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Palatability Characterization of Fresh and Dry-Aged Ground Beef Patties

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Abstract: Descriptive trained sensory attributes, fatty acids, and volatile compounds were determined to characterize the effects of dry-aging on ground beef. Beef shoulder clods were ground to include 100% fresh beef, 100% dry-aged beef, and a 50% fresh and 50% dry-aged ground beef blend. Samples comprised of 100% dry-aged beef were rated greatest ($P < 0.001$) for browned/grilled, earthy/mushroom, and nutty/roasted-nut flavors; however, panelists also detected greater ($P \leq 0.011$) incidences of sour/acidic and bitter flavors. The addition of dry-aged beef increased ($P < 0.001$) hardness and reduced ($P < 0.001$) tenderness. Dry-aging also caused a shift in saturated fatty acids, where shorter chain saturated fatty acids ($\leq$ 16:0) were reduced ($P \leq 0.034$) compared to stearic acid (18:0). Meanwhile, increases of *trans*-octadecenoic acid (18:1 *trans*) and decreases of *cis* monounsaturated fatty acids were present in dry-aged beef. Concentrations of 18:2 conjugated linoleic isomers were greatest ($P < 0.001$) in fresh beef and decreased with the incorporation of dry-aged beef. Several lipid-derived volatile compounds were greater ($P < 0.05$) in dry-aged beef compared with fresh beef, implying a greater degree of lipid degradation among dry-aged beef. Increases ($P \leq 0.031$) were determined for 3- and 2-methyl butanal with the addition of dry-aged beef. Intermediates of the Maillard reaction, 2,3-butanedione and acetoin, were determined to be greatest ($P \leq 0.046$) from dry-aged beef. Alterations of fatty acids and volatile compounds with dry-aging were determined to be related with intensity of individual flavor attributes. Overall, it may be concluded that inclusion of dry-aged beef impacts flavor profile through altered fatty acid profiles and flavor related compounds. These results support the idea that dry-aging may be utilized to impart an altered ground beef flavor experience.

Keywords: flavor, fatty acids, sensory, texture, volatile compounds
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Introduction

Beef aging is a widely accepted process in which beef is stored at refrigerated temperatures to enhance eating characteristics. It is recognized that the aging process increases tenderness in beef; however, disagreement exists about the effect of aging on other palatability characteristics, including flavor (Warren and Kastner, 1992; Idolo Imafidon and Spanier, 1994; Campbell et al., 2001; Sitz et al., 2006; Laster et al., 2008; Smith et al., 2008). Multiple surveys have shown that American consumers generally consider aging a positive term, whether they understand the process or not (Laster et al., 2008; Smith et al., 2008). Dry-aging specifically refers to storing product unpackaged and exposed to oxygen in a controlled humidity and temperature setting (Campbell et al., 2001; Smith et al., 2008). It is often perceived as a premium product in the marketplace, receiving increased overall liking ratings from consumers and an increased willingness-to-pay (Laster et al., 2008, Kim et al., 2016). As a result, foodservice has marketed dry-aged products ranging from whole muscle cuts to ground beef burgers (Laster et al., 2008).

Multiple studies have reported no changes in flavor liking, juiciness, and overall acceptability between wet and dry-aged beef (Laster et al., 2008; Smith et al., 2008). This could suggest that average consum-

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ers are not able to differentiate flavor characteristics associated with dry-aged beef. However, in other studies, dry-aged beef has received greater ratings for beefy, brown/roasted, and nutty/roasted-nut flavors compared with wet-aged or fresh beef (Warren and Kastner, 1992; Campbell et al., 2001; Sitz et al., 2006; O'Quinn et al., 2016). Therefore, the objective of this study was to further characterize the impacts of dry-aging on beef palatability. To evaluate the effects of dry-aging, ground beef patties were formulated to include specific levels of dry-aged beef. Descriptive flavor attributes, texture, fatty acid profiles, and volatile compounds were evaluated to characterize potential differences.

Materials and Methods

Experimental treatments and sample preparation

Three blends of beef chuck shoulder clods were used to evaluate the effects of dry-aging on ground beef quality characteristics. Treatments were formulated to represent 100% fresh beef (FRESH), 100% dry-aged beef (DRY-AGED), and a blend of 50% fresh and 50% dry-aged beef (BLENDED). Vacuum packaged USDA Choice beef chuck shoulder clods (IMPS 114; $n = 30$), intended for dry-aging, were purchased from a commercial processing facility in Northern Colorado and transported under refrigeration (2°C) to the Colorado State University Meat Laboratory. Upon arrival, shoulder clods were first wet-aged for 21 d (stored in vacuum-sealed packages in the absence of light at 2 to 4°C). Following the 21-d wet-aging period, shoulder clods were transported to a commercial dry-aging facility where they were dry-aged on stainless steel racks without protective packaging and exposed to oxygen at 2°C and 80% relative humidity for an additional 21 d. USDA Choice shoulder clods (IMPS 114; $n = 30$) intended to represent fresh beef were obtained from the same processing facility and held in plastic lined combos for 4 d postmortem before blending and grinding. Significant differences in total days of age (4 d vs. 42 d) were utilized FRESH and DRY-AGED beef, respectively. These conditions were applied to mimic common commercial practices of formulating FRESH ground beef with minimal days of age. No product was frozen prior to blending and grinding.

At the end of the aging periods, shoulder clods were trimmed to remove excessive fat and cut into cubes equal to or smaller than 12.9 cm^2 for grinding. The hard, dry exterior layer was not trimmed from shoulder clods prior to grinding. For each treatment, 5 batches (replicates; 13.6 kg each) were created by randomly assigning 4 subprimals to each batch. Each subprimal was represented in each batch at equal weights. Twenty wet and dry-aged subprimals were used in formulation of FRESH and DRY-AGED patties, respectively. For BLENDED patties, 10 wet and 10 dry-aged subprimals were used in the formulation of batches. Each batch was ground using a grinder (Biro, Model 7552 L04, Marblehead, OH) equipped with a coarse grinding plate (1.27 cm). After coarse grinding, each batch was blended for 3 min in a double action mixer (Blentech, Model DM-10028-PVS, Rohnert Park, CA). During the first 1.5 min of mixing, pressurized CO_2 gas was continuously added to the mixer to simulate CO_2 chilling processes that are commonly used in large, commercial grinding operations. Following mixing, batches were ground a second time using the same grinder equipped with a fine grinding plate (3.175 mm). Each batch was then formed into 151-g patties (Formax F6, equipped with the 2874–6 plate, Mokena, IL). Each piece of equipment was rinsed between treatments, with the exception of the patty-forming device which was disassembled and cleaned between batches. Patties from each batch were separated and held in a CO2 blast freezer (Martin-Baron Inc., MBI 1–18–0002–19, Irwindale, CA) for no longer than 5 h. Frozen patties were placed in 3-mm think nylon vacuum pouches (Clarity Vacuum Pouches #75001839, Koch Supplies, Kansas City, MO), vacuum packaged (C 500, MULTIVAC, Wolfertschwenden, Germany). Patties from each batch were vacuum packaged, and placed in frozen storage (-20°C) until further analysis.

Descriptive sensory analysis

Sensory analysis was conducted at Colorado State University. Panelists were trained to detect various beef flavor characteristics using the lexicon developed by Adhikari et al. (2011) and objectively quantify the presence/absence of each flavor using an unstructured 10 cm line scale (Table 1). Panelists were trained throughout 10 sixty min sessions using attribute references outlined in Table 1, in addition to beef sample representative of experimental treatments. Samples designated for sensory analysis were randomly assigned to sensory sessions so that all treatments were represented in each panel. One panel session was conducted each day with 9 samples per session for a total of 5 panel sessions. Three technical replicates were served from each batch representing each of the 3 treatments per panel session. Prior to statistical analysis, each technical replicate was averaged to produce a single value for each batch. Samples were thawed for 12 to 24 h at 2°C before each sensory session.

Table 1. Flavor and texture sensory attributes, attribute description, and anchors used to train panelists prior to sensory analysis adapted from Adhikari et al. (2011) and O'Quinn et al. (2016)

Attribute	Attribute description	Attribute anchor
Flavor		
Beefy/ Brothy	The flavor associated with cooked beef; basic meaty flavor of unseasoned beef broth	Swanson's beef broth = 3.5 Beef brisket cooked to 71°C = 8.0
Browned/ Grilled	The flavor associated with grilled or broiled beef; caramelized	Beef suet (broiled) = 5.5
Buttery/ Beef Fat	The flavor and mouth-feel associated with melted, unsalted butter or beef fat	Beef suet (broiled) = 8.0
Bloody/ Metallic	The flavor associated with a very-rare steak; flavor associated with iron; similar to putting a penny in your mouth	USDA Choice strip steak cooked to 60°C = 3.5
Gamey	The intense flavor associated with wild game	Grass fed strip steak cooked to 71°C = 4.0
Earthy/ Mushroom	The flavor associated with fresh soil; musty	Raw mushroom = 4.0
Nutty/ Roasted-Nut	The flavor associated with nuts or roasted nuts	Unsalted roasted walnut = 3.5
Livery	The flavor associated with cooked beef liver and organ meats	Beef liver = 5.0
Sour/ Acidic	Sour/acidic A sour flavor and mouth-feel; tangy; fermented	0.015% citric acid solution = 10 0.050% citric acid solution = 25
Bitter	A bitter flavor.	0.02% Caffeine Solution = 25
Texture		
Hardness	The force required to break through with molars.	Yellow American Cheese = 3.0 Peanut = 7.0
Cohesiveness	The degree to which a chewed sample holds together.	Biscuit = 2.0 Frankfurter = 6.5
Tenderness	The overall tenderness of the sample.	Beef brisket cooked to 71°C = 3.5 Beef tenderloin cooked to 71°C = 9.0
Connective Tissue	The structural component of the muscle surrounding the muscle fiber that will not break down during mastication.	Beef tenderloin cooked to 71°C = 1.0 Beef brisket cooked to 71°C = 6.0
Particle Size	How large or small the particle is.	Small pearly tapioca = 4.0 Boba tea tapioca = 6.5
Moisture Content	The amount of perceived moisture that is released from the product during mastication.	Carrot = 4.5 Watermelon = 9.5
Beef Fat/Oily Mouthfeel	The perception of oil coating the mouth during mastication.	90% lean ground beef cooked to 71°C = 3.0 70% lean ground beef cooked to 71°C = 8.0

All samples were cooked on griddle pans (Cephalon Contemporary Non-Stick 11" Square Griddle) over open gas burners on a commercial range (Southbend 4602DD-2TR, Fuquay-Varina, NC). Pans were heated for 20 min prior to cooking (400°F). Patties were cooked to an internal temperature of 71°C monitored by a Type K Thermocouple Thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT). Following cooking, patties were cut into 8 wedge-shaped, equally sized portions and held in a warming box (Cambro MFR #: UPHC400110; 51.6°C) for no more than 15 min before being served to panelists.

Samples were served under red incandescent light to mask color variation among samples during 90 min panel sessions. Panelists were supplied with distilled water, apple juice, and unsalted saltine crackers to cleanse their palettes between samples. Panelists evaluated each sample for beefy/brothy, browned/grilled, buttery/beef fat, bloody/metallic, gamey, earthy/mushroom, nutty/roasted-nut, livery, sour/acidic, and bitter flavor attributes on a 10-cm unstructured line scale (0 = not present; 10 = very intense). Panelists also evaluated 7 texture characteristics, including hardness, cohesiveness, tenderness, connective tissue, particle size, moisture content, and beef fat/oily mouthfeel on the same 10 cm line scale (0 = very soft, crumbly, very tough, no presence, fine, very dry, and very low intensity; 10 = very hard, dense, very tender, very high intensity course, very moist, and very high intensity). After each panel session, individual panelist ratings were averaged to obtain a single panel rating for each sensory attribute of each sample.

Proximate analysis

Three patties from each batch within each treatment were frozen in liquid nitrogen and homogenized into a fine powder using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS).

After homogenization, samples were placed in Whirl-Pak bags (Nasco, Fort Atkinson, WI), individually labeled, and stored at -80°C until further analysis.

Total lipid was extracted from 1 g of sample using the methods described by Folch et al. (1957) and Bligh and Dyer (1959). After extraction, lipid extracts were dried under N_2 gas and placed into a 100°C drying oven for 3 h. Samples were then cooled to room temperature (22°C) in a desiccator. Once samples were cooled, they were weighed and percentage lipid was reported on a wet-weight basis. The total percentage of sample weight comprised of lipid was calculated by dividing the final weight of the remaining sample by the initial sample weight and multiplying by 100.

Moisture was analyzed using the AOAC Official Method 950.46 (AOAC, 2006). For each sample, 2 g was weighed into an aluminum tin (low form, aluminum, fluted; Fisher Scientific, Pittsburgh, PA) and placed in a forced air drying oven (Thelco lab oven, Mandel, Inc., Guelph, Ontario, Canada) set at 100°C for 24 h. After drying, samples were cooled to room temperature (22°C) in a desiccator. Samples were then re-weighed and percent moisture was reported as the difference between initial weight and final weight.

Nitrogen content was determined using the AOAC Official Method 992.15 (AOAC, 2006; Leco TruSpec CN or Leco FP-2000; Leco Corporation, St. Joseph, MI and Rapid N cube, Elementar, Hanau, Germany) and multiplied by 6.25 to determine crude protein content (Merrill and Watt, 1973). Ash was analyzed using the AOAC Official Method 923.03 (AOAC, 2006). For each sample, 1 g was weighed into a dry crucible. Crucibles were then set in a Thermolyne box furnace (Thermo Fisher Scientific, Pittsburgh, PA) which was set at 600°C for 24 h. After removal from the incinerator, samples were cooled to room temperature (22°C) in a desiccator. Samples were then re-weighed to obtain the ash percentage. The total percentage of ash was determined by dividing the sample weight in the crucible post-incineration by the initial weight and multiplying by 100.

Fatty acid analysis

For determination of fatty acids, total lipid was extracted from 1 g of homogenized sample as described above. Saponification and methylation of lipids to form fatty acid methyl esters (FAMES) was performed using the methods of Park and Goins (1994) and Phillips et al. (2010). Analysis of FAME was done by use of a Hewlett-Packard (Avondale, PA) Model 6890 series II gas chromatograph (GC) fixed with a series 7683 injector and flame ionization detector. The GC was equipped with a 100-m × 0.25-mm (i.d.) fused silica capillary column (SP-2560 Supelco Inc., Bellefonte, PA). Helium was used as the carrier gas with a flow rate of 2.0 mL/min. Column oven temperature increased from 40°C to 150°C at a rate of 8°C/min, held for 20 min at 150°C, and then increased from 150°C to 160°C at 0.5°C/min and from 160°C to 190°C at 0.2°C/min. The detector was maintained at 300°C and the inlet at 250°C throughout the run. Individual FAME were quantified as a percentage of the total amount of FAME identified. Fatty acid standards were obtained from Nu-Check Prep (Elysian, MN). Results were reported in units of g fatty acid per 100 g original sample.

Volatile analysis

Volatile compound analysis was conducted similar to Legako et al. (2015). One patty from each batch of each treatment was thawed and cooked according to the method previously described for sensory analysis. Immediately after cooking, 3 cores (1.3-cm in diameter) were collected from each sample using a Warner-Bratzler coring tool. A 3.5g (± 0.1g) sample from the cores was weighed and placed into a 15 mL clear glass vial (Supelco, Bellefonte, PA) and closed with a screw cap. Each vial was submerged to the neck in a 65°C water bath (Thermo Scientific, Waltham, MA) and allowed to equilibrate for 5 min. After an equilibration period, an 85-µm film thickness carboxen polydimethylsiloxane solid phase microextraction (SPME) fiber was used to extract the volatile compounds. The SPME fiber, contained in a manual SPME needle and holder (Supelco, Bellefonte, PA), was exposed to the headspace in the vial above the sample for 10 min. After 10 min of extraction, the SPME fiber was retracted into the needle and capped with a GC septum to prevent contamination from volatiles present in the atmosphere. Samples were held for no more than 3 h before injection into the GC.

Volatile detection was conducted on an Agilent 6890 series gas chromatograph (Agilient Technologies, Santa Clara, CA) equipped with a 5975 mass selection detector (Agilient Technologies). Before each sample was run, the GC column was focused to 0°C using liquid N_2 oven cooling (G1566A, Agilent Technologies). Once the column reached 0°C, the SPME fiber was injected into the GC inlet and the software program was started. The SPME fiber was exposed in the GC inlet for 5 min to allow the volatile compounds to be extracted onto the GC column. Extracted volatile compounds were separated using a VF-5ms capillary

column (30m × 0.25mm × 1.00μm; Agilent J&W GC Columns, Santa Clara, CA).

Ions within 33 to 500 m/z range were detected by the MS in the electron impact mode at 70 eV. Chromatography data was collected in the selective ion monitoring/scan mode (SIM/Scan; Agilent MSD Chemstation D.03.00.611 software, Agilent Technologies). Volatile compound identities were validated by authentic external standards (Sigma-Aldrich, St. Louis, MO), after initial identification by the MS library. A 7-point external standard method was used for quantification. Standard reference compounds were injected (0.1 μL) in solutions (0.15, 0.31, 0.62, 1.25, 2.50, 5.00, and 10.00 ng/μL) of pentane (late eluting compounds) or toluene (early eluting compounds) in splitless mode. Three target ions, 1 quantitative ion and 2 qualifying ions, of a compound of interest were selected for the comparisons of ion fragments between samples and standards.

Statistical methods

All analyses were conducted using statistical procedures of SAS (SAS Inst. Inc., Cary, NC). Treatment comparisons were tested for significance using generalized linear model procedures (PROC GLM). Least squares means were calculated for proximate analysis, sensory ratings, fatty acid profiles, and volatile compounds using treatment as the main effect, with differences determined at $\alpha = 0.05$. Panel session was initially included as a random effect, but only accounted for minimal variation and was removed from the model. Additionally, Pearson correlation coefficients were calculated to show relationships between sensory attributes, fatty acid composition, and volatile compound composition.

Results and Discussion

Proximate composition

Least squares means for percentages of lipid, moisture, protein, and ash are summarized in Table 2. Percent lipid did not differ among aging treatments ($P = 0.148$). However, percent moisture was affected by ground beef treatment ($P < 0.001$). DRY-AGED samples had the least ($P < 0.001$) and FRESH samples the greatest ($P < 0.001$) percent moisture. Sitz et al. (2006) found similar results, reporting that dry-aged strip loins contained less moisture than wet-aged strip loins. Furthermore, percent protein and ash of DRY-AGED beef was greater ($P = 0.013$) than both BLENDED and FRESH beef. Due to moisture loss during the aging process, dry-aged beef typically has a more concentrated protein and ash content (Wahrmund-Wyle et al., 2000). The results of this study clearly reflect a shift in beef composition due to moisture loss.

Table 2. Proximate analysis composition of raw ground beef from three aging treatments

Treatment[1]	Lipid, %	Protein, %	Moisture, %	Ash, %
Fresh	13.38	18.45[b]	66.07[a]	0.91[b]
Blended	14.13	19.50[b]	63.79[b]	0.95[b]
Dry-Aged	13.68	21.15[a]	62.26[c]	1.07[a]
SEM[2]	0.25	0.37	0.03	0.03
P-value	0.148	< 0.001	< 0.001	0.013

[a-c]Least squares means in the same column lacking a common superscript differ ($P < 0.05$).

[1]Treatments: Fresh (100% fresh beef); Blended (50% fresh beef, 50% Dry-aged beef); dry-aged (100% dry-aged beef).

[2]Standard error (largest) of the least squares means.

Flavor and texture attributes

Treatment effects on beef flavor attributes assessed by trained panelists are presented in Table 3. DRY-AGED beef was rated greater ($P \leq 0.011$) for browned/grilled, earthy/mushroom, nutty/roasted-nut, sour/acidic, and bitter attributes than FRESH beef. Brown/grilled flavors are often associated with compounds from the Maillard reaction, which occur on the surface of cooked beef. The Maillard reaction is inhibited by moisture (Kerth and Miller, 2015); thus, the lower moisture content of dry-aged beef may have provided a more favor-

Table 3. Beef flavor attributes[1] of cooked ground beef patties from three aging treatments

	Treatment[2]				
Attribute	Fresh	Blended	Dry-aged	SEM[3]	*P*-value
Beefy/ Brothy	6.49	6.75	6.68	0.08	0.054
Browned/ Grilled	6.28[b]	6.72[ab]	7.00[a]	0.13	0.001
Buttery/ Beef Fat	5.86[ab]	6.12[a]	5.70[b]	0.08	0.003
Bloody/ Metallic	0.09	0.00	0.03	0.03	0.086
Gamey	0.04	0.00	0.04	0.02	0.322
Earthy/ Mushroom	0.23[c]	1.07[b]	1.72[a]	0.12	< 0.001
Nutty/ Roasted-Nut	0.17[c]	0.94[b]	1.53[a]	0.11	< 0.001
Livery	0.03	0.05	0.13	0.04	0.147
Sour/ Acidic	0.05[b]	0.11[b]	0.42[a]	0.09	0.011
Bitter	0.07[b]	0.37[ab]	0.61[a]	0.11	0.005

[a-c]Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

[1]Trained panel sensory scores: 0 = not present; 10 = very intense.

[2]Treatments: Fresh (100% fresh beef); Blended (50% fresh beef, 50% dry-aged beef); Dry-aged (100% dry-aged beef).

[3]Standard error (largest) of the least squares means.

able environment for these flavors to develop. O'Quinn et al. (2016) found similar results, showing that dry-aged samples rated greater for browned/grilled flavors. It is worth noting that earthy/mushroom and nutty/roasted-nut intensities were essentially not present (0.23 and 0.17, respectively) in FRESH beef patties. However, as treatments were formulated to include DRY-AGED beef, noticeable increases in these flavor attributes were observed. Other attributes were intensified as the inclusion of DRY-AGED beef increased, but the magnitude of this increase was the most measurable for earthy/mushroom and nutty/roasted-nut. Therefore, it was an increase in the intensity of these 2 attributes that showed to be the most distinguishable change between flavor profiles of FRESH and DRY-AGED beef. Buttery/beef fat was greater (P = 0.003) in BLENDED treatments over DRY-AGED treatments, with FRESH beef being similar to both treatments. Previous studies have had varied conclusions about the influence of aging type (dry versus wet) on beef flavor. Previous consumer sensory studies have found little to no differences in wet versus dry-aged beef (Sitz et al., 2006; Laster et al., 2008; Smith et al., 2008); however, studies utilizing trained sensory panelists have found dry-aged beef to intensify numerous beef flavor attributes (Warren and Kastner, 1992; Campbell et al., 2001). The current data suggest that a 100% DRY-AGED ground beef product would produce an altered flavor experience unique to more traditional FRESH ground beef blends, including an increase in sour/acidic and bitter flavor notes. Previously, increased nutty and earthy flavor notes have characterized dry-aged ground beef, whereas, wet-aged beef produces more intense sour flavors (Dashdorj et al., 2016). Although FRESH and DRY-AGED beef in the current study had vastly different days of age, it appears that DRY-AGED patties produced flavor characteristics associated with both wet- and dry-aging.

Texture characteristics are presented in Table 4. Panelists rated hardness greatest ($P < 0.001$) for DRY-AGED beef and least ($P < 0.001$) for FRESH beef. Inversely, tenderness was determined to be greatest ($P = 0.006$) in FRESH patties and least ($P = 0.006$) in DRY-AGED patties, with BLENDED patties being similar ($P > 0.05$) to both treatments. The increased hardness and reduced tenderness of DRY-AGED patties was likely caused by the inclusion of the hard, dry exterior pieces being included in ground beef patties, in addition to a lower moisture content. In contrast, in studies comparing dry and wet-aged whole muscle cuts, neither objective nor subjective differences in tenderness have been found when aging length is kept constant (Warren and Kastner, 1992; Smith et al., 2008). Neither trained panel rated cohesiveness, connective tissue content, particle size, nor moisture content was influenced ($P > 0.05$) by treatment.

Table 4. Beef texture attributes[1] of cooked ground beef patties from three aging treatments

	Treatment[2]				
Texture attribute	Fresh	Blended	Dry-aged	SEM[3]	P-value
Hardness	4.05[c]	4.83[b]	5.62[a]	0.21	< 0.001
Cohesiveness	5.80	5.93	5.98	0.13	0.58
Tenderness	6.41[a]	6.10[ab]	5.79[b]	0.13	0.006
Connective Tissue	0.56	1.00	0.55	0.17	0.113
Particle Size	4.42	4.87	4.8	0.15	0.092
Moisture Content	5.49	5.53	5.29	0.15	0.469
Beef Fat/Oily Mouthfeel	5.82[ab]	6.03[a]	5.64[b]	0.10	0.035

[a-c]Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

[1]Trained panel sensory scores: 0 = very soft; crumbly; very tough; no presence; fine; very dry; very low intensity; 10 = very hard; dense; very tender; very high intensity; coarse; very moist; very high intensity.

[2]Treatments: Fresh (100% fresh beef); Blended (50% fresh beef, 50% dry-aged beef); Dry-aged (100% dry-aged beef).

[3]Standard error (largest) of the least squares means.

Fatty Acid Composition

Differences were seen in fatty acid profiles due to ground beef treatment (Table 5); however, little to no work has previously been conducted to investigate the cause of the change in fatty acids as a result of dry-aging beef. Therefore, explanations for these differences can only be speculated. Clear segmented differences were observed as inclusion of DRY-AGED beef increased, showing an almost linear relationship among several fatty acids and inclusion level of DRY-AGED beef. The greatest ($P < 0.001$) percentage of 18:0 was in DRY-AGED beef and the least ($P < 0.001$) in FRESH beef. Inversely, 12:0, 14:0, 15:0, and 16:0 percentages were greater ($P \leq 0.034$) in FRESH beef than in DRY-AGED beef. No known studies have focused on the stability of different saturated fatty acids in beef; however, studies have indicated that shorter chain fatty acids are more readily oxidized than longer chains (Leyton et al., 1987). Thus, differences in the shorter chain saturated fatty acids may be the result of decreased oxidative stability combined with greater exposure to oxygen during aging.

Oleic acid (18:1 *cis*-9) and palmitoleic acid (16:1 *cis*-9) were found in greater ($P \leq 0.015$) concentrations in FRESH beef over DRY-AGED beef. Both of these monounsaturated fatty acids have been previously associated with desirable beef flavor (Melton et al., 1982). Concentrations of 14:1 *cis*-9 and 17:1 were both greater ($P < 0.001$) in FRESH and BLENDED beef than in DRY-AGED beef; whereas, 18:1 *trans* was found in greater

Table 5. Fatty acids in raw ground beef from 3 aging treatments

	Treatment[1]				
Fatty acid[2]	Fresh	Blended	Dry-aged	SEM[3]	*P*-value
10:0	0.05	0.05	0.05	0.01	0.242
12:0	0.08[a]	0.08[ab]	0.07[b]	0.01	0.034
14:0	3.44[a]	3.23[b]	3.04[c]	0.05	< 0.001
15:0	0.65[a]	0.64[a]	0.59[b]	0.01	0.001
16:0	26.48[a]	25.13[b]	24.30[b]	0.25	< 0.001
17:0	1.58	1.62	1.56	0.04	0.653
18:0	13.55[c]	14.63[b]	17.17[a]	0.16	< 0.001
12:1	0.03	0.03	0.03	0.01	0.621
14:1 cis-9	0.90[a]	0.83[a]	0.66[b]	0.03	< 0.001
15:1	0.01	0.02	0.01	0.01	0.624
16:1 cis-9	3.75[a]	3.47[b]	2.82[c]	0.07	< 0.001
17:1	1.08[a]	1.02[a]	0.83[b]	0.02	< 0.001
18:1 trans	2.76[b]	4.11[a]	4.60[a]	0.30	0.003
18:1 cis-9	35.67[a]	34.29[ab]	33.70[b]	0.41	0.015
20:1 cis-11	0.19	0.14	0.16	0.04	0.696
18:2 n-6	0.46	0.45	0.45	0.05	0.999
18:2 CLA[4]	2.07[a]	1.98[b]	1.71[c]	0.02	< 0.001
18:3 n-3	0.30	0.35	0.37	0.04	0.538
18:3 n-6	1.16[ab]	0.94[b]	1.25[a]	0.08	0.043
20:2 n-6	0.41	0.45	0.29	0.06	0.190

[a-c]Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

[1]Treatments: Fresh (100% fresh beef); Blended (50% fresh beef, 50% dry-aged beef); Dry-aged (100% dry-aged beef).

[2]Data presented are least squares means for the normalized weight percentage of each fatty acid, expressed as a percentage of total fatty acid weight.

[3]Standard error (largest) of the least squares means.

[4]Includes 18:2 cis-9, trans-11; 18:2 trans-10, cis-12; 18:2 cis-11, trans-13, 18:2 trans, trans.

($P = 0.003$) concentrations in DRY-AGED beef than in FRESH and BLENDED beef. It is generally accepted that *trans* fatty acids have greater stability compared with *cis* fatty acids. Thus, it again may be speculated that extended exposure to oxygen during the dry-aging process may have degraded *cis* fatty acids more rapidly.

The polyunsaturated fatty acid 18:2 CLA was greatest ($P < 0.001$) in fresh beef and decreased ($P < 0.001$) with the incorporation of dry-aged beef. Polyunsaturated fatty acids have greater susceptibility to oxidation (Mottram, 1998). Concentrations of 18:3 n-6 were greater ($P = 0.043$) in DRY-AGED beef than in BLENDED beef, with FRESH beef being similar ($P > 0.05$) to both treatments. Aging type greatly influenced fatty acid profiles; however, these types of changes have not been previously well documented in meat products. Therefore, it is suggested that changes in fatty acids were due to differences in oxidative stability, but an exact mode of action cannot be established from the current study. Because total days of age were not constant between FRESH and DRY-AGED beef in the current study, nor were shoulder clods paired between treatments, it is difficult to completely credit these changes to the dry-aging process alone. However, the aging parameters used reflect those that would be used in a commercial setting and provide evidence that the different aging procedures may have influenced fatty acid profiles.

Volatile compounds

Of the 40 compounds analyzed in the current study, 12 were influenced ($P \leq 0.046$) by ground beef treatment (Table 6). Furthermore, 11 compounds were found in greater ($P \leq 0.046$) concentrations in DRY-AGED beef than in FRESH beef (Table 6). Thus, it is evident that dry-aging impacted the development of various flavor compounds. Additionally, several of these compounds have been described as being end-products of bacterial fermentation, including 2,3-butanedione, 2-heptanone, and 2-propanone (Joffraud et al., 2001). Similar to fatty acid profiles, differences in volatile compounds seemingly followed linear trends as the inclusion of DRY-AGED beef increased. The DRY-AGED beef had greater ($P < 0.012$) concentrations of hexanal compared with FRESH beef, with

Table 6. Volatile compounds in cooked ground beef from 3 aging treatments

Volatile compound	Treatment[1]				
(ng/g cooked sample)	Fresh	Blended	Dry-aged	SEM[2]	*P*-value
Alcohols					
1-Hexanol	0.04[b]	0.07[a]	0.10[a]	0.01	< 0.001
n-Aldehydes					
Pentanal	0.16[b]	0.28[ab]	0.33[a]	0.04	0.050
Hexanal	0.56[b]	0.97[ab]	1.37[a]	0.16	0.012
Strecker aldehydes					
3-Methyl butanal	0.74[b]	1.57[ab]	3.47[a]	0.59	0.020
2-Methyl butanal	0.47[b]	1.15[ab]	2.95[a]	0.59	0.031
AAlkanes					
Octane	0.22[b]	0.43[a]	0.40[a]	0.04	0.004
Furans					
2-Pentylfuran	0.00[b]	0.01[a]	0.01[a]	0.01	0.001
Ketones					
2-Propanone	14.15[b]	16.29[b]	32.01[a]	3.40	0.006
2,3-Butanedione	0.40[b]	0.54[ab]	0.91[a]	0.13	0.046
3-Hydroxy-2-butanone	5.26[b]	7.45[b]	10.76[a]	0.74	0.001
2-Heptanone	0.02[b]	0.04[ab]	0.05[a]	0.01	0.011

[a,b]Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

[1]Treatments: Fresh (100% fresh beef); Blended (50% fresh beef, 50% dry-aged beef); Dry-aged (100% dry-aged beef).

[2] Standard error (largest) of the least squares means.

quantities of hexanal from BLENDED beef being similar ($P > 0.05$) to both FRESH and DRY-AGED beef. Hexanal is derived from the lipid oxidation of 18:1 *cis*-9 and 18:2 n-6 (Cerny, 2007), which are often related to off-flavors (Maruri and Larick, 1992; Stetzer et al., 2008). Other lipid oxidation products, pentanal, 1-hexanol, octane, and 2-pentylfuran, were also found in greater ($P \leq 0.004$) concentrations in DRY-AGED and BLENDED beef over FRESH beef. Octane and 2-pentylfuran also originate from 18:1 *cis*-9 and 18:2 n-6, respectively (Frankel, 1983).

Multiple ketones were influenced by ground beef treatment, as 2-propanone, 2,3-butanedione, acetoin, and 2-heptanone were each greater ($P \leq 0.046$) in DRY-AGED beef than in FRESH beef. Both 2,3-butanedione and acetoin are C4 sugar fragment Maillard reaction intermediates. These intermediates originate from retro aldol reactions of reducing sugars, such as glucose (Martins et al., 2001; Yaylayan and Keyhani, 1999). Aging has been shown to increase glucose content (Koutsidis et al., 2008), therefore, greater abundance of 2,3-butanedione and acetoin in DRY-AGED beef could in part be due to the concentration of reducing sugars during the aging process. Furthermore, acetoin and 2,3-butanedione are both products of lactic acid bacteria metabolism (García-Quintáns et al., 2008), therefore, they would be expected to increase the longer a product is aged. In agreement with the current study, O'Quinn et al. (2016) also found 2,3-butanedione and acetoin to be greater in dry-aged ground beef than from wet-aged treatments.

Strecker aldehydes are a result of the interaction between Maillard reaction and lipid oxidation products (Van Ba et al., 2012). Both 3- and 2-methyl butanal were most prominent ($P \leq 0.031$) in DRY-AGED beef and least ($P \leq 0.031$) in FRESH beef. Again, O'Quinn et al. (2016) found both compounds in greater concentrations from dry-aged beef compared to wet-aged beef. Strecker aldehydes form via the degradation of free amino acids during the Maillard reaction, where 3-methyl butanal originates from leucine and 2-methyl butanal originates from isoleucine (Cerny, 2007). As previously discussed, DRY-AGED patties had more ($P < 0.001$) protein and less ($P < 0.001$) moisture than FRESH patties, which could have provided greater substrate (amino acids) and less Maillard reaction inhibition (water content). Furthermore, aging is known to increase free-amino acid content (Field and Chang, 1969; Feidt et al., 1996); therefore, it is possible that the increased quantities of 3- and 2-methyl butanal in this study were affected by increased quantities of free amino acids due to differences in aging length among treatments.

Correlations

Correlation coefficients between fatty acids and descriptive flavor attributes are presented in Table 7. Capric acid (10:0) was the only fatty acid that showed a relationship ($r = -0.57$; $P < 0.05$) to beefy/brothy flavor

Table 7. Pearson correlation coefficients between fatty acids and flavor attributes of three aging treatments[1]

	Flavor attribute							
Fatty acid	Beefy/ brothy	Browned/ grilled	Bloody/metallic	Gamey	Earthy/ mushroom	Nutty/ roasted-nut	Sour/ acidic	Bitter
10:0	-0.57*	-0.62*	0.26	-0.46	-0.44	-0.39	-0.38	-0.23
12:0	0.04	-0.25	-0.14	-0.01	-0.64*	-0.53*	-0.28	-0.30
14:0	-0.48	-0.68*	0.42	-0.25	-0.86*	-0.85*	-0.45	-0.54*
15:0	-0.15	-0.43	0.09	-0.20	-0.75*	-0.66*	-0.46	-0.42
16:0	-0.50	-0.71*	0.36	-0.16	-0.89*	-0.87*	-0.51	-0.50
18:0	0.35	0.66*	-0.33	0.04	0.89*	0.87*	0.60*	0.64*
14:1 cis-9	-0.38	-0.64*	0.30	-0.09	-0.85*	-0.80*	-0.59*	-0.52*
15:1	0.29	-0.13	-0.26	-0.46	-0.03	0.01	-0.09	0.20
16:1 cis-9	-0.37	-0.66*	0.31	-0.05	-0.91*	-0.85*	-0.61*	-0.59*
17:1	-0.16	-0.45	0.21	0.01	-0.79*	-0.72*	-0.54*	-0.53*
18:1 trans	0.46	0.62*	-0.20	-0.05	0.84*	0.75*	0.59*	0.46
18:1 cis-9	-0.41	-0.46	0.17	0.36	-0.70*	-0.62*	-0.56*	-0.49
20:1 cis-11	-0.11	-0.38	0.56*	0.36	-0.03	-0.25	0.31	-0.60*
18:2 CLA[2]	-0.28	-0.55*	0.20	-0.02	-0.88*	-0.80*	-0.67*	-0.57*
18:3 n-6	-0.27	0.19	0.33	0.67*	0.16	0.16	0.32	-0.13
20:2 n-6	-0.06	-0.40	-0.15	-0.59*	-0.32	-0.38	-0.45	0.01

*Correlation coefficient differs from 0 ($P < 0.05$).

[1]Treatments: Fresh (100% fresh beef); Blended (50% fresh beef, 50% dry-aged beef); Dry-aged (100% dry-aged beef).

[2]Included 18:2 *cis*-9, *trans*-11; 18:2 *trans*-10, *cis*-12; 18:2 *cis*-11, *trans*-13, 18:2 *trans*, *trans*.

attributes. Neither beefy/brothy intensity nor capric acid concentrations differed ($P > 0.05$) among treatments. Additionally, capric acid concentrations were very low (0.05% of total fatty acids for each treatment), suggesting little to no relevance in influencing the development of beefy/brothy flavors. Oleic acid (18:1 *cis* 9) has typically shown to be positively related to beef-like flavors (Marchello et al., 1970; Baublits et al., 2009; O'Quinn et al., 2016); however, oleic acid showed no relationship ($P > 0.05$) with beef/brothy, browned/grilled, or buttery/beef fat flavors in the current study, regardless of notable differences in concentrations among treatments. Oleic acid did, however, show strong negative relationships to ($P < 0.05$) earthy/mushroom, nutty/roasted-nut, and sour/acidic flavors.

Stearic acid (18:0) and 18:1 *trans* were the only 2 fatty acids positively associated with browned/grilled flavor attributes ($r = 0.66$ and 0.62, respectively; $P < 0.05$). These 2 fatty acids also showed ($P < 0.05$) positive relationships with earthy/mushroom ($r = 0.89$ and 0.75, respectively), nutty/roasted-nut ($r = 0.87$ and 0.75, respectively), and sour/acidic flavor notes ($r = 0.60$ and 0.59, respectively). Furthermore, stearic acid was the only fatty acid positively associated with bitter intensity ($r = 0.64$). These flavor attributes, as well as, stearic acid and 18:1 *trans* fatty acids, were found in greater ($P < 0.05$) quantities in DRY-AGED beef than in FRESH beef. Therefore, it is plausible that these 2 fatty acids may be large contributors to flavor differences between DRY-AGED and FRESH beef observed in the current study. Although browned/grilled is considered a desirable flavor attribute, concentrations of stearic acid have previously been related to decreases in overall flavor desirability (Westerling and Hedrick, 1979; O'Quinn et al., 2016). Stearic acid is also found in greater concentrations in grass-fed beef and has shown to be related to off-flavors associated with those types of beef products (Melton et al., 1982; O'Quinn et al., 2016).

Correlations between descriptive flavor attributes and volatile compounds are presented in Table 8. Multiple relationships of interest were determined between flavor attributes and volatile compounds, many of which originated from lipid oxidation compounds. Many ketones are major compounds derived from lipid oxidation during cooking, although they can be formed via other routes, such as bacterial fermentation (Resconi et al., 2013). Each of the ketones (2-propanone, 2,3-butanedione, 2-butanone, acetoin, and 2-heptanone) identified in the current study were positively associated ($P < 0.05$) with earthy/mushroom flavor attributes, with acetoin showing the strongest relationship ($r = 0.87$). Furthermore, each of these compounds, apart from 2,3-butanedione, were also positively related ($P < 0.05$) to sour/acidic flavors. As previously discussed, these volatile compounds and flavor attributes were all increased in DRY-AGED beef. Previously, the ketones listed above have been described as having aromas such as: pungent, buttery, creamy, chemical-like, fruity-green, and cheesy (Kerth and Miller, 2015).

Pentanal and hexanal fall into the group of compounds known as aldehydes. Along with ketones, aldehydes are major lipid derived volatile compounds that influences beef flavor development (Resconi et al., 2013). Both pentanal and hexanal showed positive associations ($P < 0.05$) with beefy/brothy, browned/grilled, bloody/metallic, earthy/mushroom, and livery flavor notes. O'Quinn et al. (2016) found pentanal to be positively correlated with buttery/beef fat flavors, as well as, overall flavor desirability. Hexanal, a major product of the oxidation of linoleic acid, has been used as an indicator of lipid oxidation in stored meat and off-flavor development (Gray and Monahan, 1992), making sense why it was found in greater concentrations in dry-aged beef.

The Strecker aldehydes 2- and 3-methyl butanal were positively correlated ($P < 0.05$) to bloody/metallic, earthy/mushroom, nutty/roasted-nut, and livery flavor attributes. As products of the reactions between amino acids and lipids, these compounds have been described as malty, chocolate, caramel, nutty, and burnt (Keith and Powers, 1968; Guadagni et al., 1972; Machiels, 2004). Kerth and Miller (2015) described these compounds as being closely related to trained sensory ratings for beef identity, brown/roasted, and umami. Additionally, O'Quinn et al. (2016) found 2- and 3-methyl butanal to be positively associated with browned/grilled, buttery/beef fat, and nutty flavors, with 3-methyl butanal also being associated with increased overall flavor desirability.

Conclusions

Dry-aging of shoulder clods for inclusion in ground beef patties increased the intensity of many flavor attributes. The dry-aging process used in the current study may have resulted in a product with altered fatty acid profiles and an increase in numerous lipid-derived flavor volatile compounds during cooking. As shown through correlation coefficients, these differences influenced the perceived flavor of trained sensory panelists. Including DRY-AGED beef into ground beef blends increased ratings for both positive and negative sensory attributes, clearly creating an altered flavor profile compared to that of FRESH ground beef. Although days of age were largely dif-

Table 8. Pearson correlation coefficients between volatile compounds and beef flavor attributes of 3 aging treatments[1]

	Flavor attribute									
Volatile compound (ng/g cooked sample)	Beefy/ brothy	Browned/ grilled	Buttery/ beef fat	Bloody/ metallic	Gamey	Earthy/ mushroom	Nutty/ roasted-nut	Livery	Sour/ acidic	Bitter
Alcohols										
1-Hexanol	0.63*	0.66*	-0.47	0.61*	-0.08	0.79*	0.14	0.56*	0.71*	0.65*
n-Aldehydes										
Pentanal	0.67*	0.55*	-0.52*	0.57*	-0.18	0.54*	0.28	0.62*	0.49	0.49
Hexanal	0.57*	0.63*	-0.47	0.61*	-0.26	0.61*	0.27	0.65*	0.60*	0.54*
Heptanal	0.40	0.73*	-0.58*	0.33	0.22	0.36	-0.29	0.38	0.45	0.03
Octanal	0.14	0.39	-0.39	0.00	0.56*	-0.03	-0.43	-0.02	0.07	-0.17
Nonanal	-0.05	0.14	-0.29	-0.03	0.58*	-0.13	-0.26	-0.23	0.01	-0.28
Decanal	0.08	0.02	-0.17	0.01	0.62*	-0.19	-0.24	-0.27	-0.07	-0.19
Strecker aldehydes										
Isobutanal	0.41	0.44	-0.36	0.61*	-0.36	0.55*	0.58*	0.65*	0.48	0.46
3-Methyl butanal	0.41	0.52*	-0.41	0.63*	-0.34	0.63*	0.52*	0.65*	0.56*	0.49
2-Methyl butanal	0.43	0.51	-0.39	0.63*	-0.33	0.57*	0.56*	0.67*	0.52*	0.47
Methional	-0.57*	-0.45	0.56*	-0.58*	0.18	-0.59*	-0.16	-0.56*	-0.63*	-0.29
Benzaldehyde	0.01	0.09	-0.17	-0.04	0.52*	0.11	-0.13	-0.14	-0.01	-0.04
Phenylacetaldehyde	0.32	0.09	-0.11	0.01	0.67*	-0.08	-0.31	-0.17	-0.07	0.12
AAlkanes										
1-Octene	0.29	-0.15	0.01	-0.06	0.14	0.55*	-0.16	0.01	0.27	0.55*
Octane	0.74*	0.62*	-0.76*	0.59*	0.21	0.51	0.10	0.55*	0.56*	0.17
Carboxylic acids										
Hexanoic acid	0.23	-0.05	0.06	-0.26	0.51*	0.22	-0.52*	-0.36	0.12	0.29
Heptanoic acid	0.16	0.30	-0.12	-0.11	0.52*	0.02	-0.45	-0.05	0.00	-0.13
Octanoic acid	-0.03	0.01	0.20	-0.25	0.57*	-0.12	-0.45	-0.42	-0.11	0.06
Nonanoic acid	0.09	0.01	-0.14	-0.09	0.68*	-0.18	-0.34	-0.38	-0.08	-0.13
Decanoic acid	0.04	0.01	-0.22	0.01	0.60*	-0.09	-0.33	-0.33	0.01	-0.18
Furans										
2-Pentylfuran	0.60*	0.42	-0.52*	0.40	0.36	0.44	-0.24	0.21	0.44	0.22
Ketones										
2-Propanone	0.26	0.38	-0.34	0.68*	-0.50	0.63*	0.35	0.42	0.64*	0.43
2,3-Butanedione	0.35	0.35	0.02	0.22	-0.15	0.59*	0.09	0.27	0.38	0.84*
2-Butanone	0.48	0.34	-0.49	0.49	-0.09	0.59*	0.25	0.47	0.53*	0.23
Acetoin	0.36	0.61*	-0.42	0.62*	-0.37	0.87*	0.17	0.53*	0.72*	0.60*
2-Heptanone	0.60*	0.62*	-0.56*	0.65*	-0.06	0.66*	0.32	0.62*	0.60*	0.45
Pyrazines										
Methyl pyrazine	0.53*	0.39	-0.34	0.46	-0.16	0.41	0.53*	0.62*	0.27	0.58*
2,5-dimethyl pyrazine	0.41	0.32	-0.28	0.28	-0.04	0.26	0.51	0.50	0.10	0.52*
3-Ethyl-2,5-dimethyl pyrazine	0.28	0.30	-0.30	0.28	0.13	0.22	0.59*	0.33	0.10	0.31
Sulfur Compounds										
Methanethiol	0.19	0.47	-0.21	0.34	-0.10	0.60*	0.13	0.28	0.43	0.55*
Dimethyl sulfide	0.21	0.01	-0.08	0.36	-0.61*	0.11	0.26	0.33	0.12	0.16
Dimethyl disulfide	0.30	0.43	-0.30	0.54*	-0.30	0.53*	0.57*	0.57*	0.40	0.56*

*Correlation coefficient differs from 0 ($P < 0.05$).

[1]Treatments: Fresh (100% fresh beef); Blended (50% fresh beef, 50% dry-aged beef); Dry-aged (100% dry-aged beef).

ferent among treatments, DRY-AGED patties still imparted more intense nutty/roasted nut and earthy/ mushroom flavors generally associated with dry-aged beef. Additionally, formulating ground beef to include half DRY-AGED beef and half FRESH beef created a blend that was essentially a mid-point between the 2 blends. Consumers have varying preferences for beef flavor and, although many do not prefer the taste of dry-aged beef, some consumers prefer the overall eating experience of dry-aged beef and are willing to pay a premium for it (Sitz et al., 2006; Laster et al., 2008, Kim et al., 2016). This data shows that including dry-

aged beef at different levels in ground beef blends is an effective way of altering beef flavor profiles. Additional research is needed to further explain the changes in fatty acid profiles and other flavor precursors that occur during the dry-aging process.

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