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Frozen storage stability of vacuum-packaged precooked restructured steaks manufactured from mature cow beef[☆]

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Abstract

Beef trimmings from nine cows, equally representing three animal age groups (2–4, 6–8, and 10–12 year), were restructured into steaks formulated with propyl gallate, alone or in combination with a beefy flavoring agent, to enhance palatability and storage stability. Steaks were fully cooked prior to being stored under vacuum for 6 months at −29 °C. Animal age did not affect steak quality and lipid stability, whereas sensory palatability scores and reheating yield decreased significantly beyond 3 months. Propyl gallate did not impart any additional protection against lipid oxidation beyond that provided by vacuum packaging. On the other hand, inclusion of beefy flavoring agent masked all mature, forage-fed beef off-flavors, intensified beefy flavor and improved steak tenderness, juiciness and reheating yield. The incorporation of a beefy flavoring agent was shown to be an effective means to enhance the palatability of vacuum packaged precooked steaks manufactured from mature cows.
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Keywords: Antioxidant; Mature beef; Precooked; Restructured beef

1. Introduction

In an industry devoted to the production of whole-muscle, grain-fed beef from young steers and heifers, limited marketing options exist for beef from mature cows due to inferior tenderness, the presence of objectionable flavors (Hilton et al., 1998; Smith et al., 1982), and dark lean color (Powell, 1991). While age-related sensory differences are generally more substantial when comparisons are made across the broad range of USDA physiological maturity scores (A versus E maturity), sensory panel tenderness, connective tissue amount and flavor scores have been shown to deteriorate as carcass maturity progresses from C to E maturity (Hilton et al., 1998; Smith et al., 1982). Furthermore, our recent study revealed that advanced maturity not only intensified cow beef toughness, but also decreased oxidative stability (Xiong et al., 2007).

Meat restructuring technology has been utilized as an economical means to convert trimmings, less expensive and lower grade carcass cuts, unsuited for whole-muscle merchandizing, into products uniform in composition and quality that could compete in the marketplace at a reasonable unit cost. The processes of grinding and mixing increase the susceptibility of restructured meats to lipid oxidation and rancid flavor development, which could be effectively retarded by inclusion of antioxidants such as propyl gallate (Reverte, Xiong, & Moody, 2003). Another hindrance to the marketing of raw restructured meat items is the rapid discoloration that occurs in these products after they are manufactured and continues to increase as storage time progresses (Chu, Huffman, Egbert, & Trout, 1988). We have previously demonstrated that color of raw restructured steak, notably the colorimetric *a* value (redness), deteriorated from the onset of frozen storage despite the presence of propyl gallate (Reverte et al., 2003; Stika, Xiong, Suman, Blanchard, & Moody, 2007). Additionally, the pigments present in the beefy flavoring agent, utilized in the steak formulation to overcome the undesirable off-flavors inherent to mature beef, negatively impacted steak color initially (Stika et al., 2007).

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Cooking restructured meats prior to storage is an effective means to eliminate color concerns and simultaneously enhances convenience. However, thermal processing facilitates the mixing of muscle lipids and oxidative catalysts, and accelerates flavor deterioration during storage (Asghar, Gray, Buckley, Pearson, & Booren, 1988). Tims and Watts (1958) first used the term ''warmed-over'' to describe the oxidized flavor developed rapidly in cooked meats, which is a major deterrent to the acceptability of precooked restructured meats. However, warmed-over flavor and rancidity development in meat products could be retarded by exclusion of oxygen via vacuum packaging (Lynch, Kastner, Kropf, & Caul, 1986) and inhibited by using phenolic antioxidants (Pearson, Gray, Igene, & Yamauchi, 1983).

The objective of this study was to determine the effect of physiological age of cows on precooked microwavable restructured beef steak palatability. Specifically, the study tested the hypothesis that restructuring, in combination with antioxidant and beefy flavoring, could reduce the objectionable flavors associated with mature, forage-fed cattle and simultaneously, improve the oxidative stability, of fully cooked beef during extended frozen storage.

2. Materials and methods

2.1. Experimental design and carcass handling

Nine cows composed predominantly of Angus × Simmental genetics were purchased from local producers with established record-keeping programs to ensure the genetic integrity and chronological age of each animal. Three different age categories were equally represented by the inclusion of three animals in each of the following age groups: (1) 2–4; (2) 6–8; and (3) 10–12 years of age. To establish specific age intervals, all animals utilized were calved in the spring of the year. Cows selected as experimental units were acquired as they became available and placed on fescue pasture for a minimum of 2 months prior to slaughter.

The cattle were humanely slaughtered using standard industry procedures and the carcasses were electrically stimulated as described previously (Stika et al., 2007). Carcasses were chilled in a 2 °C cooler for 24 h, and then ribbed between the 12th and 13th ribs for carcass quality evaluation.

2.2. Steak manufacture

Meat, deboned from the chuck, plate and brisket from both sides of each carcass and trimmed free of excessive fat and heavy connective tissue, was structured into loaves as described previously (Stika et al., 2007). Lipid content of all ground meat batches was adjusted upward to a target level of 8% through the addition of frozen fat (subcutaneous and intermuscular fat) obtained from the same carcass and previously ground through a 3.2 mm plate. Formulation treatments included: control (CON) [1.5% NaCl and 0.25% sodium tripolyphosphate (STP)]; antioxidant (AOX) [1.5% NaCl, 0.25% STP, and 0.02% propyl gallate on a fat content basis]; and antioxidant + beefy flavoring (ABF) [1.5% NaCl, 0.25% STP, 0.02% propyl gallate, and 0.75% beefy flavoring (F & C Wild Flowers Inc., Cincinnati, OH, USA)]. Freshly prepared restructured loaves were chilled at −29 °C for 1 h, removed from the molds, and allowed to freeze throughout at −29 °C for 24 h. Frozen loaves were sawed into uniform 2.54-cm thick steaks, immediately thawed and then cooked as described below.

2.3. Cooking and storage

Frozen steaks were thawed at 2 °C for 16 h and cooked to an internal temperature of 70 °C on a Farberware Open Hearth electric broiler (Farberware Inc., Bronx, NY, USA) while the core temperature was monitored with a handheld thermocouple (Model 31308-KF, Atkins Technical Inc., Gainesville, FL, USA).

Cooked steaks were randomly distributed in the following manner: one steak, further divided into quarters, for raw lipid oxidation analysis at 0, 1, 3, and 6 months of storage; four steaks for reheating yield and textural evaluation at 0, 1, 3, and 6 months of frozen storage; and four steaks for sensory evaluation at the conclusion of each storage period. All steaks were packaged in three mil standard barrier nylon/PE vacuum pouches (Cryovac, Simpsonville, SC, USA) and stored frozen at −29 °C until analysis.

2.4. Lipid oxidation

Lipid oxidation was measured using the thiobarbituric acid (TBA) assay (Sinnhuber & Yu, 1977). The TBA-reactive substances (TBARS), expressed as mg of malonaldehyde per kg of sample, was calculated as TBARS ($\mathrm{mg\,kg^{-1}}$) = (A_{520}/W_s) × 9.48, where, W_s is the meat sample weight and the value 9.48 is a constant derived from the sample dilution and the absorption coefficient (152,000 $\mathrm{M^{-1}\,cm^{-1}}$) of the TBA–malonaldehyde adduct.

2.5. Reheating of precooked steaks

Frozen steaks were placed individually on porcelain plates and reheated to an internal temperature of 70 °C (approximately 6 min) in a household microwave oven equipped with a turntable. Steaks were flipped one time midway through the reheating process to assist uniform heating. Center temperatures were monitored midway through and at the conclusion of the reheating process using a handheld thermocouple (Model 31308-KF, Atkins Technical Inc., Gainesville, FL, USA). Steaks utilized for sensory evaluation were maintained warm, while all other steaks were allowed to cool for 2 h at room temperature prior to analysis. Reheating yield was calculated as the reheated steak weight (immediately after reheating) divided by frozen-cooked steak weight then multiplied by 100.

2.6. Textural measurements

An Instron Universal Testing Machine (Model 4301, Instron Corp., Canton, MA, USA) was used to determine rigidity and rupture force of reheated steaks as previously described (Xiong, Noel, & Moody, 1999). Following reheating, steaks were allowed to equilibrate to room temperature before analysis. Samples were prepared with a razor sharp knife by cutting steaks into cubes measuring 15 mm^3 (with the reheated surfaces removed). The cubes were placed between two parallel plates and compressed at a 200 mm min^{-1} crosshead speed uniaxially to obtain both a 20 and an 80% sample height reduction. The compressive force generated by a 20% height reduction was used to indicate sample rigidity (hardness). An 80% sample deformation resulted in structural failure of all samples. The point of structural failure, identified by a sharp rise and subsequent fall in compressive force, was used to determine the rupture force (binding strength). Ten samples were prepared and compressed for each steak and the mean was used to determine final values.

2.7. Sensory evaluation

Palatability characteristics of reheated steaks were evaluated by an eight-member trained panel in a sensory evaluation laboratory with partitioned booths illuminated by red lights to mask color differences between samples. The panelists were selected faculty, staff, and graduate students who had previously participated in meat sensory evaluation. Prior to the actual sensory evaluation, three training sessions were conducted (AMSA, 1995). Samples were provided to the panelists in a random fashion during each session. Panelists evaluated steak samples for tenderness, juiciness, beefy flavor, off-flavor, rancidity, and overall acceptability on a numeric scale of 1–8 (1 = extremely tough, dry, bland, unacceptable; 2 = very tough, dry, bland, unacceptable; 3 = moderately tough, dry, bland, unacceptable; 4 = slightly tough, dry, bland, unacceptable; 5 = slightly tender, juicy, intense, acceptable; 6 = moderately tender, juicy, intense, acceptable; 7 = very tender, juicy, intense, acceptable; and 8 = extremely tender, juicy, intense, acceptable).

2.8. Statistical analysis

The experimental setup was a randomized complete block design, using slaughter group to establish blocks; one cow from each age group was slaughtered on the same day. Data were analyzed as a split-plot with animal age as the whole-plot factor, product formulation as the sub-plot factor, and storage time as the sub-sub-plot factor, using the GLM procedure (SAS, 2001). The main effects and interaction means were separated using least squares procedures when the respective F-tests were significant ($P < 0.05$).

3. Results and discussion

3.1. Lipid oxidation

Previous research has shown that lipid oxidation (TBARS) in fresh or precooked ground beef during storage increased with animal age (Xiong et al., 2007). However, the present study demonstrated that lipid oxidation was not influenced ($P > 0.05$) by animal age nor by product formulation, but increased ($P < 0.05$) as frozen storage exceeded 3 months (Table 1). The result confirmed an earlier study on raw restructured steaks (Stika et al., 2007), suggesting that the meat restructuring process with the basic salt and phosphate ingredients diminished any age effect on lipid stability. Propyl gallate did not impart a protective benefit against lipid oxidation during storage, as mean TBARS values were similar ($P > 0.05$) across formulations. Vacuum packaging ostensibly minimized the availability of oxygen to participate in oxidative reactions, and could have masked the antioxidant activity of propyl gallate. Similarly, Craig, Bowers, and Seib (1991) found that vacuum packaging was effective in inhibiting hexane development in cooked, frozen stored turkey to the point where phosphate provided little additional protection from oxidative changes.

Mean TBARS values did not increase ($P > 0.05$) in precooked steaks until 3 months. While vacuum packaging did not completely eliminate lipid oxidation, it did appear to reduce the extent of rancidity development. Kulshrestha and Rhee (1996), and Matlock, Terrel, Savell, Rhee, and Dutson (1984) also observed reductions in TBARS content in vacuum packaged precooked beef and pork patties when compared to patties packaged with PVC.

3.2. Reheating yield

Animal age did not influence ($P > 0.05$) the yield of reheated steaks (Table 2). However, the inclusion of a beefy flavoring agent improved ($P < 0.05$) the yield compared to those of CON and AOX steaks, which were similar ($P > 0.05$) to each other. The result was consistent with previous observations on aerobically stored steaks (Stika et al., 2007). The yeast extract incorporated as a component of the beefy

Table 1
Lipid oxidation main effect means (TBARS[c]) of precooked restructured steaks manufactured from mature cows of various ages and vacuum stored at −29 °C

Main effects												
Animal age (year)				Formulation				Storage time (months)				
2–4	6–8	10–12	SE*	CON	AOX	ABF	SE*	0	1	3	6	SE*
1.15	1.12	1.22	0.09	1.15	1.13	1.17	0.04	1.11[b]	1.09[b]	1.15[b]	1.28[a]	0.07

*Standard error.
[a,b] Mean values for the same main effect without a common letter differ significantly ($P < 0.05$).
[c] TBARS means expressed as mg malondialdehyde/kg sample.

Table 2
Product reheating yield and textural measurement main effect means of precooked-reheated restructured steaks manufactured from mature cows of various ages and vacuum stored at −29 °C

Item	Main effects												
	Animal age (year)				Formulation				Storage time (months)				
	2–4	6–8	10–12	SE*	CON	AOX	ABF	SE*	0	1	3	6	SE*
Reheating yield[d] (%)	87.8	88.8	88.2	0.61	87.6[b]	88.1[b]	89.1[a]	0.24	89.9[a]	89.1[a]	87.7[b]	86.3[c]	0.45
Textural measures[e]													
Rigidity	19.4	17.7	18.8	0.75	19.3[a]	19.7[a]	17.0[b]	0.72	20.1[a]	17.7[bc]	17.2[c]	19.6[ab]	0.70
Rupture force	127.6	125.5	128.4	6.00	133.5	129.3	118.8	5.70	119.2[bc]	113.3[c]	127.5[b]	148.8[a]	4.11

*Standard error.
[a–c] Mean values for the same main effect in the same row without a common letter differ significantly ($P < 0.05$).
[d] Reheating yield (%) = (reheated weight ÷ frozen precooked weight) × 100.
[e] Textural measurement means are expressed in Newtons.

flavoring agent could have contributed to the enhancement in water-binding capacity, thus, improved product yield. Other researchers have offered similar explanations for cooking yield (DeYonge-Freeman, Pringle, Reynolds, & Williams, 2000; Reverte et al., 2003; Scanga et al., 2000). Reheating yield for all steaks decreased ($P < 0.05$) progressively after 1 month of storage.

The observed reduction in steak reheating yield over time may have been partially due to storage-induced protein oxidation. Parkington, Xiong, Blanchard, and Xiong (2000) reported that protein carbonyl content increased in beef-heart surimi under frozen storage conditions and suggested that the newly generated protein-bound carbonyls formed cross-linkages with free amino groups of other proteins. In the present study, protein oxidation might have occurred during storage and as the number of cross-linkages increased, the ability of the gel network to retain moisture would decrease.

3.3. Textural properties

Neither rigidity nor rupture force was influenced ($P > 0.05$) by animal age. However, incorporation of a beefy flavoring agent lowered ($P < 0.05$) rigidity values compared to CON and AOX steaks (Table 2). These data corresponded inversely with the product yield, suggesting that the inclusion of the beefy flavoring agent reduced sample hardness probably by improving moisture retention during reheating. While storage time had an inconsistent effect on steak rigidity, rupture force significantly increased beyond 3 months. As previously mentioned, the observed increase in rupture force might have resulted from an increase in steak gel network forming ability brought about by oxidative protein modifications during storage and increased gel cohesiveness (Parkington et al., 2000).

3.4. Sensory characteristics

Animal age did not influence ($P > 0.05$) reheated steak sensory characteristics (Table 3). Hilton et al. (1998) and Smith et al. (1982) reported that intact muscle tenderness and flavor desirability decreased as carcass maturity score advanced from C to E maturity. The absence of an age-associated tenderness difference among precooked steaks proved that meat restructuring is an effective method to improve the consistency in tenderness of beef from mature cows. Diet has been shown to influence the flavor profile of beef (Brown, Melton, Riemann, & Backus, 1979; Larick et al., 1987; Larick & Turner, 1990). While nutritional history varied among animals studied by Hilton et al. (1998), all cows used in the current study were placed in the same nutritional systems (i.e., fescue pasture) for 2 months prior to slaughter. The same nutritional regimen was likely responsible for the lack of observable flavor differences between the animal age groups in the present study.

Although the inclusion of propyl gallate slightly enhanced ($P < 0.05$) juiciness and overall acceptability of AOX steaks

Table 3
Sensory panel score main effect means of precooked-reheated restructured steaks manufactured from mature cows of various ages and vacuum stored at −29 °C

Sensory attribute[d]	Main effects												
	Animal age (year)				Formulation				Storage time (months)				
	2–4	6–8	10–12	SE*	CON	AOX	ABF	SE*	0	1	3	6	SE*
Tenderness	5.0	5.0	4.9	0.23	4.7[b]	4.9[b]	5.3[a]	0.08	5.0[a]	5.1[a]	5.0[a]	4.5[b]	0.10
Juiciness	4.5	4.7	4.7	0.14	4.2[c]	4.5[b]	5.4[a]	0.09	5.0[a]	4.8[ab]	4.6[b]	4.2[c]	0.12
Beefy flavor	4.8	4.9	4.7	0.11	3.9[b]	4.2[b]	6.3[a]	0.10	5.0[a]	4.8[a]	4.9[a]	4.5[b]	0.11
Off-flavor	1.7	1.7	1.8	0.07	1.9[a]	1.7[ab]	1.6[b]	0.05	1.6[c]	1.4[c]	1.9[b]	2.1[a]	0.07
Rancidity	1.2	1.2	1.3	0.03	1.3[a]	1.3[a]	1.1[b]	0.02	1.0[c]	1.1[bc]	1.2[b]	1.5[a]	0.05
Overall acceptability	4.9	4.9	4.8	0.16	4.4[c]	4.7[b]	5.5[a]	0.09	5.2[a]	5.0[ab]	4.8[b]	4.4[c]	0.11

*Standard error.
[a–c] Mean scores for the same main effect in the same row without a common letter differ significantly ($P < 0.05$).
[d] Scores of 1–8.

compared to control steaks, both treatments were rated similar ($P > 0.05$) for all other traits, suggesting that the antioxidant had a minimal benefit on sensory characteristics. The lack of difference in rancidity scores between AOX and CON corresponded well with their similar TBARS values. Apparently, vacuum packaging provided adequate protection against oxidative changes during storage and undermined any additional protection by propyl gallate, a phenomenon that was also seen previously in raw steaks under aerobic storage (Stika et al., 2007).

The ABF steaks scored higher ($P < 0.05$) on overall acceptability, tenderness, juiciness, and beefy flavor, when compared to CON and AOX steaks. While the more intense beefy flavor could be directly attributed to the flavoring agent, the enhancements in tenderness and juiciness seemed to reflect a stronger water-binding ability because they corresponded well with the higher reheating yield values of the ABF steaks. A similar relationship between tenderness and moisture retention in meat products has been reported (DeYonge-Freeman et al., 2000; Reverte et al., 2003; Scanga et al., 2000; Stika et al., 2007).

Rancid flavors were only marginally detectable in all steaks, and were least evident when beefy flavoring agent was present. The increase in TBARS values beyond 3 months likely contributed to the detected rancidity flavor, which, in essence, could be ‘‘warmed-over’’ flavor. White, Resurreccion, and Lillard (1988) reported that consumers could detect ‘‘warmed-over’’ flavors in reheated beef semimembranosus steaks when TBARS values exceeded 6.3 mg kg^{-1}. Off-flavors, characterized as ‘‘grassy’’, ‘‘metallic’’ and/or ‘‘livery’’, were also less detectable ($P < 0.05$) in ABF steaks compared to CON steaks and coincided with those identified in previous studies as undesirable flavors inherent to beef from mature or forage-fed cattle (Hilton et al., 1998; Larick et al., 1987; Mandell, Buchanan-Smith, & Campbell, 1998; Reverte et al., 2003; Xiong, Moody, Blanchard, Liu, & Burris, 1996). The reduction ($P < 0.05$) in objectionable flavors in ABF steaks suggested that the incorporation of beefy flavoring agent was effective in masking the undesirable flavor typically associated with precooked/reheated meats and mature, forage-fed beef. DeYonge-Freeman et al. (2000) and Reverte et al. (2003) reported similar findings.

Overall, steak palatability traits were unchanged ($P > 0.05$) through 1 month, but tended to deteriorate as storage progressed, most notably beyond 3 months (Table 4). While beefy flavor intensity for all formulations decreased after 6 months, the decline was more evident ($P < 0.05$) in CON steaks compared to others. Storage increased both the intensity of off-flavors inherent to mature, forage-fed beef (i.e., ‘‘grassy’’) and rancidity. In general, storage time had a similar influence on the palatability traits of precooked restructured steaks when stored under vacuum conditions.

Table 4
Formulation × storage mean sensory panel scores[c] of precooked-reheated restructured steaks manufactured from mature cow beef with antioxidant and beefy flavoring agents and vacuum stored at −29 °C

Formulation	Storage time (months)			
	0	1	3	6
Tenderness (SE* = 0.18)				
CON	4.7	4.8	4.8	4.5
AOX	5.1	5.1	5.0	4.4
ABF	5.4	5.6	5.2	4.9
Juiciness (SE* = 0.22)				
CON	4.5	4.2	4.2	3.8
AOX	5.0	4.4	4.5	3.9
ABF	5.6	5.7	5.1	5.0
Beefy flavor (SE* = 0.19)				
CON	4.3^{ay}	3.9^{aby}	4.1^{ay}	3.4^{bz}
AOX	4.5^{ay}	3.9^{by}	4.4^{aby}	4.1^{aby}
ABF	6.2^{bx}	6.8^{ax}	6.3^{abx}	5.9^{bx}
Off-flavor (SE* = 0.12)				
CON	1.7	1.5	1.8	2.4
AOX	1.6	1.4	1.9	2.0
ABF	1.4	1.4	1.9	1.9
Rancidity (SE* = 0.09)				
CON	1.0	1.2	1.2	1.7
AOX	1.0	1.2	1.3	1.5
ABF	1.0	1.1	1.1	1.2
Overall acceptability (SE* = 0.21)				
CON	4.7	4.6	4.5	3.7
AOX	5.2	4.8	4.5	4.3
ABF	5.9	5.8	5.3	5.2

*Standard error.
[a,b] Mean scores in the same row without a common letter differ significantly ($P < 0.05$).
[x–z] Mean scores for the same sensory trait in the same column without a common letter differ significantly ($P < 0.05$).
[c] Scores of 1–8.

4. Conclusions

Beef from mature cows with similar nutritional backgrounds, when intended for precooked/reheated restructured steaks, could be handled as a homogeneous meat block since physiological age had no influence on the palatability during frozen storage. Vacuum packaging provided sufficient protection against lipid oxidation and the antioxidant propyl gallate offered no additional benefit. However, when the antioxidant was used in combination with a beefy flavoring agent, a significant improvement in all sensory panel palatability traits was observed. Thus, incorporation of a proper flavoring agent(s) seems to be required for the manufacture of acceptable fully cooked restructured beef steaks from mature cows when subjected to reheating following vacuum frozen storage.

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