg; Beef and Lamb New Zealand, 2020) than in Australia (about 21-24 kg; Meat and Livestock Australia, 2019) or the USA (about 27 kg; American Lamb Board, 2020).

Results from the current study showed an increase in overall liking with increasing levels of IMF% up to G4 (3.1%). In line with overall liking scores, the highest percentage of loins categorized as 'Premium' quality corresponded to G4. Model fitting showed a quadratic response of sensory traits to IMF% in loins, achieving maximum overall liking scores at 4.1%. Highest sensory scores were previously reported for lamb loins with IMF values between 3.5 to 4.5% (Heylen, Suess, Freudenreich, & Von Lengerken, 1998) and 4 to 5% IMF (Lambe et al., 2017) in agreement with Pannier et al. (2014); while Hopkins, Hegarty, Walker, and Pethick (2006) recommended minimum values of 5% IMF in lamb to achieve maximum consumer liking scores.

Chong et al. (2020) highlighted that consumer preference variability in the eating quality of meat is one of the challenges faced by the meat industry, indicating that few individuals may be regarded as 'average' in consumer studies. Chong et al. (2020), Font i Furnols et al. (2009) and Realini et al. (2009) showed that consumer clustering can be a valuable tool in understanding drivers of overall liking by allocating consumers with similar liking patterns into segments. Consumers in this study were segmented based on their liking response to the increasing levels of IMF%. Results suggest that most consumers (n=111/165, 67%) would prefer higher IMF% levels in lamb meat with a linear liking response to increasing levels of IMF%, that can be described as 'IMF lovers: the more the better'; while a smaller number of consumers (n=54/165, 33%) would prefer lower IMF% levels in the range of 2.5-3.5%, regarded as 'IMF optimizers: just the right amount'. This different pattern in preference towards IMF% levels in lamb, was not associated with any of the sociodemographic or frequency of meat consumption data, which did not differ (P>0.05) between consumer clusters (Table 1). The lack of differences in socioeconomic status and consumers' habits between clusters has been frequently reported (Chong et al., 2020; Oliver et al., 2006; Realini et al., 2009), while O'Reilly et al. (2020) indicated a significant influence of some demographic factors on sheep meat sensory scores in a large cross-cultural consumer study. Consumer preferences for lamb are determined to a large extent by their past experience and cooking methods (Font-i-Furnols & Guerrero, 2014; Miller, 2020; Sañudo et al., 2000). O'Reilly et al. (2017) showed that Australian consumers were more sensitive towards IMF differences when scoring liking of sheep meat than Chinese and American consumers. Hastie, Ashman, Torrico, Ha, and Warner (2020) also highlighted cultural differences in consumer responses to red meat between Australian and Asian consumers. The Asian group indicated that too much subcutaneous fat was undesirable but high IMF content was related to a premium eating experience. Considering that most New Zealand lamb is exported, gaining consumer insights in major export markets around consumer preferences for fatness including IMF would be valuable information. Non-invasive and rapid spectroscopy tools have been developed for measuring meat quality traits from different species (Dixit et al., 2017) including fresh lamb (Craigie et al., 2017). Furthermore, Dixit et al. (2020) has recently shown that hand-held and miniaturized spectrophotometers have potential as fast, ultra-compact and cost-effective devices for IMF% prediction of freeze-dried and pulverized lamb loin samples. Reliable predictions of IMF% in lamb at processing plants would enable product sorting for target markets (Pannier, Gardner, O'Reilly, & Pethick, 2018).

4.2. Relationships among intramuscular fat, fatty acid composition and consumer liking

Meat tenderness, flavour and juiciness are all key determinants of the overall eating quality of lamb as evidenced by their high, positive and significant correlations. Similar significant correlations of sensory attributes with overall liking of lamb loins have been reported by Pannier et al. (2014), with the highest being with flavour liking (0.94), followed by tenderness (0.87) and juiciness (0.85). For lamb, flavour has been identified as the main driver of consumer liking (Miller, 2020), while in this study it seems that flavour and tenderness made similar contributions to consumer overall liking. New Zealand lambs are typically harvested under one year of age which may explain why flavour is not the dominant determinant of overall liking in this study, compared to other published research involving older animals. Meat that has been shown to have higher levels of 'mutton' flavour from older sheep is generally less acceptable to consumers than meat from younger lambs (Hopkins et al., 2006; Montossi, Font-i-Furnols, del Campo, San Julián, Brito, & Sañudo, 2013). Lamb flavour is influenced by a number of factors other than animal age including diet, gender, time on feed and breed (Font-i-Furnols et al., 2014; Realini, Bianchi, Bentancur, & Garibotto, 2017). However, all lambs in the current study were purposely sourced from one flock of ewes to avoid confounding factors with the evaluated IMF% levels, which may also explain the similar contribution of flavour and tenderness to consumer overall liking of lamb.

Intramuscular fat was highly and positively correlated with BCFA, SFA and MUFA and highly and negatively correlated with PUFA, n-6 and n-3 fatty acids. Ruminants preferentially deposit PUFA in phospholipids (Enser, Hallett, Hewett, Fursey, Wood, & Harrington, 1998), so very lean animals will have relatively high proportions of PUFA compared with fatter lambs in which the phospholipid effect is diluted by higher levels of neutral storage lipid (Fisher et al., 2000). All sensory traits except juiciness had significant positive correlations with IMF% around 0.25 supporting the positive response in consumer liking scores to increasing levels of IMF% in lamb loins. The low to modest correlation coefficients also indicate that IMF% level is only one factor contributing to overall consumer liking of lamb. Lambe et al. (2017) reported similar correlations of sensory parameters with IMF (0.21 to 0.26), with the lowest correlation for juiciness, but this was still statistically significant. Frank et al. (2016) showed that higher fat content in meat resulted in higher initial and sustained juiciness scores based on consumers and trained panellists, and Pannier et al. (2014) reported the highest magnitude of response across a 4.5% IMF range for juiciness. Angood, Wood, Nute, Whittington, Hughes, and Sheard, (2008) also indicated that juiciness was the trait most affected by increasing levels of marbling fat, associated with greater retention of water in lamb during cooking. The authors attributed increased juiciness scores to the higher level of IMF, while increased flavour rating was attributed to differences in the fatty acid composition of lamb.

Fatty acid composition determines the firmness/oiliness of adipose tissue associated to its melting point and the oxidative stability of muscle, which in turn affects flavour (Wood, Enser, Richardson, & Whittington, 2008). Monounsaturated fatty acids are characterised by lower melting points than saturated fatty acids, a property that favours meat flavour, tenderness and juiciness (Hayakawa et al., 2015). Kerth, Harbison, Smith, and Miller (2015) indicated that the primary impact of lipids on flavour and volatile compounds is found in the phospholipid fraction of the lean tissue. In the current study, the association between consumer liking scores and proportions of individual and major groups of fatty acids was modest. Other authors also found weak (Gravador et al., 2020) or no associations (Najafi, Zeinoaldini, Ganjkhanlou, Mohammadi, Hopkins, & Ponnampalam, 2012; Ponnampalam, Sinclair, Egan, Ferrier, & Leury, 2002) between fatty acid composition in lamb and sensory properties of meat. In the present study, overall, flavour and tenderness liking scores were positively correlated with MUFA and negatively correlated with total PUFA, n-6 and n-3 fatty acids. Correlations between consumer liking scores and individual PUFA were significant for the longer chain fatty acids only. Baublits et al. (2009) and Hwang and Joo (2017) also described a positive correlation between MUFA and overall palatability, but a negative correlation between PUFA and sensory attributes in meat. However, other authors have found positive correlations between sensory attributes of lamb with PUFA (Francisco et al., 2015). Many factors differ across studies looking into the relationship between lipid content and composition with sensory characteristics of meat which prevent direct comparisons. Moreover, most studies evaluated nutritional or animal effects on the eating quality of meat that often produce significant changes in key flavour compounds, while the current study looked at increasing levels of IMF% from animals with similar background. Since IMF is highly correlated with fatty acid composition, it is also difficult to conclude a direct effect of individual or groups of fatty acids on sensory attributes, given that high levels of PUFA are associated with lower levels of IMF and therefore negatively correlated with consumer liking scores.

5. Conclusions

Consumer overall liking of lamb loins increased significantly at around 3% IMF achieving maximum scores at 4% IMF. Two consumer segments were identified with distinct patterns of preference for IMF% in lamb. Around two thirds of the consumers showed a linear increase in overall liking within the evaluated IMF% range that can be described as ‘IMF lovers: the more the better’; while a third preferred levels from 2.5-3.5% and were regarded as ‘IMF optimizers: just the right amount’. Intramuscular fat was modestly correlated with sensory attributes indicating that other factors are involved, but these results suggest advantages to maximising the proportion of loins with IMF% values above 3 to increase the likelihood of superior eating experiences for premium and other markets. Moreover, further information should be acquired on IMF% optimums to maximise consumer preferences in major export markets for different lamb cuts. Animal diet strategies combined with longer term genetic improvement approaches to optimising current IMF levels in New Zealand lamb should be considered along with product sorting for target markets.

Ethical Statements: The project (4000021760) was submitted via the Massey University Human Ethics Committee process for consideration and was deemed low risk and not needing full ethics approval. Informed consent was obtained from all participants.

Declaration of Competing Interest: The authors declare no conflict of interest.

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Highlights

- Consumer liking increased with increasing intramuscular fat (IMF%) peaking at 4%
- Two consumer clusters were identified with different preferences for IMF% in lamb
- Intramuscular fat was correlated with all sensory attributes except juiciness
- Liking was correlated with monounsaturated (+) and polyunsaturated (-) fatty acids

Table 1. Sociodemographic characteristics for all consumers and their clusters.

Characteristics (% of total)	All consumers	Cluster-1	Cluster-2	Cluster effect P-value Chi-Square
N	165	111	54	
Age				
< 20 y	0.61	0.91	0.0	0.959
20-29 y	23.17	24.5	20.4	
30-39 y	28.66	29.1	27.8	
40-49 y	20.73	20.0	22.2	
50-59 y	20.73	19.1	24.7	
> 60 y	6.1	6.3	5.6	
Gender				
Male	41.21	39.6	44.4	0.614
Female	58.79	60.4	55.6	
Ethnicity				
Asian	24.85	24.32	25.93	0.917
European	56.36	57.66	53.70	
Middle Eastern/ Latin American/ African	8.48	9.01	7.41	
Maori	1.82	1.85	1.85	
Other Ethnicity	7.88	6.31	11.11	
Pacific Peoples	0.61	0.90	0.00	
Education [a]				
A	7.88	8.11	7.41	0.177
B	4.24	4.50	3.70	
C	7.27	3.60	14.81	
D	71.52	74.77	64.81	
E	6.67	7.21	5.56	
F	2.42	1.80	3.70	
Occupation				
Administration / Office	6.06	4.50	9.26	0.814
Home maker	5.45	6.31	3.70	
Labourer	0.61	0.90	0.00	
Other employment	7.88	5.41	12.96	
Professional	30.91	32.43	27.78	
Retired	1.21	0.90	1.85	
Sales/Services	3.03	2.70	3.70	
Student	29.7	31.53	25.93	
Technical	12.12	11.71	12.96	
Trades	2.42	2.70	1.85	
Unemployed	0.61	0.90	0.00	
Household income, NZ$				
Less than $25,000	16.36	18.02	12.96	0.861
$25,001 to $40,000	16.36	14.41	20.37	
$40,001 to $55,000	6.67	7.21	5.56	
$55,001 to $70,000	17.58	17.12	18.52	
$70,001 to $100,000	23.03	21.62	25.93	
$100,001 to $150,000	13.94	14.41	12.96	
More than $150,000	6.06	7.21	3.70	

Lamb consumption, frequency				
Daily	0.00	0.00	0.00	0.134
4-5 times a week	4.24	4.50	3.70	
2-3 times a week	11.52	13.51	7.41	
Weekly	32.12	25.23	46.30	
Fortnightly	29.7	33.33	22.22	
Monthly	21.21	22.52	18.52	
Never	1.21	0.90	1.85	
Beef consumption, frequency				
Daily	1.21	0.90	1.85	0.933
4-5 times a week	7.27	6.31	9.26	
2-3 times a week	34.55	36.04	31.48	
Weekly	36.36	34.23	40.74	
Fortnightly	12.73	14.41	9.26	
Monthly	6.06	6.31	5.56	
Never	1.82	1.80	1.85	
Pork consumption, frequency				
Daily	2.42	1.80	3.70	0.692
4-5 times a week	1.21	1.80	0.00	
2-3 times a week	12.12	11.71	12.96	
Weekly	28.48	31.53	22.22	
Fortnightly	17.58	17.12	18.52	
Monthly	29.09	28.83	29.63	
Never	9.09	7.21	12.96	
Poultry consumption, frequency				
Daily	0.00	0.00	0.00	0.714
4-5 times a week	12.73	12.61	12.96	
2-3 times a week	46.67	45.05	50.00	
Weekly	29.7	30.63	27.78	
Fortnightly	6.06	5.41	7.41	
Monthly	3.64	4.50	1.85	
Never	1.21	1.80	0.00	
Venison consumption, frequency				
Daily	0.61	0.90	0.00	0.761
4-5 times a week	0.00	0.00	0.00	
2-3 times a week	1.21	1.80	0.00	
Weekly	0.61	0.90	0.00	
Fortnightly	3.64	4.50	1.85	
Monthly	48.48	45.95	53.70	
Never	45.45	45.95	44.44	
Fish consumption, frequency				
Daily	1.82	0.00	5.56	0.142
4-5 times a week	1.21	1.80	0.00	
2-3 times a week	12.73	15.32	7.41	
Weekly	31.52	32.43	29.63	
Fortnightly	23.03	22.52	24.07	
Monthly	26.67	25.23	29.63	
Never	3.03	2.70	3.70	

[a] A: NZ Higher School Certificate or Higher Leaving Certificate or NZ University Bursary / Scholarship or National Certificate level 3 or NCEA level 3 or NZ Scholarship, B: NZ School

Certificate in one or more subjects or National Certificate level 1 or NCEA level 1, C: NZ Sixth Form Certificate in one or more subjects or National Certificate level 2 or NZ UE before 1986 in one or more subjects or NCEA level 2, D: Tertiary qualification (i.e. Bachelor's degree or higher), E: Trades certificate (i.e. Electrical Engineering), and F: None.

Table 2. Effect of loin intramuscular fat percentage (IMF%) on sensory scores (overall, flavour, tenderness, juiciness) for all consumers and overall liking scores for consumers in Cluster 1 and Cluster 2. (Least-square means ± SEM).

	IMF % groups (G1 to G6)				
	G1	G2	G3	G4	G
n	18	18	18	17	1
IMF %	1.7 ± 0.1 [f]	2.1 ± 0.1 [e]	2.6 ± 0.1 [d]	3.1 ± 0.1 [c]	3.5 ±
Carcass weight, kg	18.7 ± 0.2 [d]	19.4 ± 0.2 [b]	19.2 ± 0.2 [c]	19.4 ± 0.3 [b]	19.3 ±
Consumer liking scores (n=165)					
Overall	64.9 ± 1.6 [c]	64.9 ± 1.6 [c]	68.9 ± 1.6 [abc]	72.6 ± 1.6 [a]	66.9 ±
Flavour	61.8 ± 1.6 [b]	61.3 ± 1.6 [b]	65.8 ± 1.6 [ab]	68.4 ± 1.7 [a]	64.2 ±
Tenderness	67.9 ± 1.8 [b]	65.9 ± 1.8 [b]	70.1 ± 1.8 [ab]	74.9 ± 1.8 [a]	69.5 ±
Juiciness	65.0 ± 1.7 [bc]	61.8 ± 1.7 [c]	68.5 ± 1.7 [ab]	71.9 ± 1.7 [a]	65.0 ±
Overall liking by Cluster					
Cluster 1 (n=111)	67.5 ± 1.9 [abc]	62.5 ± 1.9 [c]	64.1 ± 1.9 [c]	69.4 ± 2.0 [ab]	73.8 ±
Cluster 2 (n=54)	60.1 ± 2.5 [c]	69.8 ± 2.5 [b]	78.6 ± 2.5 [a]	79.2 ± 2.5 [a]	52.7 ±

[a,b,c,d,e,f] Least-square means within rows with uncommon superscript letters differ (P<0.05).
Consumer liking scores from 0: dislike extremely to 100: like extremely.

Table 3. Effect of intramuscular fat percentage (IMF%) on the proportion of lamb loins rated into four eating quality levels by all consumers and their clusters. (Least-square means ± SEM).

	IMF % groups (G1 to G6)*				
Quality level of lamb loins	G1	G2	G3	G4	G
All consumers (n=165)					
Unsatisfactory	9.4 ± 2.3	10.0 ± 2.4	10.0 ± 2.4	4.8 ± 1.6	10.5 ±
Good every day	46.0 ± 3.9 ^{ab}	53.3 ± 3.9 ^{a}	37.5 ± 3.8 ^{b}	36.3 ± 3.9 ^{b}	43.0 ±
Better than every day	32.1 ± 3.7	24.2 ± 3.4	32.1 ± 3.7	32.5 ± 3.8	27.9 ±
Premium	10.5 ± 2.4 ^{c}	10.5 ± 2.4 ^{c}	18.2 ± 3.2 ^{ab}	25.4 ± 3.8 ^{a}	16.4 ±
Cluster 1 consumers (n=111)					
Unsatisfactory	6.7 ± 2.3 ^{bc}	12.8 ± 3.3 ^{ab}	15.4 ± 3.5 ^{a}	6.2 ± 2.3 ^{bc}	4.1 ±
Good every day	41.5 ± 4.9 ^{b}	56.9 ± 4.9 ^{a}	42.4 ± 4.9 ^{b}	43.6 ± 5.0 ^{ab}	34.2 ±
Better than every day	37.8 ± 4.7 ^{a}	19.8 ± 3.8 ^{c}	25.2 ± 4.2 ^{bc}	27.3 ± 4.4 ^{abc}	36.0 ±
Premium	12.1 ± 3.3 ^{bc}	8.7 ± 2.7 ^{c}	14.7 ± 3.6 ^{abc}	20.8 ± 4.3 ^{ab}	23.7 ±
Cluster 2 consumers (n=54)					
Unsatisfactory ^{z}	13.4 ± 5.2 ^{ab}	3.6 ± 2.3 ^{b}	0.0 ± 0.0	0.0 ± 0.0	23.3 ±
Good every day	55.6 ± 6.8 ^{a}	46.3 ± 6.8 ^{a}	27.8 ± 6.1 ^{bc}	21.8 ± 5.8 ^{c}	61.1 ±
Better than every day	20.4 ±5.4	33.3 ± 6.4	46.3 ± 6.8	43.1 ± 6.9	11.1 ±
Premium	6.2 ± 3.3 ^{cd}	13.0 ± 4.9 ^{bc}	24.1 ± 6.7 ^{ab}	33.3 ± 7.8 ^{a}	1.5 ±

^{a,b,c,d,e,f} Least-square means within rows with uncommon superscript letters differ (P<0.05).
^{z}Analysis performed removing G3 and G4 as none of the consumers in Cluster 2 ranked samples as Unsatisfactory for these IMF% groups.
*IMF % values corresponding to each group (G1 to G6) are presented in Table 2.

Table 4. Relationships between overall, flavour, tenderness and juiciness consumer scores with intramuscular fat percentage (IMF%) for all consumers and for consumers in Cluster 1 and Cluster 2. Quadratic terms were retained in the equations when that term was significant at P ≤ 0.10.

	Intercept			IMF%			IMF	
Consumer liking	estimate	SE	P-value	estimate	SE	P-value	estimate	S
Overall								
All consumers	53.28	5.89	<0.001	8.35	3.89	0.035	-1.01	0
Cluster 1	60.22	2.99	<0.001	2.41	0.49	0.008		
Cluster 2	46.61	10.91	<0.001	13.53	7.18	0.063	-1.93	1
Flavour								
All consumers	51.39	5.02	<0.001	7.44	3.30	0.027	-0.90	0
Cluster 1	56.83	2.96	<0.001	2.31	0.82	0.006		
Cluster 2	61.55	4.66	<0.001	0.72	1.37	0.601		
Tenderness								
All consumers	62.93	2.93	<0.001	2.55	0.90	0.006		
Cluster 1	62.15	3.30	<0.001	2.53	1.01	0.014		
Cluster 2	63.3	4.45	<0.001	2.45	1.32	0.067		
Juiciness								
All consumers	52.29	6.55	<0.001	8.88	4.31	0.043	-1.25	0
Cluster 1	61.16	3.27	<0.001	1.56	0.98	0.115		
Cluster 2	67.99	5.17	<0.001	-0.77	1.53	0.615		

Table 5. Pearson correlation coefficients between intramuscular fat percentage (IMF%) and composition (selected groups of fatty acids) and consumer liking scores (overall, flavour, tenderness and juiciness) of lamb loins for all consumers.

		Consumer liking			
Variables	IMF%	Overall	Flavour	Tenderness	Juiciness
Consumer liking					
Overall	**0.235**	--	–	–	–
Flavour	**0.243**	**0.888**	--	–	–
Tenderness	**0.256**	**0.900**	**0.758**	--	–
Juiciness	0.123	**0.832**	**0.747**	**0.776**	–
Selected groups of fatty acids					
BCFA	**0.484**	0.007	0.049	0.030	0.002
SFA	**0.690**	0.094	0.091	0.121	0.055
MUFA	**0.576**	**0.253**	**0.234**	**0.227**	0.149
PUFA	**-0.853**	**-0.200**	**-0.187**	**-0.205**	-0.119
n-6	**-0.845**	**-0.190**	-0.178	**-0.209**	-0.122
n-3	**-0.847**	**-0.233**	**-0.210**	**-0.241**	-0.158

Values in bold are different from 0 with a significance level alpha=0.05.
BCFA (Branched-chain fatty acids): ∑ (iso C15:0, iso C16:0, iso C17:0, anteiso C15:0, anteiso C17:0).
SFA (Saturated fatty acids): ∑ (C10:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0).
MUFA (Monounsaturated fatty acids): ∑ (C14:1, C16:1, C17:1, C18:1 trans-9, C18:1 trans-11, C18:1 cis-9, C18:1 cis-11).
PUFA (Polyunsaturated fatty acids): ∑ (n-6, n-3, C18:2 cis-9, trans-11).
n-6 (Omega-6 fatty acids): ∑ (C18:2, C20:3, C20:4).
n-3 (Omega-3 fatty acids): ∑ (C18:3, C20:5, C22:5, C22:6).

Figures

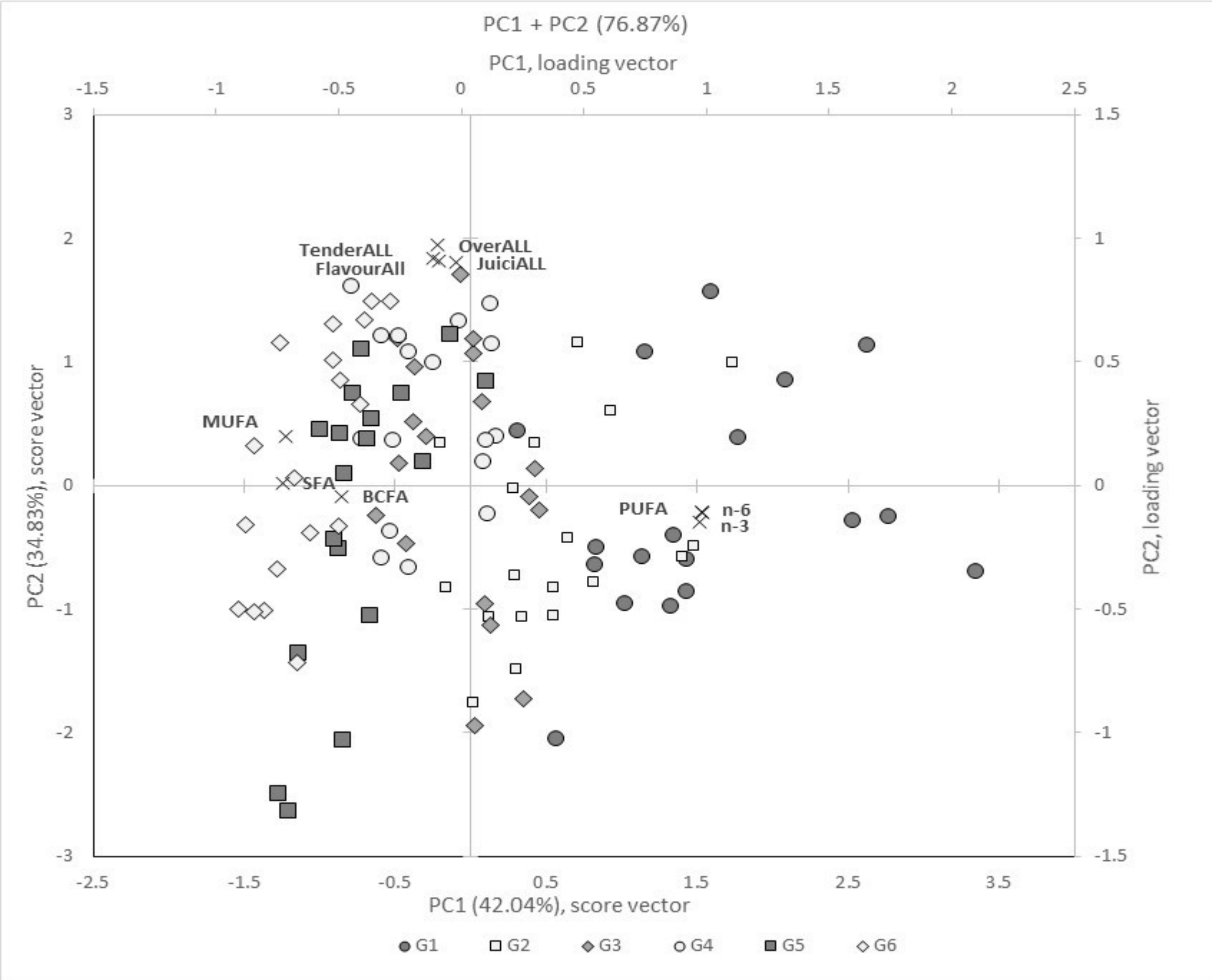
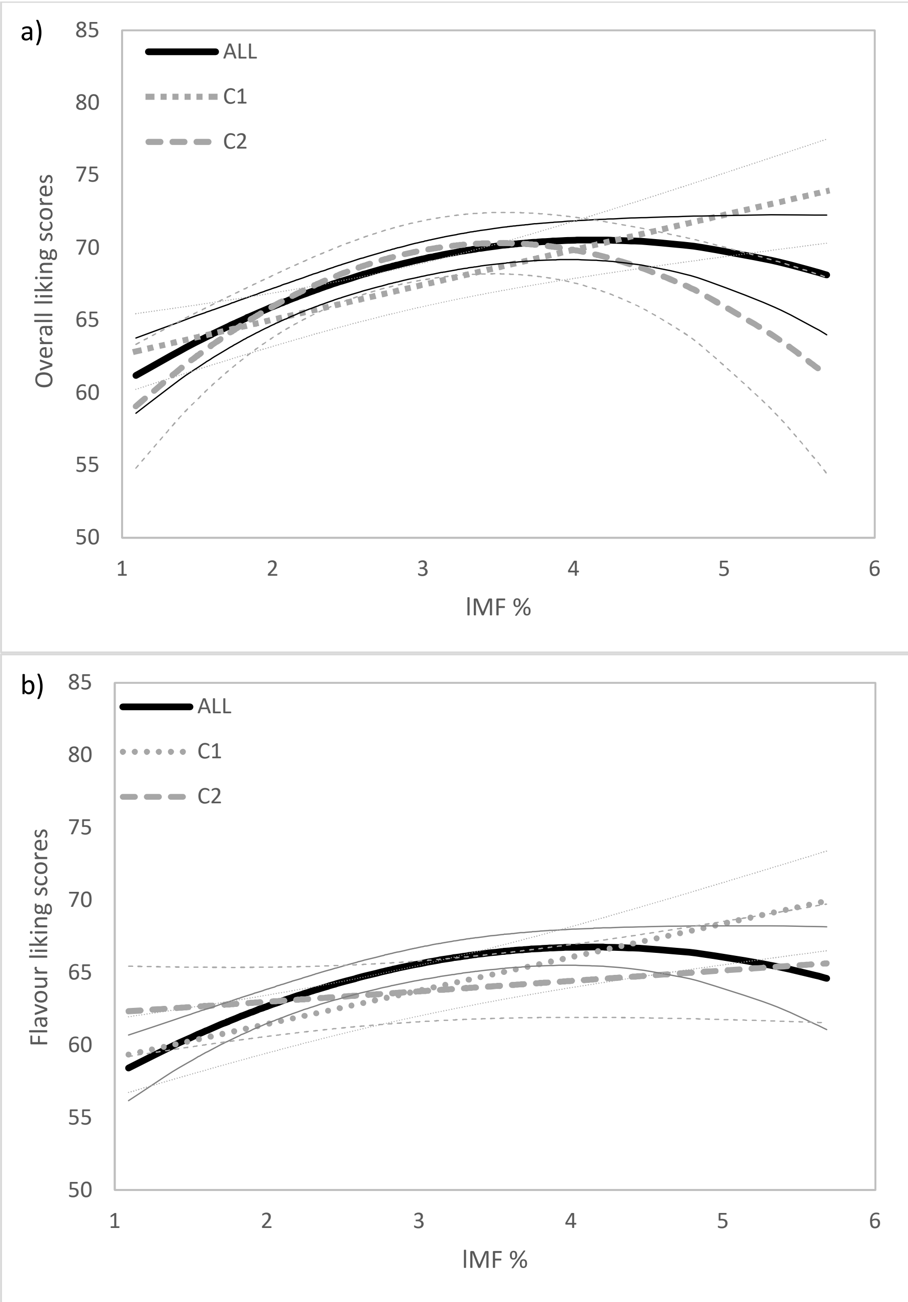


Figure 1. Representation onto the space defined by the first two principal components of the lamb loin samples (n=107) with different IMF% groups (G1: 1.65, G2: 2.12, G3: 2.65, G4: 3.20, G5: 3.58 and G6: 4.40) and the loading plot of the sensory and fatty acid composition variables. Sensory variables: overall (OverALL), flavour (FlavourALL), tenderness (TenderALL) and juiciness (JuiciALL) liking scores of meat samples for all consumers. Groups of major fatty acid variables from meat samples: Branched-chain fatty acids (BCFA), Saturated fatty acids (SFA), Monounsaturated fatty acids (MUFA), Polyunsaturated fatty acids (PUFA), Omega-6 fatty acids (n-6), and Omega-3 fatty acids (n-3).


a)
85
80
75
70
65
60
55
50
Overall liking scores
ALL
C1
C2
1
2
3
4
5
6
IMF %
b)
85
80
75
70
65
60
55
50
Flavour liking scores
ALL
C1
C2
1
2
3
4
5
6
IMF %

c) d)

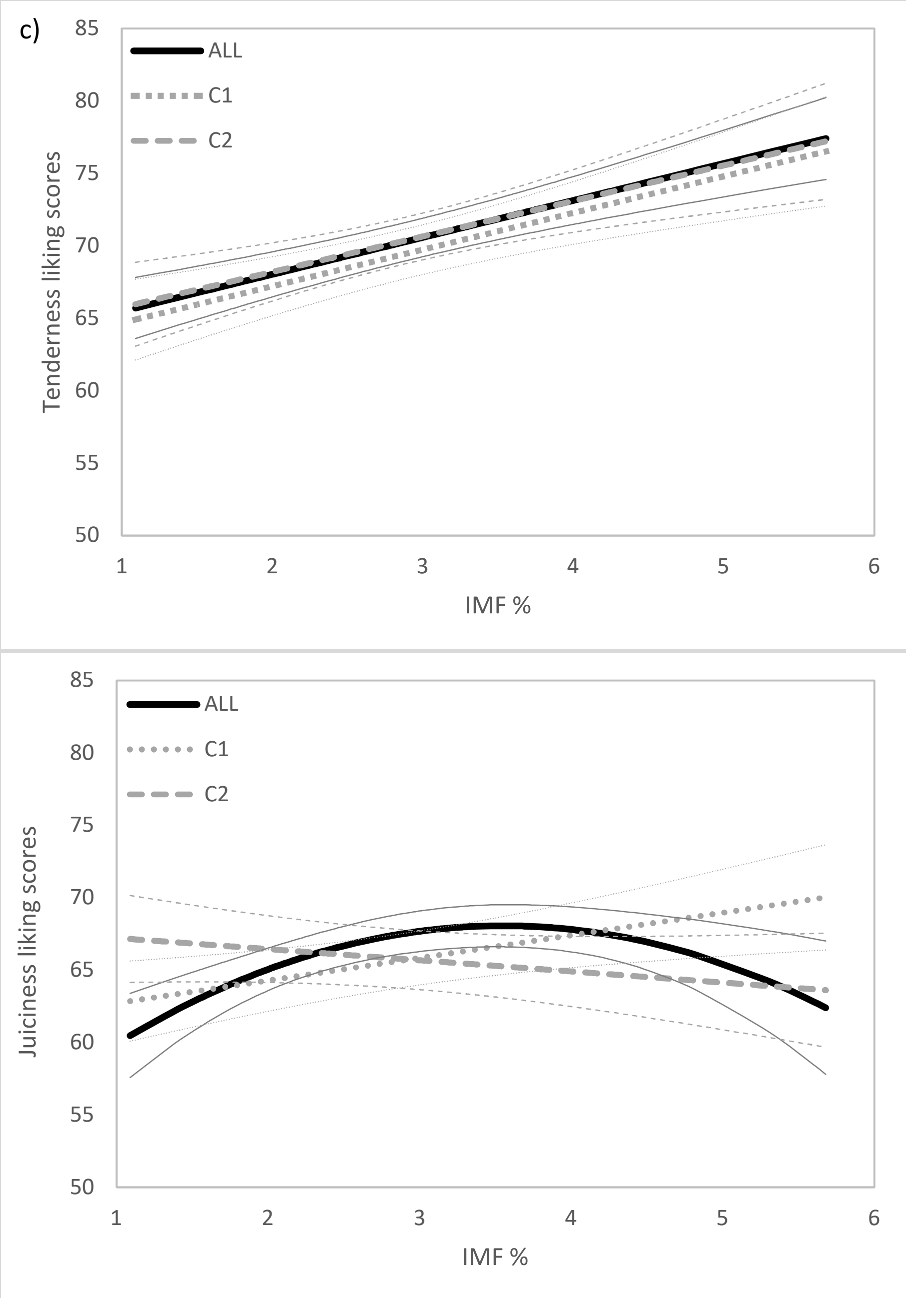


Figure 2. Relationships between overall (a), flavour (b), tenderness (c) and juiciness (d) consumer liking scores with loin intramuscular fat percentage (IMF%) for all consumers (ALL) and for consumers in Cluster 1 (C1) and 2 (C2). Lines represent least-square means (± S.E.) for the consumer liking scores across the IMF% range.