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

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

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Highlights

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

Abstract

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

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

Keywords: ovine, lamb, flavor, volatile compounds

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Introduction

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

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

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

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

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

Materials and Methods

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

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

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

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

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

Gas Chromatography/Mass Spectrometry

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

Statistical Analysis

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

Results and Discussion

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

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

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

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

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

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

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

Conclusion

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

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	*P* – 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[b]	1.9[a]	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[b]	12.7[a]	0.45	< 0.001
Connective Tissue	11.7 [b]	12.8 [a]	0.88	< 0.001

282 *Standard error
283 [a,b]Means in the same row with different superscripts differ significantly ($P < 0.05$).

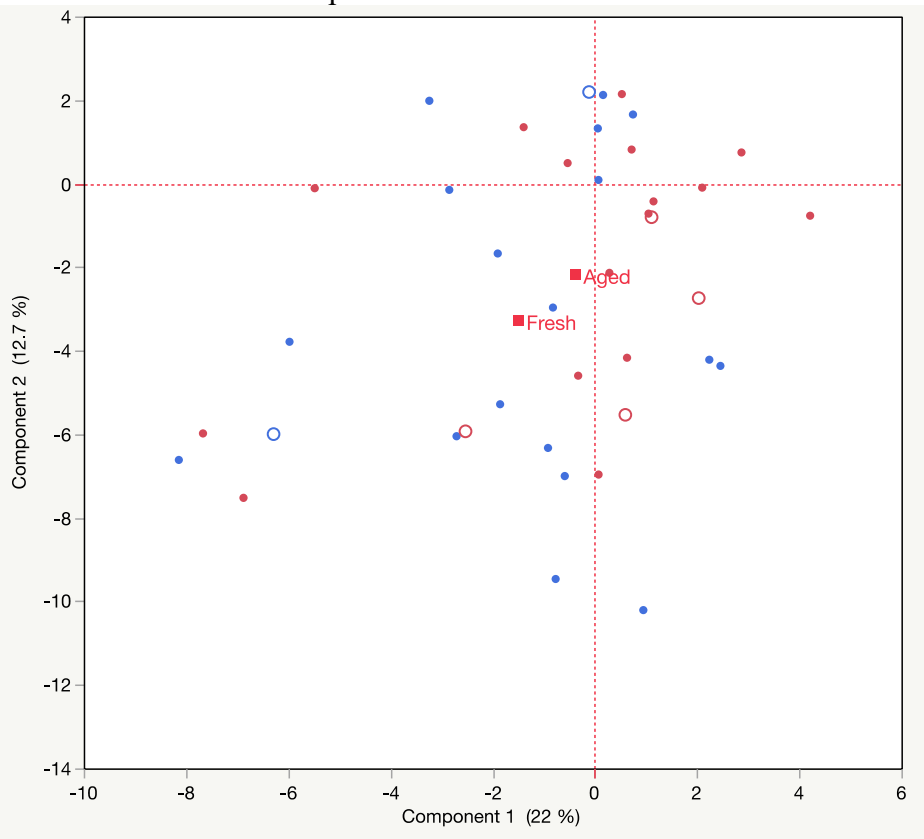
Table 3. Least Squares Means for volatile organic compounds (mg/100g of meat) identified in lamb loin chops with no or 14d post-harvest aging time.

Volatile	No Age	14d Age	SEM	*P*-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[b]	6.1[a]	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

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

[a,b]Means with different letters differ significantly ($P < 0.05$)

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



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_{10}(Pentanal)	0.065	0.257
Log_{10}(Nonanal)	0.066	0.257
Log_{10}(Acetaldehyde)	-0.006	-0.024
Log_{10}(2-methyl-butanal)	0.199	0.234
Log_{10}(Heptanal)	0.195	-0.070
Log_{10}(Octanal)	0.052	-0.231
Log_{10}(3-methyl-butanal)	0.092	0.133
Log_{10}(Hexanal)	0.057	-0.076

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