



# Sensory and volatile aromatic compound differences of paired lamb loins with 0 or 14 day dry aging

Kayley Wall, Chris Kerth, Rhonda Miller, Jane Boles

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2 aging

3 Wall, Kayley<sup>bb</sup>, Kerth, Chris<sup>a</sup>, Miller, Rhonda<sup>a</sup> and Boles, J.A.<sup>cc</sup>

4 Affiliation:

5 <sup>a</sup>Texas A&M University, College Station, TX; [c-kerth@tamu.edu](mailto:c-kerth@tamu.edu); [rmiller@tamu.edu](mailto:rmiller@tamu.edu)

6 Cargill Innovation Center, Wichita, KS; [Kayley\\_Wall@cargill.com](mailto:Kayley_Wall@cargill.com)

7 <sup>c</sup>Montana<sup>c</sup> State University, Bozeman, MT; [jboles@montana.edu](mailto:jboles@montana.edu); corresponding author

8 Highlights

- 9 • Loins with or without dry aging resulted in a similar flavor and volatile profile
- 10 • Aging increased tenderness of the loin samples.
- 11 • A tendency for increased mutton and green flavors was observed with dry aging.
- 12 • Dry aging for 14d can improve tenderness without negatively impacting flavor.

13

14 Abstract

15 Flavor of lamb is a major driving factor in eating satisfaction. Dry aging has been used in beef to  
16 alter flavor and tenderness. The objective of the research was to determine what affect dry aging  
17 had on flavor attributes and the volatile compounds that influence the perception of flavor. Lambs  
18 (n = 10) were fed an alfalfa-based concentrate diet for 60 d prior to harvest. Loins were obtained  
19 from both sides of the carcass and randomly assigned to an aging treatment; no age (boned and  
20 frozen day 0) or 14 d of dry age in cold storage (4°C, 55%RH). Descriptive flavor profile panel  
21 evaluated samples and volatile compounds were analyzed from cooked samples. No differences  
22 were detected by descriptive flavor panel between fresh and dry aged loin chops for most flavor  
23 attributes. However, aged loins were rated saltier than loins not aged. Additionally, aged loin chops

24 tended to have a greater intensity score for mutton and green attributes. Aldehydes were the  
25 greatest proportion of the volatile aroma compound chemical classification recovered and  
26 identified from the lamb samples. Dry-aged lamb loins yielded greater thiobis-methane (a  
27 sulfurous, fishy aroma) than loins without ageing. As expected, muscle fiber tenderness as  
28 evaluated by sensory panel was greater for aged loin chops than no age (12.7 and 10.0,  
29 respectively). Aged loin chops tended to be juicier as well. Aging in aerobic conditions for up to  
30 14 d can improve tenderness in lamb without significantly impacting flavor, however, there is a  
31 tendency to increase the mutton and green flavors with dry aging.

32 Keywords: ovine, lamb, flavor, volatile compounds

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41 Introduction

42 Flavor is a major contributor to lamb eating satisfaction. Consumer surveys in the United  
43 States indicate that flavor is one of the major drivers of the purchase of lamb (Wall and Kerth.  
44 2016). Reports from abroad have also indicated that flavor is an important factor in consumer  
45 acceptance of lamb (Pleasants et al., 2005; Pethick et al., 2006). In many parts of the world, the  
46 distinct species flavor of sheepmeat has been identified as one of the main reasons for low

47 consumption of the product (Batcher et al., 1969; Cramer, 1983; Sink and Caporaso, 1977; Jones  
48 et al., 1988).

49 Inconclusive information has been reported on the effects of breed, sex, diet and age on  
50 sheepmeat flavor. Discrepancies with type of sensory panels used and panelist makeup has in  
51 part contributed to the varied results regarding lamb flavor outcomes. Differences in palatability  
52 and acceptability of lamb differ both within and between human populations (Griffin et al., 1992;  
53 Hopkins et al. 1995; Prescott *et al.* 2001) which in turn can influence taste panelists ratings and  
54 account for differences observed between studies. Crouse (1983) concluded the profile method  
55 or descriptive panels must be used in lamb flavor research if definitive observations are to be  
56 made.

57  
58 Using flavor profile panels and analysis of volatile compounds with gas chromatography  
59 and mass spectrometry, researchers have identified specific compounds that are responsible for  
60 specific flavor notes. Branched chain fatty acids, 4-methyloctanoic (MOA), 4-methylnonanoic  
61 acid (MNA) and 4-ethyloctanoic acid (EOA), have been linked to “mutton” flavor (Young et al.,  
62 2003; Watkins et al., 2013; 2014). Furthermore, these compounds have been associated with meat  
63 from older animals (Rousset-Akrim et al., 1997) and ones receiving grain-based finishing diets  
64 (Young et al., 2003). However, this process can be complicated by management practices.  
65 Salvatore et al., (2007) reported higher levels of MOA in meat from younger lambs (8 months)  
66 compared to older sheep (22 months). Additionally, Watkins et al., (2010) evaluated 533 sheep  
67 from commercial harvest facilities for MOA, EOA and MNA. They found that branched chain  
68 fatty acids increased with age, but it was not consistent enough to be able to use the compounds to  
69 identify carcasses as lamb, hogget (yearling lamb in Australia) and mutton. This indicates that  
70 older animals may not result in meat with strong flavors. Young et al., (2003) concluded that the

71 variation of branched chain fatty acids reported in the literature within and between trials is likely  
72 due to diet, age, sex and breed effects.

73 In beef, tenderness is a major driver of overall liking and consumer acceptance (Toldra,  
74 1998). Post-mortem aging is a common practice in the beef industry and is effective at increasing  
75 consumer scores for tenderness (Watanabe et al., 2015). Though, a balance must be achieved to  
76 reach a tenderness threshold without curation of off flavors. Recently the increased demand for  
77 grass-finished beef has challenged the industry to find ways to reduce the negative perceptions of  
78 tenderness and flavor of the product (Bowling et al., 1977; Santin et al., 2021). Sensory panelists  
79 often use terms like “fishy,” “gamey,” “grassy” or “milky” to describe grass-fed beef products in  
80 contrast to using “beef-fat” for grain-fed beef ([Larick & Turner, 1990](#); [Melton et al, 1982](#)). [Chail](#)  
81 [et al. \(2016\)](#) reported that grass-fed beef had lower flavor liking, overall liking and perceived  
82 quality, when compared to grain-fed beef. One approach to improve tenderness and flavor  
83 perception is to incorporate dry aging into the system. Berger et al., (2018) reported that dry aging  
84 could improve the eating quality attributes of grass-fed beef loins with low marbling. Incorporation  
85 of dry aging in a lamb production system could result in improvement of flavor of meat from  
86 strong flavored carcasses.

87 Literature is sparse on the impact dry aging practices of sheepmeat, on flavor but Gürbüz  
88 (2022) reported differences in flavor, juiciness, tenderness and overall acceptability of loin  
89 samples between 0 and 7 d of aging but saw no difference between 7 and 14 d of aging. In contrast,  
90 Hastie et al. (2022a) reported aging method had no effect on consumer acceptability of longissimus  
91 thoracis and semimembranosus samples from mutton. Further analysis of the data combining  
92 hierarchical clustering and preference mapping found there were clusters of consumers that had  
93 different preferences for sheepmeat flavor (Hastie et al., 2022b). Altering the flavor by dry aging

94 could allow for categorizing specific types of sheepmeat and could improve the ability to meet  
95 expectations of the consumer. Therefore, the objective of this study was to determine the flavor  
96 and texture differences between paired fresh and 14-d dry-aged lamb loin chops.

97

## 98 *Materials and Methods*

99         This research was approved by the Texas A&M University Institutional Research Board  
100 (IRB2017-0618) and Montana State University Agricultural Animal Care and Use Committee  
101 (2019-AA10). South African Meat Merino cross lambs (n = 10) were selected at weaning. They  
102 were fed a diet of free choice hay for 2 weeks to acclimate to the pen, and then were started on a  
103 full diet of commercial alfalfa pellets (crude protein 16.9%, calcium 1.26%, phosphorus 0.54 % salt  
104 >0.5<1.0%, selenium  $\geq 0.37$  ppm, Vitamin A  $\geq 2,000$  IU / lb, Vitamin D  $\geq 200$  IU / lb, Vitamin E  
105  $\geq 50$  IU / lb) for 60 d prior to harvest. Animals were harvested at a small commercial plant, chilled  
106 overnight before collection of loins. Carcass data was collected by an experienced evaluator  
107 (carcass weight –  $26 \pm 2$  kg, fat thickness –  $0.27 \pm 0.04$  cm, ribeye area –  $14.6 \pm 1.3$  cm<sup>2</sup>) and  
108 ultimate pH of the loins was determined with a Hanna portable pH meter fitted with an Orion spear  
109 probe. All carcasses achieved an ultimate pH of  $5.6 \pm 0.05$ . Loins were obtained from both sides  
110 of the carcass and randomly assigned to an aging treatment; no age (boned, vacuum packaged and  
111 frozen on day 0) or 14 d dry aging (bone in) in cold storage (average temperature of  $3.3 \pm 0.09$  °C,  
112  $55 \pm 5.8\%$  relative humidity). After aging, loins (n = 10) were boned, vacuum packaged and frozen  
113 whole. Both aged and non-aged loins were shipped to College Station, TX for sensory and volatile  
114 compound analysis. Loins were cut from frozen into 1.9 cm-thick chops, labeled, and individually  
115 packaged. Prior to analysis, samples were thawed at 4°C overnight.

116 Loin chops (1.91-cm thick) were cooked on a 2.54-cm-thick flat top Star Max 536TGF 91 cm  
117 Countertop Electric Griddle (Star International Holdings Inc. Company, St. Louis, MO) set to 232  
118 °C. Chops were placed on the grill, turned when the internal temperature reached 35 °C and  
119 removed when the internal temperature reached 71 °C. Internal chop temperatures were monitored  
120 by iron-constantan thermocouples (Omega Engineering, Stanford, CT) inserted into the geometric  
121 center of the chop. Temperatures were displayed using an Omega HH501BT Type T thermometer  
122 (Omega Engineering, Stanford, CT).

123 After cooking, chops were cut into 1.27-cm x 1.27-cm x chop thickness cubes. Three cubes  
124 per sample were served in clear, plastic soufflé cups to panelists. Samples were identified with  
125 random three-digit codes, arranged in random serving order, and cut and served immediately to  
126 assure they were approximately 37°C upon time of serving. During evaluation, panelists were  
127 seated around a benchtop, and asked to evaluate each sample individually. After panelists  
128 evaluated a single sample, a consensus score was agreed upon and used in subsequent statistical  
129 analyses (consensus sensory analyses; AMSA, 2016).

130 An expert beef flavor descriptive attribute taste panel comprised of six panelists was trained  
131 for 100 h (AMSA, 2016) on 16 major attributes (listed in Table 1), 4 other attributes, and 3 texture  
132 attributes from the beef lexicon (Adhikari et al., 2011) for six days prior to testing. Panelists were  
133 trained to scale for each attribute on a sixteen-point intensity scale (0 = none, 15 = extremely  
134 intense) according to AMSA (2016). Panelists were validated prior to testing (Kerth et al., 2023).  
135 This panel was retrained using the lexicon with the addition of attributes for lamb identity, mutton,  
136 and lanolin flavors (0 = none and 15 = extremely intense) for 14 d. Prior to the start of each trained  
137 panel evaluation day, panelists were calibrated using one orientation sample of ground lamb that  
138 was evaluated and discussed orally (Kerth et al., 2023). After training, panelists evaluated eight

139 samples per session with a minimum of five minutes between each sample and a break given after  
140 the fourth sample. Each panelist was given as much time as they needed to complete the descriptive  
141 analysis of each sample. Two sessions were conducted per day. Double-distilled water and saltless  
142 soda crackers were available for cleansing the palette between samples.

### 143 *Gas Chromatography/Mass Spectrometry*

144 After chops were cooked, all external fat was removed, and each chop was cut into pieces as  
145 done for sensory panel evaluation (1.27-cm × 1.27-cm × chop thickness cubes). Pieces were quick  
146 frozen in liquid nitrogen and stored (-80°C) until analysis (Kerth et al., 2023). These pieces (5g)  
147 were placed in a 20-mL glass vial with a Teflon septum lid, spiked with 10 uL of 1,3-  
148 dichlorobenzene solution (2.5ug/uL) as an internal standard. Samples were then placed in an  
149 electric heating block (Satandard Analog Heat ing Block, VWR, Radnor, PA) and held at 65°C.  
150 The volatile compounds present in the headspace were collected using a solid-phase micro-  
151 extraction (SPME) portable field sampler (Supelco 504,831, 75 µm carboxen/  
152 polydimethylsiloxane, Sigma-Aldrich, St. Louis, MO) for 20 min (Kerth et al., 2023). Upon  
153 completion of collection, the volatiles were eluted from the SPME and separated using gas  
154 chromatograph (GC; Agilent Technologies 7920 series GC, Santa Clara, CA) where the sample  
155 was desorbed at 280°C for 3 min. The sample was loaded onto a gas chromatograph fitted with a  
156 column (30 m × 0.25 mm ID/ BPX5 [5% phenyl polysilphenylene-siloxane] × 1.0 µm, SGE  
157 Analytical Sciences, Austin, TX) using helium as the carrier gas at 1.0 mL/min. The GC  
158 temperature started at 40°C for 1 min and increased at a rate of 20°C/min until reaching 250°C  
159 then 20°C/min to 250°C. Compounds were identified and quantified with a mass spectrometer  
160 (MS; Agilent Technologies 5975 series MS, Santa Clara, CA) for relative quantification and  
161 identification, using the NIST Chemical Library. (Kerth et al., 2023)

162 *Statistical Analysis*

163 Data were analyzed using JMP Pro 15 software (SAS Inc.). Expert panel data were  
164 analyzed as paired data between fresh and aged loin effects. For expert sensory panel, panelist  
165 and serving order were analyzed as random effects using a mixed model analysis. The variance  
166 found among testing day and panelist were tested and found to not be a significant source of  
167 variability ( $P > 0.05$ ), so those factors were averaged and the mean testing day/panelist value for  
168 each expert sensory descriptor within a replication was used for further analyses of treatment  
169 effects. Least squares means for main effects were generated and separated using Fisher's  
170 protected LSD when a significant ( $P < 0.05$ ) F-test was found. GC/MS data were normalized  
171 against the internal standard, calculated as mg/g of sample, and analyzed by 2 sample comparison  
172 of loin effect with 2 technical replications of the GC/MS analysis. A predetermined significance  
173 level of 0.05 was used for all comparisons. Multivariate relationships were investigated using  
174 Pearson's correlations between sensory and volatile data. A principal component analysis (on the  
175 correlations) was employed using sensory attributes and aldehydes to explore multivariate  
176 correlations amongst the samples. Significant components were described as a result of Bartlett's  
177 test.

178 *Results and Discussion*

179 Flavor is a very complex attribute to measure as it encompasses both basic tastes and  
180 volatile compounds to influence the palatability of meat (Calkins and Hodgen, 2007; Kerth and  
181 Miller, 2015). Furthermore, cooking adds other flavor components from Maillard reaction,  
182 Strecker degradation and proteolysis (Hastie et al., 2022c). Further complicating the issue in lamb,  
183 is different consumer preferences (Hastie et al. 2022b). Thus, consumer preferences are important  
184 to consider when evaluating lamb flavor. In this study comparing dry aging to no aging of young

185 lamb, no differences ( $P > 0.05$ ) were detected between dry and no aged loin chops for most flavor  
186 attributes (Table 2). Salty was the only attribute that was identified as being significantly ( $P <$   
187  $0.05$ ) different when comparing dry aging to no aging (1.9 and 1.5, respectively). However, aged  
188 loin chops tended ( $P < 0.10$ ) to have a greater intensity score for mutton and green attributes than  
189 loin chops that had not been aged. Similarly, Hastie et al., (2022a) reported no improvement in  
190 mutton flavor due to dry aging when flavor was evaluated by consumers. This could be  
191 confounded because certain consumer groups prefer strong sheepmeat flavors (Hastie et al.,  
192 2022b). In contrast, Insausti et al. (2021) identified a reduction in livery and bloody flavor upon  
193 aging of longissimus thoracis from Navarra lambs for four days compared to one day. Gürbüz et  
194 al., (2022), also reported significant differences in flavor scores between 7 day aged loin samples  
195 and no age. However, these researchers utilized a 10-point Hedonic scale indicating like - dislike  
196 for flavor so individual flavor notes could not be identified. Wang et al (2022) reported different  
197 results for lamb when the relative humidity during dry aging was different suggesting aging  
198 conditions are important to the flavors developed.

199 Unlike data reported for beef (Li et al. 2014), umami taste did not increase with dry aging  
200 in chops from young sheep. In a review, Dashdorj et al., (2016) indicated numerous workers  
201 reported the flavor of dry aged beef was more intense with the flavors typically described as beefy,  
202 buttery rich, nutty, and/or earthy flavor profiles. This concentration of flavors could be influenced  
203 by the loss of moisture during dry aging. Dry aged loins lost an average of  $10.4 \pm 0.7$  % of the  
204 beginning weight of the loin. Similar losses were reported by Ribeirio et al. (2021) for dry-aged  
205 beef striploins. This loss of weight could concentrate some tastes like salt while the time of aging  
206 could contribute to differences in perception of other flavors. Our data shows little impact of dry  
207 aging on the flavor of loin chops from bone in loins aged for 14 days. Differences in results for

208 dry aging of lamb could be influenced by strong flavor existing in the meat before aging which  
209 can be influenced by age, breed or feeding regime. Total time of dry aging as well as drying  
210 conditions could also impact results. Aging lamb loins for 14 d post-mortem increased saltiness  
211 of the meat; however, increased dry aging time further may increase green and mutton-like off  
212 flavors. More research should be completed to understand the occurrence of these flavor attributes  
213 in association with aging time.

214 As expected, muscle fiber tenderness as evaluated by sensory panel was greater ( $P < 0.001$ )  
215 for aged loin chops than chops that had not been aged (Table 2, 12.7 and 10.0, respectively).  
216 Connective tissue was also perceived as being greater ( $P < 0.001$ ) for aged loin chops (11.7 and  
217 12.8, respectively). Aged loin chops tended to be juicier ( $P < 0.10$ ) as well. Thompson et al.  
218 (2005) studied the effects of physiological age of lamb, carcass suspension method, temperature  
219 at pH of 6.0 and post-mortem aging time (2, 5, or 14 d) on different lamb muscles. Although,  
220 temperature at pH of 6.0 was the most important factor on consumer perception of tenderness,  
221 aging time did increase tenderness liking slightly. Martinez-Cerezo et al. (2005) also reported  
222 tenderness increased with increased ageing time, with optimal differences occurring at 4 d and no  
223 detriment past 16 d. Sensory panelists indicated the presence of more connective tissue upon aging  
224 (Table 2). In contrast, Nishimura et al (1998) reported a decrease in raw shear force value of  
225 intramuscular connective tissue upon aging. However, it has been reported that this degradation  
226 of collagen during aging is not detectable after cooking (Purslow, 2005). A possible explanation  
227 for the sensory panel detecting more collagen could be the decrease in moisture that results from  
228 the dry aging process.

229 Of the volatile compounds ( $n = 40$ ), aldehydes were the greatest proportion of chemical  
230 classification recovered and identified (30% of total compounds). Other researchers have

231 identified 33-43 volatile compounds from lamb (Almela et al., 2010; Vasta et al., 2012; Bueno et  
232 al., 2014; Bravo-Lamas et al., 2018). Xiao et al. (2020) also found aldehydes to share the greatest  
233 proportion of volatiles in lamb meat. Additionally, aging time increased the abundance of  
234 aldehydes, alcohols and hydrocarbons in lamb meat aged up to 7d. Contradictorily, Callejas-  
235 Cardenas et al. (2014) reported a decrease in the sum of aldehydes (hexenal, heptanal, octanal, and  
236 nonenal) in aged lamb meat; however, the study was conducted under anaerobic conditions. Wet  
237 (anaerobic) aging has been reported by several researchers to result in different flavor development  
238 when compared to dry aged meat (Parrish et al., 1991; Warren and Kastner, 1992; Li et al., 2014).

239 Dry aged lamb loins yielded more than three times greater ( $P = 0.037$ ) thiobis-methane  
240 than loins without ageing (Table 3). This compound has been associated with a sulfurous, creamy,  
241 tomato odor (Burdock, 2010) but also with cabbage and corn flavor notes (Jones et al., 2022). No  
242 differences were detected ( $P > 0.10$ ) between aging conditions for other volatiles identified. A  
243 trend was identified for both “green flavor” and “mutton” ( $P=0.09$ ) by the expert sensory panel.  
244 Volatile compounds that were identified in the samples that could contribute to the “green flavor”  
245 are thiobis-methane (higher,  $P=0.037$ ), hexanal (higher,  $P=0.98$ ), octanal (higher,  $P=0.5$ ),  
246 acetaldehyde (higher  $P=0.9$ ), 2 pentyl furan (higher,  $P=0.18$ ), and 2-methyl butanal (higher,  $P=0.2$ )  
247 (Calkins and Hodgen, 2007; Kerth and Miller, 2015). Only, thiobis-methane was significantly  
248 higher after aging, however, different volatile compounds have different thresholds so small  
249 differences in compounds and multiple compounds together could contribute to the detection of  
250 the “green flavor”. Branched chain fatty acids are often associated with mutton flavors (Young et  
251 al., 2003; Watkins et al., 2013; 2014). The expert panel did identify a tendency ( $P=0.09$ ) for an  
252 increase in mutton flavors, however, the main branched chain fatty acid associated with the mutton  
253 flavor, 4-methyl octanoic acid (MOA) was not identified in the volatile compounds. All lambs

254 were less than one year old and had been fed the same diet. This could contribute to the lack of  
255 differences, or no MOA being identified in the samples from no and dry aged samples.  
256 Furthermore, the loss of weight during aging could concentrate the flavor of the lamb.

257 Variation between loins aged for no and 14d was further examined using principal  
258 component analysis (PCA) in order to identify multivariate correlations of sensory attributes and  
259 aldehyde volatile compounds (Figure 1). Components one and two of the PCA were able to  
260 account ( $P < 0.01$ ) for 22% and 12.7%, respectively, of the variation within the data set. The lack  
261 of differentiation of samples into quadrants or groups signifies the similarity between the two  
262 sample sets for flavor attributes and presence of aldehydes. Table 4 defines the coefficients for  
263 the eigenvectors of the PCA components. Juiciness, muscle fiber tenderness, connective tissue,  
264 green, fat-like, bloody/serummy, and metallic were the major positive contributors of component 1;  
265 whereas cardboardy, musty/earthy, brown, and roasted were the major negative contributors. Salty,  
266 sweet, umami, lanolin/animal hair, pentanal and 2-methyl-butanal were the major positive  
267 contributors of component 2, and bloody/serummy and octanal were the major negative drivers.  
268 Thus, while the two groups did not differ greatly, aldehyde differences may be significant  
269 indicators of product quality and should be investigated further.

#### 270 *Conclusion*

271 Dry aging lamb loins resulted in a similar flavor and volatile profile as those not aged, but  
272 aging increased tenderness of the loin samples. Aging in aerobic conditions for up to 14 d can  
273 improve tenderness in lamb without negatively impacting the flavor. However, there is a tendency  
274 to increase the mutton and green flavors with dry aging suggesting a need for further study.

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277 Table 1. Definitions and references for trained panel descriptive attributes and scaling intensities.

Attribute	Definition	References
Lamb identity	Amount of lamb identity in the sample	Knorr Lamb Stock Cubes = 3.0 Lean Ground Lamb = 6.0 Lamb broth sample (from crockpot) = 7.0
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Bitter	The fundamental taste factor associated with a caffeine solution.	0.2g of 200mg caffeine pill = 2.0 1 whole 200 mg caffeine pill = 3.5 1 whole and 0.2g 200mg caffeine pills = 5.0
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.045% citric acid solution = 3.0 0.065% citric acid solution = 5.0
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% Accent flavor enhancer solution = 7.5
Fat-like	Aromatics associated with cooked animal fat.	Hillshire Farms Lit'l Beef Smokies = 7.0 80% Lean Ground Lamb = 6.0 Lamb suet (Seared) = 10.0
Brown	A round, full aromatic generally associated with lamb suet that has been broiled.	Lamb suet (Seared) = 7.0 80% Lean Ground Lamb = 4.0
Roasted	A round, full aromatic generally associated with lamb that has been broiled/roasted.	Lamb Crock Pot Roast = 11.0
Metallic	The impression of slightly oxidized metal, such as iron, copper, and silver spoons.	0.10% Potassium Chloride Solution = 1.5 Lamb leg steak grilled to 58°C = 5.0 Dole Canned Pineapple Juice = 6.0
Liver-like	Aromatics associated with cooked organ meat/liver.	Beef Liver (broiled) = 12.0 Braunschweiger liver sausage = 10.0
Cardboardy	Aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging.	Dry Cardboard = 5.0 Wet Cardboard = 7.0
Bloody/Serumy	The aromatics associated with blood on cooked meat products, closely related to metallic aromatic.	Lamb stew pieces grilled to 63°C = 6.0 Leg steak grilled to 63°C = 3.0
Musty-Earthy	Musty, sweet, decaying vegetation.	Sliced button mushrooms = 3.0 Le Nez Du Café No. 1 = 8.0

Lanolin/Animal Hair	The aromatics perceived when raw wool is saturated with water; a sweet, oily aromatic off-flavor associated with lamb.	Raw wool = 4.0 Bag balm = 9.0
Mutton	Strong, musty, gamey aromatics characteristic of meat from older sheep.	Chopped fresh sage = 2.0 Wool from 2 year old Angora billy = 6.0 4-methyloctanoic acid (200 uL on cotton ball in snifter) = 10.0
Green	Sharp, slightly pungent aromatics associated with green/plant/vegetable matters such as parsley, spinach, pea pod, fresh cut grass, etc.	Fresh parsley water = 9.0
Juiciness	The amount of perceived juice that is released from the product during mastication.	Carrot = 8.5 Mushroom = 10.0 Cucumber = 13.5 Apple = 13.5 Watermelon = 15.0 Beef strip loin grilled to 58°C = 9.0 Beef strip loin grilled to 80°C = 4.0
Muscle Fiber Tenderness	The ease in which the muscle fiber fragments during mastication.	Beef eye of round steak cooked to 70°C = 4.0 Beef strip loin cooked to 70°C = 8.0 Beef tenderloin cooked to 70°C = 14.0
Connective Tissue	The structural component of the muscle surrounding the tissue amount during mastication.	Beef brisket steak cooked to 70°C = 4.0 Beef tenderloin cooked to 70°C = 11.0

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280 Table 2. Least Squares Means differences of consensus trained sensory panel scores for lamb  
 281 loin chops with no or 14 d post-harvest aging time.

Attribute	No Age	14d Age	SEM	<i>P</i> – Value
Lamb Identity	3.6	3.8	0.24	0.55
Brown	7.9	7.6	0.43	0.43
Roasted	5.8	5.3	0.39	0.26
Salty	1.5 <sup>b</sup>	1.9 <sup>a</sup>	0.18	0.042
Sweet	1.7	1.7	0.17	0.77
Bitter	3.0	3.1	0.25	0.70
Sour	2.6	2.5	0.15	0.33
Umami	3.5	3.7	0.22	0.51
Fat-like	1.3	1.6	0.20	0.24
Bloody/serumy	2.3	2.2	0.22	0.51
Metallic	2.6	2.5	0.23	0.67
Live-like	0.1	0.2	0.14	0.49
Cardboardy	3.0	3.0	0.32	1.00
Musty/Earthy	3.3	3.2	0.18	0.42
Lanolin/Animal Hair	1.7	1.7	0.22	0.82
Mutton	0.6	1.0	0.20	0.09
Green	1.1	1.5	0.22	0.09
Juiciness	8.2	8.9	0.38	0.09
Muscle Fiber Tenderness	10.0 <sup>b</sup>	12.7 <sup>a</sup>	0.45	< 0.001
Connective Tissue	11.7 <sup>b</sup>	12.8 <sup>a</sup>	0.88	< 0.001

282 \*Standard error

283 <sup>a,b</sup>Means in the same row with different superscripts differ significantly (*P* < 0.05).

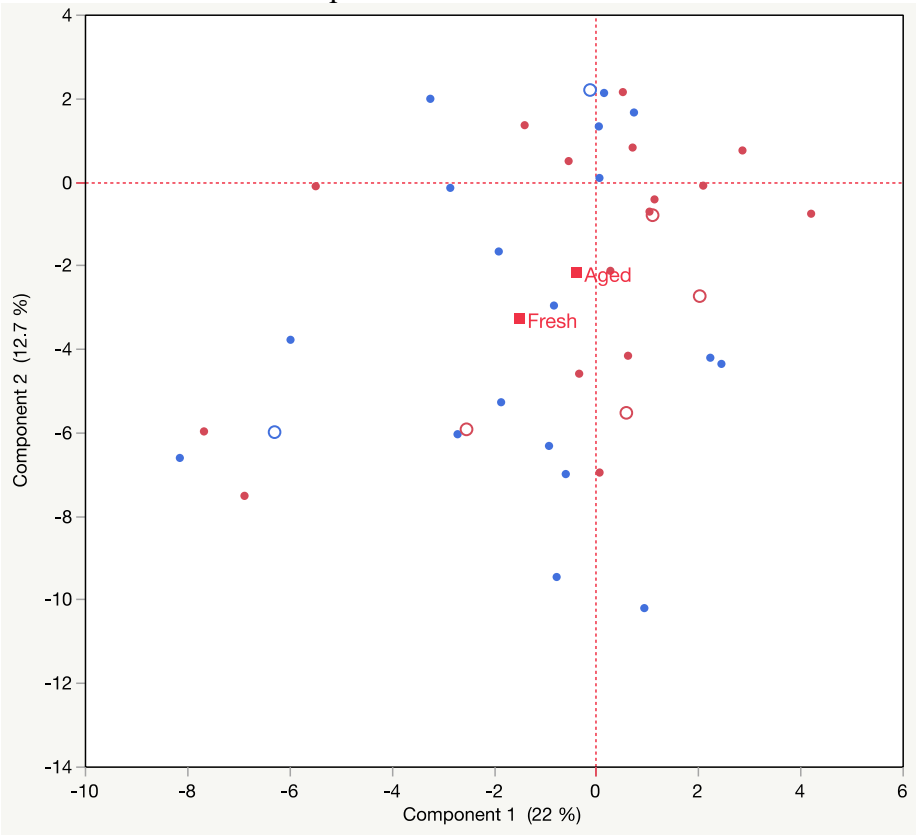
284 Table 3. Least Squares Means for volatile organic compounds (mg/100g of meat) identified in  
 285 lamb loin chops with no or 14d post-harvest aging time.

Volatile	No Age	14d Age	SEM	<i>P</i> -Value	n**
2-ethyl-3-methyl-pyrazine	0.6	0.9	0.51	0.68	6
2-ethyl-3,5-dimethyl-pyrazine	0.4	0.9	0.33	0.32	17
2-methyl-butanal	25.7	46.7	11.46	0.20	37
2-methyl-propanal	4.7	8.9	3.13	0.34	14
2-methyl-2-propenoic acid, methyl ester	4.2	4.8	1.86	0.82	27
2-pentanone	1.7	1.8	0.63	0.91	27
2-pentyl furan	0.8	1.8	0.49	0.18	16
2-propanone	20.0	34.3	8.17	0.21	33
2,3-pentanedione	0.9	0.2	0.47	0.32	23
2,3,5-trimethyl-pyrazine	1.3	2.0	1.02	0.64	7
2,4-dimethyl-heptane	1.1	3.5	1.28	0.19	11
2,5/6-dimethyl-pyrazine	4.0	6.1	1.90	0.46	30
3-ethyl-2,5-dimethyl-pyrazine	0.1	1.3	0.49	0.37	14
3-hydroxy-4-butanone	2.0	5.6	2.08	0.22	7
3-methyl-2-pentanone	5.9	11.0	4.34	0.41	12
3-methyl-butanal	28.2	53.9	13.5	0.19	37
4-methyl-octane	1.7	2.3	0.59	0.42	21
Acetaldehyde	6.6	6.9	1.64	0.90	37
Benzaldehyde	3.5	5.9	1.36	0.22	34
Butanal	0.2	6.6	4.66	0.34	5
Carbon disulfide	90.7	114.7	27.70	0.54	38
Decane	2.8	3.1	0.61	0.78	28
Dodecane	3.5	3.8	0.74	0.76	25
Heptanal	16.1	16.6	3.47	0.93	38
Heptane	2.1	2.3	0.83	0.83	19
Hexanal	92.7	93.5	21.00	0.98	39
Hexane	52.7	56.2	2.64	0.92	24
Hexanoic acid, methyl ester	1.0	4.0	1.89	0.28	11
Iso-butyraldehyde	1.3	6.4	3.25	0.28	7
Methyl-benzene	2.3	3.0	1.24	0.71	18
Methyl-pyrazine	0.7	0.9	0.36	0.52	14
Nonanal	22.9	30.0	4.51	0.44	36
Nonane	0.2	0.7	0.17	0.058	20
Octanal	13.6	17.3	3.83	0.50	38
Octane	9.1	9.9	2.12	0.78	38
Pentanal	8.7	10.7	3.31	0.67	23
Thiobis-methane	1.9 <sup>b</sup>	6.1 <sup>a</sup>	1.35	0.037	25
Thiourea	1.6	2.9	1.25	0.46	10
Toluene	2.3	3.6	1.55	0.55	14

286 n = number of lamb samples that had that volatile present (n = 40 total possible; 10 lambs x 2  
 287 aging times x 2 technical replications)

288 <sup>a,b</sup>Means with different letters differ significantly (*P* < 0.05)

289 Figure 1. Principal component analysis using sensory and aldehyde results from lamb loins with  
290 no or 14d post-mortem age. Components 1 and 2 of the PCA accounted for 22% and 12.7%,  
291 respectively (Bartlett's test;  $P < 0.01$ ). Blue markers indicate a compound with a negative  
292 correlation and the red dots indicate a compound with a positive correlation to the statistical  
293 clusters marked with an open marker.



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296 Table 4. Coefficients of eigenvalues for sensory attributes and aldehydes contributing to the  
 297 significant variation of component 1 and 2 of Figure 1.

Attribute	Principal Component 1	Principal Component 2
Lamb ID	0.041	0.181
Brown	-0.264	0.092
Roasted	-0.252	0.237
Salty	0.088	0.334
Sweet	0.167	0.337
Bitter	-0.156	0.088
Sour	0.054	-0.101
Umami	0.111	0.326
Fat-Like	0.249	0.242
Bloody/Serumy	0.244	-0.257
Metallic	0.281	0.073
Liver-Like	0.086	-0.098
Cardboardy	-0.305	0.117
Musty/Earthy	-0.294	-0.022
Lanolin/Animal Hair	0.025	0.297
Mutton	0.042	0.183
Green	0.236	-0.117
Juiciness	0.321	-0.185
Muscle Fiber Tenderness	0.269	0.025
Connective Tissue	0.260	0.009
Log <sub>10</sub> (Pentanal)	0.065	0.257
Log <sub>10</sub> (Nonanal)	0.066	0.257
Log <sub>10</sub> (Acetaldehyde)	-0.006	-0.024
Log <sub>10</sub> (2-methyl-butanal)	0.199	0.234
Log <sub>10</sub> (Heptanal)	0.195	-0.070
Log <sub>10</sub> (Octanal)	0.052	-0.231
Log <sub>10</sub> (3-methyl-butanal)	0.092	0.133
Log <sub>10</sub> (Hexanal)	0.057	-0.076

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