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Effects of sheep production systems on oxidative storage stability of lean lamb patties

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Abstract

Rambouillet lambs were assigned to three production systems varying in physical environment and diet: RF (a new, raised-floor feeding structure, with animals fed a pelleted mixture of 85% oat hay, 7.5% barley and 7.5% molasses); FL (a feedlot, with animals fed high-concentrate rations); and P (a pasture, with animals given access to the pasture and a high-concentrate supplement). Lengths of time on feed were adjusted to produce similar final shorn weights for each system. Ground meat patties were made with knife-separable lean from hind legs and aerobically refrigerated. Fat content of patties was not significantly different between RF and FL or P, while total unsaturated fatty acid percentage was slightly lower ($P<0.05$) for RF treatment. Patty color (redness) was most stable for RF. Lipid oxidation in raw patties also was lower ($P<0.05$) for RF than FL, but oxidation in cooked patties was greater for RF.

Keywords: Sheep production systems; Lamb patties; Color; Lipid oxidation; Fatty acids

1. Introduction

It has been shown that fatty acid profiles of ruminant tissues can be influenced by animal production system (encompassing diet and physical environment/facility used to produce or finish animals) or nutritional background (Marmer, Maxwell, & Williams, 1984; Larick & Turner, 1989; Rhee, 2000; Rhee, Ziprin, Bishop, & Waldron, 1997; Rhee, Waldron, Ziprin, & Rhee, 2000; Rowe, Macedo, Visentainer, Souza, & Matsushita, 1999). The production systems commonly employed to date for ruminant meat animals have been a feedlot system (animals being placed in a feedlot and fed a grain-based ration) and a pasture system (animals being given access to a pasture or rangeland for grazing, with or without supplemental feed). For lambs and goats whose fibers are valued, it is difficult to produce clean, high-value fibers on animals being fed in feedlots, due to the inherent dustiness and/or muddiness of most commercial feedlots and the requirement to maximize daily gains. To produce distinctly high-value fibers from lambs (and goats), a new indoor production system was developed at Texas A&M University Agricultural Research and Extension Center at San Angelo. Lambs were housed in a special, covered feeding facility with a raised, slatted floor (slatted to release fecal material and urine, and raised to facilitate removal of manure and provide adequate ventilation) and open sides. Since the lambs in such a confined feeding facility would have less physical activity than even those in a feedlot, they were fed a special diet (lower in energy density compared to typical feedlot rations), so that they would not become too heavy before attaining fiber growth of 9.5 cm or more (Rhee, Lupton, Ziprin, & Rhee, 2003). The effects of such a production system on lamb meat storage traits have not been determined. We previously reported on carcass traits and fatty acid profiles of intramuscular fat and subcutaneous fat from Rambouillet and Merino × Rambouillet lambs produced with the new system vs. traditional production systems (Rhee et al., 2003). With

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diet composition slightly modified for the new (raised-floor) production system to enhance the fecal matter consistency, the current study has focused on evaluation of the production system effects on oxidative storage stability of ground leg-meat patties from Rambouillet lambs, in conjunction with fatty acid profiles.

2. Materials and methods

2.1. Sheep production and materials

Lambs (Rambouillet wethers; $n = 143$) were raised on ranges in the San Angelo area and the feeding trial started on 1 September 2000. Lambs at ~5 months of age were assigned [blocked by weight; 37.38 (mean) ± 2.99 kg (standard deviation)] to three production systems which varied in physical environment and diet: an open-sided barn with raised/slatted floor designed to produce high-value wool, with animals fed a pelleted mixture of 85% oat hay, 7.5% barley and 7.5% molasses (production system designated as RF); a feedlot, with animals fed typical step-up/high-concentrate rations (production system designated as FL); and a pasture, with animals given access to the pasture and a supplement (production system designated as P). Eighty-eight, 27 and 28 lambs were assigned to RF, FL and P, respectively. Compositions of FL-lamb diets and P-lamb supplements are shown in Table 1. The RF-lamb diet composition in this study (85% oat hay, 7.5% barley and 7.5% molasses) differed from that of the previous study (Rhee et al., 2003) where the diet contained 85% oat hay, 10% wheat and 5% molasses. The changes (specifically 7.5% barley and 7.5% molasses rather than 10% wheat and 5% molasses) were made to improve the consistency of the fecal material. In the previous study (Rhee et al., 2003), we observed that the fecal matter was very soft and did not readily fall through the slatted floors. The diet change effected in the current study considerably lessened the fecal problem. As with the previous study (Rhee et al., 2003), days to slaughter (or treatment duration) were aimed at producing ~59 kg shorn final weight.

Table 1
Percentages of ingredients in the feedlot diets and pasture supplements

Production treatment	Diet (time fed, week)		
FL	Diet #1 (1)	Diet #2 (14)	
P	Diet #1 (1)	Diet #2 (3)	Diet #3 (15.5)
Diet ingredient	Ingredient percentage		
Sorghum grain (milo)	65.50	67.75	60.00
Dehydrated alfalfa meal	10.00	5.00	10.00
Cottonseed hulls	10.00	10.00	0
Cottonseed meal	10.00	12.00	10.00
Soybean meal	0	0	10.00
Molasses	3.00	3.00	4.00
Urea	0	0.50	0.50
Ammonium chloride	0.50	0.50	0
Calcium carbonate	0.50	1.00	0
Monodicalcium phosphate	0	0	1.00
Vitamin–mineral–antibiotic pre-mix	0.50	0.50	0.25
Salt	0	0	4.00

Slaughter and carcass evaluations were conducted in San Angelo at the Ranchers Lamb of Texas commercial slaughter facility. Nine animals in each treatment group, whose shorn final weights were close to the mean of the respective group (59.37, 59.15, and 60.78 kg for the P, FL, and RF groups, respectively) were selected for sampling/evaluations for this study. At ~24 h post-mortem, each carcass was ribbed at 12th and 13th rib interface. Backfat thickness was measured over the center of the ribeye between the 12th and 13th ribs, and bodywall thickness was measured at ~2.5 cm below the ribeye. During carcass evaluation, a portion (>20 g) of *semimembranosus* muscle and a whole hind leg were removed from each of the nine carcasses/treatment, double-bagged in Ziploc® freezer bags (for muscle samples) or large heavy-duty plastic bags (for legs), and frozen (−20 °C). The muscle samples, legs, and representative samples of the RF-lamb diet, the finishing diet for FL lambs (diet #2, Table 1) and the finishing supplement given to P lambs (diet #3, Table 1) were transported frozen to the Texas A&M University Meat Chemistry Laboratory, College Station. Upon receiving, muscle samples and legs were individually vacuum-packaged, while the diet samples were double-bagged in Ziploc® freezer bags. All samples were kept at −20 °C until analysis or processing.

2.2. Processing and storage of leg-meat patties

Three legs (from three animals; one hind leg/animal) were pooled to form an experimental unit, with three units (batches) of lean ground meat being prepared for each production treatment. The vacuum-packaged frozen legs were thawed for 2 days at 4 °C without breaking the vacuum seal before dissection. Bones and all knife-separable fat and connective tissue were removed. Then, the lean pieces were combined according to experimental unit/treatment, ground twice (through a 1.27-cm plate, followed by a 0.32-cm plate), and formed into 115-g patties. One-half of the patties from each group were cooked in a preheated electric skillet set at 164 °C [two patties at a time; 5 min on one side and 9 min on the other side (total cooking time = 14 min)] to an internal temperature of ~74 °C and cooled on stainless steel racks for 15 min before weighing or packaging. Raw and cooked patties were placed on polyfoam trays (two patties/tray), over-wrapped with oxygen-permeable polyvinyl chloride film [O_2 transmission rate = 2325 cm^3/

mil/m^2/24 h at 25 °C; film thickness in the British unit (mil) as provided by the manufacturer (Reynolds Food Service Packaging, Richmond, Virginia) = 0.5 mil (= 12.7 μm)], and stored at 4 °C for 0, 3 or 6 days (2 patties/storage time/ground meat batch (experimental unit)/production treatment).

2.3. Analytical methods

Moisture was analyzed by the AOAC (1990) oven-drying procedure. Total lipids were extracted by the procedure of Folch, Lees, and Sloane-Stanley (1957). Total fat content was determined on aliquots of lipid extracts after solvent removal. To determine fatty acid composition, aliquots of lipid extracts were freed of solvent under a nitrogen stream and transmethylated using tetramethylammonium hydroxide in methanol (Metcalfe & Wang, 1981). Fatty acid methyl esters were analyzed by gas chromatography as described by Rhee, Ziprin, Ordonez, and Bohac (1988). Results for each fatty acid were expressed as a percentage of the sum of the peak areas of all identified fatty acids.

Red color (a^*) values of raw leg-meat patties were measured using a Minolta Chroma Meter CR-300 equipped with a DP-301 data processor (Minolta, Inc., Japan). The chromameter was standardized with a white tile ($a^* = -0.23$). Measurement was made perpendicular to the patty surface, on four different locations per patty, and the mean value for each patty was used in data analysis.

Lipid oxidation in raw and cooked meat patties was assessed by measuring 2-thiobarbituric acid-reactive substances (TBARS). A modified distillation TBARS procedure (Rhee, 1978) was used; a propyl gallate-EDTA solution was added at the sample blending step to minimize potential further lipid oxidation during analysis and the TBA reagent was prepared with no acid. Each patty was analyzed in duplicate (two distillations/patty) and the mean value for each patty was used in data analysis. Results were expressed as mg malonaldehyde equivalents/kg meat sample.

The Statistical Analysis System software (SAS, 1997) was used to perform data analysis. A mixed model (PROC MIXED) was used, with the following treated as random effects: "animal" ($n = 9$ per treatment) for carcass data and fatty acid data on *semimembranosus* muscle samples, and "ground meat batch" ($n = 3$ per treatment) for data on ground leg-meat patties. Least squares means were computed by LSMEANS, with pairwise comparisons obtained by the PDIFF option. PROC CORR was used to determine correlations between variables. Significance was established at $P \leqslant 0.05$ unless otherwise indicated. [We could not replicate the production treatments because specific pasture and environmental conditions can never be accurately reproduced and our resources were limited. Thus, each animal was used as an experimental unit for each treatment for data on carcasses and *semimembranosus* muscle samples, while each ground meat batch—the meat pooled from three animals (see Section 2.2)—was used as an experimental unit for data on leg-meat patties.]

3. Results and discussion

Animal and carcass data are shown in Table 2. Initial weights of the lambs used for this study averaged ~37.2 kg, with no difference ($P > 0.05$) among treatments. Likewise, final shorn weights of lambs and carcass weights were similar ($P > 0.05$) for the three treatments. RF lambs were lower in dressing percentage than P and FL lambs. Similarly, backfat thickness and bodywall thickness were less for RF lambs. By comparison, in our previous study (Rhee et al., in press) dressing percentage was not significantly different between RF and P lambs while backfat thickness and bodywall thickness were less for P lambs. Such differences between the studies could be largely due to diet composition changes for RF and P lambs. Dietary changes for RF treatment have been alluded earlier. Because of a worse drought—thus, even less adequate vegetation in the pasture—during the second (this) study vs. the first (previous) study, P lambs had to consume more supplemental feed (high-concentrate ration) in this second study than in the previous one (Rhee et al., 2003).

Fatty acid profiles of lamb diets are shown in Table 3. The changes made in this study for RF-lamb diet (85% oat hay–7.5% barley–7.5% molasses vs. 85% oat hay–10% wheat–5% molasses in the previous study) apparently decreased total PUFA percentage (~44% vs. ~61%) and increased total MUFA percentage (~30% vs. ~11%). Compositions of the principal FL-lamb diet

Table 2
Production treatment effects[a] on carcass traits for lambs used in this study

Production treatment	Initial weight (kg)	Shorn final weight (kg)	Days to slaughter	Hot carcass weight (kg)	Dressing percentage	Backfat thickness (cm)	Bodywall thickness (cm)
P	37.10 a	58.79 a	137 b	30.86 a	52.52 a	0.58 a	3.15 a
FL	36.65 a	58.10 a	108 c	30.69 a	52.82 a	0.74 a	3.33 a
RF	37.24 a	60.37 a	167 a	28.09 a	46.52 b	0.43 b	2.62 b

[a] Means in the same column which are not followed by a common letter are different ($P < 0.05$).

Table 3
Fatty acid compositions of the supplement for pasture lambs and diets for feedlot and raised-floor lambs

Fatty acids	P supplement (Diet #3, Table 1)	FL diet (Diet #2, Table 1)	RF diet
12:0	0.04	0.02	0.34
14:0	0.17	0.22	0.54
15:0	0.05	0.02	0.18
16:0	16.00	16.83	21.00
16:1	0.59	0.56	0.30
17:0	0.10	0.10	0.18
17:1	0	0	0.04
18:0	1.93	1.84	2.62
18:1	27.84	29.38	28.96
18:2	49.53	48.22	36.10
18:3	2.31	2.13	7.64
20:0	0.19	0.22	0.44
20:1	0.27	0.14	0.25
22:0	0	0.08	0.52
22:1	0.34	0.04	0.62
23:0	0.63	0.15	0.04
24:0	0	0.06	0.24
SFA[a]	19.11	19.53	26.09
UFA[b]	80.89	80.47	73.91
MUFA[c]	29.05	30.12	30.18
PUFA[d]	51.84	50.35	43.74
UFA/SFA	4.23	4.12	2.86
MUFA/SFA	1.52	1.54	1.17
PUFA/SFA	2.71	2.58	1.69

[a] SFA = total saturated fatty acids.
[b] UFA = total unsaturated fatty acids.
[c] MUFA = total monounsaturated fatty acids.
[d] PUFA = total polyunsaturated fatty acids.

and P-lamb supplement (diet #2 and diet #3, respectively, in Table 1) were not notably different between the current and previous studies—thus no distinct fatty acid profile differences.

The fat content of leg-meat patties was higher for FL than for P, with no significant difference found between RF and P and between RF and FL (Table 4). Raw patty fat content did not correlate ($P > 0.05$) with carcass weight ($r = -0.15$) or backfat thickness ($r = 0.47$). Cooking yields were slightly higher ($P < 0.05$) for RF and P patties than for FL patties (no more than 2.2%, or 0.022 fold, difference).

Table 4
Fat percentages of raw patties and cooking yields[a]

	Treatment					
	P		FL		RF	
	Mean	S.D.[b]	Mean	S.D.	Mean	S.D.
Raw patty fat (%)	3.41b	0.59	4.14a	0.65	3.85ab	0.36
Cooking yield (%)	73.97a	2.13	72.46b	2.47	74.06a	2.03

[a] Means within the same row which are not followed by a common letter are different ($P < 0.05$).
[b] S.D. = standard deviation.

Table 5
Production treatment effects[a] on fatty acid compositions (%) of intramuscular fat

Fatty acid	Production treatment					
	P		FL		RF	
	Mean	S.D.[b]	Mean	S.D.	Mean	S.D.
14:0	2.01a	0.25	1.99a	0.29	1.85a	0.34
15:0	0.36b	0.05	0.47a	0.08	0.31b	0.05
16:0	23.34b	1.26	23.89b	1.18	24.69a	1.73
16:1	1.97a	0.25	1.92a	0.31	1.35b	0.11
17:0	1.38b	0.18	1.92a	0.50	1.10b	0.19
17:1	1.12b	0.14	1.49a	0.38	0.54c	0.26
18:0	12.45b	1.43	11.89b	0.79	15.91a	0.91
18:1	44.59a	2.31	44.43a	1.47	44.70a	1.87
18:2	8.52a	1.59	8.37a	1.34	6.30b	0.35
18:3	0.41b	0.10	0.30c	0.11	0.76a	0.15
20:3	0.21a	0.03	0.20a	0.05	0.17b	0.02
20:4	3.34a	0.71	2.91a	0.50	2.00b	0.25
24:0	0.30a	0.09	0.22b	0.09	0.32a	0.05
SFA[c]	39.84b	1.53	40.38b	1.55	44.18a	1.96
UFA[d]	60.16a	1.53	59.63a	1.55	55.82b	1.96
MUFA[e]	47.68a	2.34	47.85a	1.32	46.59a	1.73
PUFA[f]	12.48a	2.31	11.77a	1.84	9.23b	0.56
UFA/SFA	1.51a	0.10	1.48a	0.09	1.27b	0.10
MUFA/SFA	1.20a	0.09	1.19a	0.06	1.05b	0.09
PUFA/SFA	0.31a	0.06	0.29a	0.05	0.21b	0.02

[a] Means within the row which are not followed by a common letter are different ($P < 0.05$).
[b] S.D. = standard deviation.
[c] SFA = total saturated fatty acids.
[d] UFA = total unsaturated fatty acids.
[e] MUFA = total monounsaturated fatty acids.
[f] PUFA = total polyunsaturated fatty acids.

Fatty acid profiles of the intramuscular (IM) fat (the fat extracted from *semimembranosus* muscle) and raw leg-meat patties are shown in Tables 5 and 6, respectively. IM fat from RF lambs was higher in total saturated fatty acids (SFA) and lower in total polyunsaturated fatty acids (PUFA) than that from P or FL lambs, as it was in our previous study (Rhee et al., 2003). Similarly, RF, rather than FL or P, resulted in a higher SFA percentage in the leg-meat patties as well. However, treatment effects on MUFA and PUFA levels were different between the fat extracted from leg-meat patties and the IM fat: FL > RF in leg-meat patties vs. no significant treatment effect in IM fat for MUFA, and a smaller PUFA level difference between FL and RF in patties compared to IM fat. As for individual fatty acids in patties, the most notable differences due to treatments were found in percentages of the two major polyunsaturated acids, i.e., 18:2 (P > RF) and 20:4 (P > FL or RF), vs. the second major saturated acid, 18:0 (RF > P or FL).

When raw patties were refrigerated aerobically, the meat color (redness) values on day 0 were highest for RF patties (Fig. 1). On day 3, both RF and P patties were redder than FL patties. After 6 days of storage,

Table 6
Production treatment effects[a] on fatty acid composition (%) of raw leg-meat patties

Fatty acid	Production treatment					
	P		FL		RF	
	Mean	S.D.[b]	Mean	S.D.	Mean	S.D.
14:0	2.29ab	0.07	2.43a	0.25	2.04b	0.17
15:0	0.42b	0.02	0.56a	0.01	0.39b	0.03
16:0	23.51a	0.24	23.71a	0.69	23.86a	1.05
16:1	2.10a	0.07	2.33a	0.25	1.45b	0.15
17:0	1.41b	0.08	1.92a	0.20	1.21b	0.05
17:1	1.17b	0.09	1.53a	0.22	0.76c	0.05
18:0	13.22b	0.43	11.81c	0.80	16.43a	0.62
18:1	44.70a	0.96	45.62a	1.40	44.19a	1.51
18:2	7.71a	0.61	7.13ab	0.56	6.50b	0.15
18:3	0.44b	0.16	0.44b	0.06	0.92a	0.21
20:3	0.16a	0.02	0.17a	0.03	0.16a	0.02
20:4	2.62a	0.27	2.06b	0.16	1.76b	0.09
24:0	0.26a	0.08	0.20a	0.01	0.32a	0.06
SFA[c]	41.11b	0.23	40.64b	1.10	44.25a	1.49
UFA[d]	58.89a	0.24	59.36a	0.93	55.75b	1.48
MUFA[e]	47.96ab	1.08	49.56a	1.73	46.41b	1.51
PUFA[f]	10.93a	1.03	9.80ab	0.80	9.34b	0.42
UFA/SFA	1.43a	0.01	1.46a	0.06	1.26b	0.08
MUFA/SFA	1.17ab	0.03	1.22a	0.08	1.05b	0.07
PUFA/SFA	0.27a	0.03	0.24ab	0.01	0.21b	0.01

[a] Means within the row which are not followed by a common letter are different ($P<0.05$).
[b] S.D. = standard deviation.
[c] SFA = total saturated fatty acids.
[d] UFA = total unsaturated fatty acids.
[e] MUFA = total monounsaturated fatty acids.
[f] PUFA = total polyunsaturated fatty acids.

color deterioration was extensive in all patties, with no significant a^* value differences observed among treatments. Results indicated that, during a normal course of ground meat storage/merchandizing at retail (i.e. aerobically packaged ground meat placed in a refrigerated display case for no more than a few days), RF patties would likely remain redder than P and FL patties. This would be an important advantage for RF because color is the most influential factor when consumers judge the quality of fresh meat (Hood & Riordan, 1973). Additionally, lipid oxidation in raw patties was also lower in RF than FL patties (Fig. 2). When correlations were computed from mean TBARS and a^* values for each storage time/treatment, raw patty TBARS values were significantly and positively correlated with a^* values ($r=-0.77$; $P<0.05$), indicating an association between meat color deterioration and lipid oxidation in raw meat. This correlation has theoretical basis. During aerobic refrigeration of raw meat, oxymyoglobin (responsible for the red color of fresh meat) is oxidized, producing hydrogen peroxide and metmyoglobin (brown). The interaction of the oxidized pigment (metmyoglobin) and hydrogen peroxide forms ferrylmyoglobin radicals that can initiate or catalyze lipid

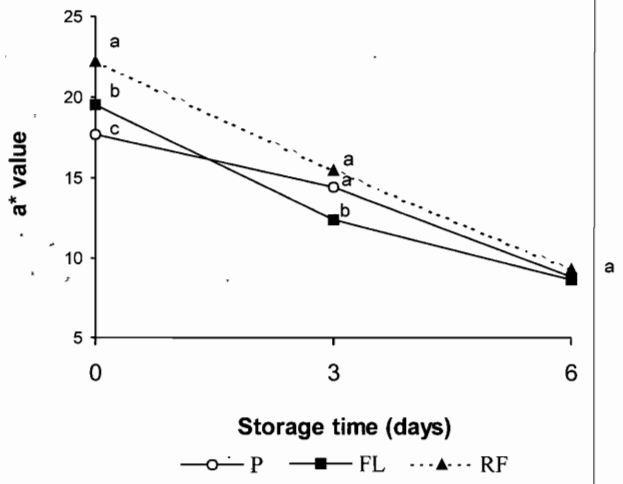

Fig. 1. Production treatment effects on a^* values (redness) of raw leg-meat patties aerobically stored at 4 °C for 0, 3 or 6 days. Means within each storage time that do not bear a common letter are different ($P<0.05$). Standard error of the treatment-by-day least squares means = 0.43.

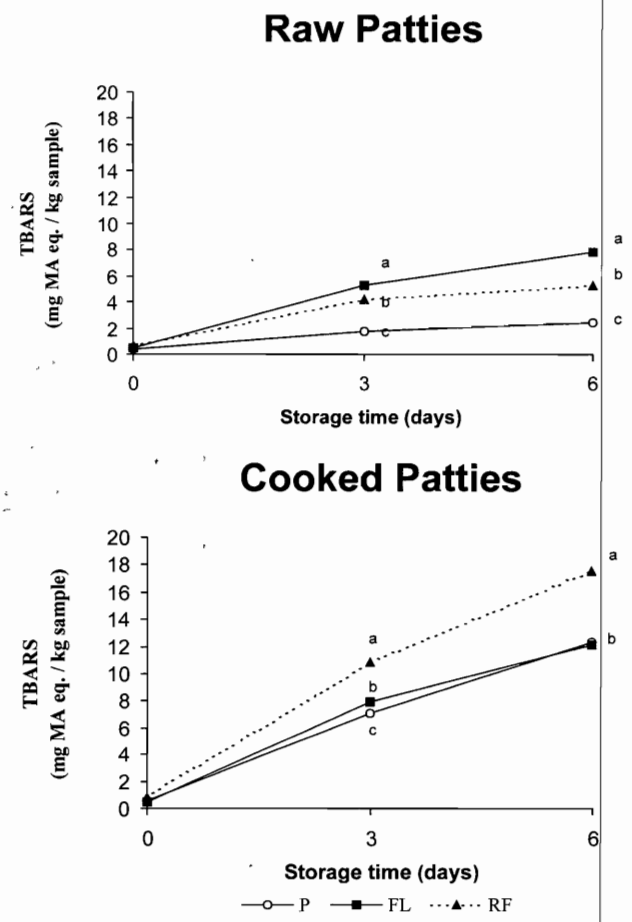

Fig. 2. Production treatment effects on TBARS content (mg malonaldehyde equivalents/kg sample) of raw and cooked leg-meat patties aerobically stored at 4 °C for 0, 3 or 6 days. Means within each storage day in the same graph that do not bear a common letter are different ($P<0.05$). Standard errors of the treatment-by-day least squares means: 0.44 for raw patties and 0.55 for cooked patties.

oxidation (Harel & Kanner, 1985; Rhee, 1988; Xu et al., 1990). Since color degradation during the early part of storage was less in RF patties (Fig. 1), the level of ferrylmyoglobin radicals may also have been lower in RF. Then, one may ask why P patties exhibited lower TBARS values (lipid oxidation) compared to RF patties, in spite of a higher percentage of PUFA (the most oxidizable fatty acid group). The enhanced lipid stability of P patties could be due to natural antioxidants contributed by pasture plants. This hypothesis is partly based on bovine studies. When beef cattle were removed from pasture and fed a grain-based diet, amounts of α-tocopherol and total carotenoids in meat (muscle tissue) decreased (Holden, 1985; Mann, 1983), indicating that pasture plants were better sources of these natural antioxidants than the grain diet. Yanng, Brewster, Lanari, and Tume (2002), who evaluated α-tocopherol and β-carotene concentrations in tissues from pasture- and grain-fed cattle (with or without vitamin E supplementation), also found higher amounts of both antioxidants in muscles from the control pasture-fed cattle than in muscles from the control grain-fed cattle. Additionally, numerous plant species have been known to contain various antioxidative phenolic compounds (Ho, Lee, & Huang, 1992; Shahidi & Naczk, 1995).

When cooked patties were refrigerated, more lipid oxidation occurred in RF than P or FL patties (Fig. 2). Reasons for this are not clear. For lipid oxidation in fully cooked meat, the pigment oxidation issue would be irrelevant, because meat pigments, whether deoxymyoglobin, oxymyoglobin or metmyoglobin, are all denatured when meat is cooked "well done" (an internal temperature of ~74° C in this study) and become denatured metmyoglobin. Total fat and PUFA levels do not explain the cooked patty TBARS (RF > FL), either. Based on raw meat data (Tables 4 and 6) in conjunction with cooking yields (~74% for both RF and FL patties), fat content and PUFA percentage could have been similar for cooked RF and FL patties. Thus, some other unknown factors apparently caused RF patties to be more susceptible to lipid oxidation after cooking.

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