Response of Beef Flavor to Oxygen Depletion and an Antioxidant/Chelator Mixture

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Meat flavor deterioration (MFD) is characterized by increased levels of off-flavor sensory characteristics and by a decline in desirable-flavor attributes. MFD, long associated with the process of warmed-over flavor development in meat products, is attributed to the free-radical reactions that occur as a result of lipid peroxidation. Data is presented showing the effect of these mechanisms on meat flavor and chemistry. Data demonstrate that several mechanisms act synergistically to remove desirable flavors and heighten off-flavor development. Factor analysis is utilized as a means to graphically render correlations existing among the experimental treatments (dose response), sensory descriptors, and chemical flavor attributes.

INTRODUCTION

Meat flavor deterioration (MFD) is a dynamic process of flavor change principally due to reactions provoked through the cascade of oxidative events and free-radical chemistries (Love, 1983; Asghar et al., 1988; Spanier et al., 1992b). Numerous laboratories, using different experimental approaches, have examined the deterioration of food flavor marked by increased rancidity (Shank and Lundquist, 1963; Stites et al., 1989; Bentley et al., 1989; Nolan et al., 1989). The increased rancidity or off-flavor development is mediated through the oxidation of cellular lipids. The degree of rancid off-flavor development is determined typically by measurement of thiobarbituric acid reactive substances (TBARS; Tarladgis et al., 1960) or other aromatic, volatile markers of rancidity such as hexanal (Buttery and Teranishi, 1963). MFD, on the other hand, does not only involve an increase in rancid off-flavor components but also, perhaps more importantly, involves a loss of desirable flavor components (St. Angelo et al., 1990; Spanier et al., 1990, 1992a,b).

Food flavor is difficult to characterize because of the complexity of human flavor perception of flavor notes. Human perception is not based on the sensory input of a single compound or a small group of compounds, but rather on a much more complex interaction of chemically based neurological responses (Spanier et al., 1992b). If industrial producers are to prepare products that will be purchased repeatedly, they must have a clear understanding of the molecular interactions of the chemical components of food and how they correlate with the experience of human flavor perception. The experiments described herein utilized vacuum packaging, antioxidants, and chelators as tools to examine the relationship(s) among the sensory and chemical attributes of meat subjected to various treatments.

MATERIALS AND METHODS

Preparation and Handling of Ground Beef Patties. Meat, purchased from a local supermarket, was USDA-Choice, top round (*semimembranosus* muscle) from Black Angus-cross steers. The local supermarket gets its steers routinely from Monford; steers are 10–12 months old at slaughter and are fed for 5–6 months on grass and finished on grain for 5–6 months with a grain fed weight gain of approximately 2.5 pounds/day. Beef, trimmed of all visible tallow, was ground by two passes through a grinding disk with 1.0-cm-diameter holes and two passes through a second disk with 0.75-cm holes (General Slicer/grinder Model MC-100). The fat content of the final ground round was determined to average 4.25 ± 0.21% fat using the perchloric–acetic acid method (Koniecko, 1985).

Ground meat was divided into 850-g parcels per "repetition" per "treatment". Each parcel was hand-mixed with either 10 mL of the mixed-additive in water or in water only. Water served as the vehicle of additive administration. Additives used were propyl gallate (PG) and the tetrasodium salt of ethylenediaminetetraacetic acid (EDTA). The concentrations of additives used were either 25, 50, or 100 parts per million (ppm) where ppm represents 1 part additive per million parts of ground beef (wet weight). Experimental and control samples were allowed to marinate (4 °C) in either water or water-plus-additives overnight. Glass Petri dishes (8.9-cm diameter, Kimax) were used as molds to form 10 uniformly shaped patties of 85 ■ 0.02 g from the 850-gram parcel. All patties were cooked on an open-top electric grill (Farberware) for 7 min on each side. The ambient temperature half-way between the heating coils and the grill platform was 179.4 °C. Final end-point cooking temperature of the burgers was 63.6 ± 0.5 °C. Experimental samples were cooked following marination and then stored in a refrigerator with or without vacuum for a period of 3 days. Vacuum packaging was performed in large desiccator jars twice purged with nitrogen. Final vacuum was better than 4 mmHg.

The group of uncooked patties representing the "standard" was immediately frozen (−20 °C) and stored until the day of the experiment; this group was given the notation "SNO" to represent a standard (S) with no vacuum (N) and no additives (O). Initial cooking of the patties was on a Farberware grill for 7 min on each side, yielding cooked burgers having an appearance of medium to a medium/well done with a final end-point temperature of 63.6 °C (Spanier et al., 1992b; Drumm and Spanier, 1991). The four experimental samples (ENO, EVO, ENA, and EVA) were cooked on day 0, placed in a refrigerator either with (EVO, EVA) or without (ENO, ENA) vacuum and then rewarmed to 52 °C in a 121 °C oven for 25 min before presentation in covered Petri dishes to the sensory panel or prior to instrumental and chemical analysis. The experimental groups (treatments) are given the following notations: (1) "ENO" for meat stored (4 °C) for 3 days, i.e. 3-day MFD sample; (2) "EVO" for 3-day MFD sample maintained under vacuum (V); (3), "ENA" for 3-day MFD sample containing the additive (A) mixture; (4) "EVA" representing the 3-day MFD sample maintained under vacuum and containing additive. All five groups were presented to the sensory panel at each meeting. Each panelist received and examined two portions from each sample (treatment). Each sample represented one-

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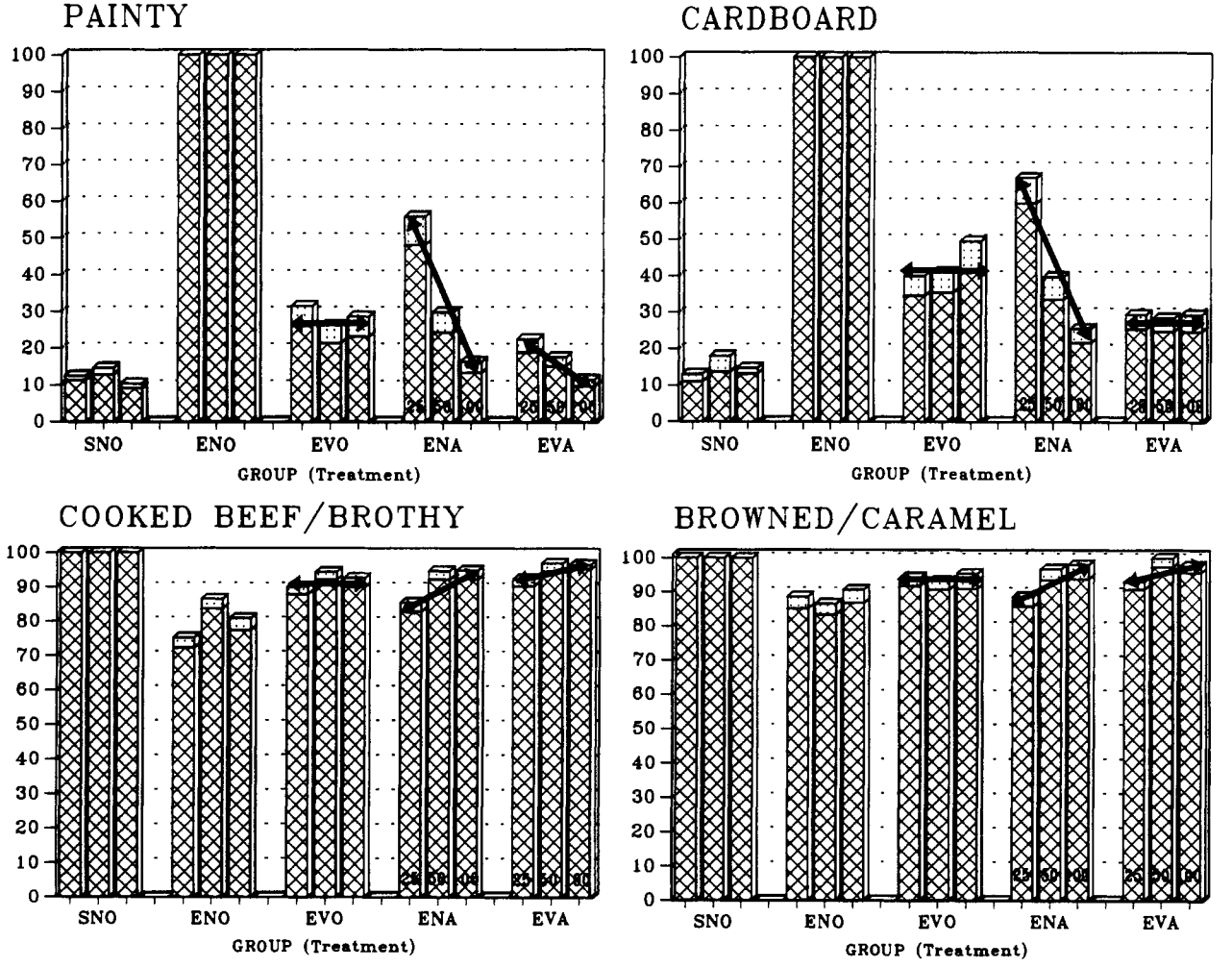

Figure 1. Effect of vacuum (V) and additives (A) on cooked-beef flavor. The main graph is divided into four graphs each representing a different sensory descriptor. Clockwise from the top left the descriptors are painty, cardboard, cooked beef/brothy, and browned/caramel. Each of the four graphs is defined by five clusters of three bars each. From left to right the clusters represent the mean of the standard burgers (SNO), the cooked burger in which flavor was allowed to deteriorate for 3 days at 4 °C (ENO), the ENO sample maintained under vacuum with no additives (EVO), the ENO sample with the additives but no vacuum (ENA), and the ENO sample with vacuum and additives (EVA). Each set of two bars in each cluster (from left to right) represent the descriptor intensity ± SEM at a given concentration of 25, 50, or 100 ppm each of propyl gallate (antioxidant) and EDTA (chelator). Since all five groups were examined at each repetition, both the additive containing and the comparable nonadditive control group are listed at the representative additive concentration (see description in text). Arrows are drawn to indicate the trend of the data.

eighth of a pie-like slice of the patty. All treatments were examined at each session to allow for animal-to-animal variability. Each dosage of antioxidant/chelator mixture was presented in four repetitions.

Thiobarbituric Acid Reactive Substances (TBARS). TBARS are used as an indication of the degree of lipid oxidation or rancidity development in foods and are measured by the distillation procedure of Tarladgis et al. (1960).

Gas Chromatographic (GC) Analysis of Flavor Volatiles. A GC packed-column procedure (Dupuy et al., 1987) was utilized and consisted of a modification of the procedure developed by Dupuy et al. (1978) for foods other than meat. The column was packed with a thermostable Tenax polymer, 2,6-diphenyl-*p*-phenylene oxide, 60–80 mesh coated with 7% poly(*m*-phenoxylene). The column oven was heated from ambient to 80 °C during the first 4 min, from 80 to 200 °C at 4 deg/min, and the final temperature maintained for 20 min. The detector temperature was set at 275 °C. Analysis was performed using a Tracor MT-220 gas chromatograph (Tracor, Inc., Austin, TX) with dual independent hydrogen flame detectors; data were collected using an MT22 Westronics recorder and an Hewlett-Packard 3357 automated data system.

Sensory Analysis. Descriptive sensory profiles of beef patties were generated by the Spectrum method described by Meilgaard et al. (1987). Sensory attributes included the following defined by Johnsen and Civille (1986): salty (STY), cooked beef/brothy (CBB), painty (PTY), serumy (SER), browned/caramel (BRC), cooked liver (CKL), cardboard (CBD), sour (SOU), sweet SWT), and bitter (BTR). The panel consisted of 12 Southern Regional Research Center staff members trained in descriptive sensory analysis of meat. A 15-point universal intensity scale (Meilgaard et al., 1987) was used. The proficiency of each panelist was statistically tested by the method of Love (1988) before data was used in experiments; the majority of the panelists have served on the panel for over 2 years.

Statistical Analysis. All statistical analyses were performed on the raw, unnormalized data. Both PC and mainframe versions of SAS (1985) were used to perform statistical analysis. Analysis of variance (ANOVA) was performed on raw data meaned over panelists. The general linear models procedure was used to conduct ANOVA's for identifying differences among treatments and/or dosage of treatment. Error terms were formed by pooling nonsignificant interactions with F values less than 1.7 with the experimental error term. Principal factor analysis (PFA) using the maximum likelihood solution option was performed on sensory, chemical, and instrumental attributes. PFA factor scores were averaged for each experimental combination (defined by the design matrix) composing the ANOVA, and bivariate plots (maps) were produced (Figure 3).

Data Presentation. Some data, such as those in Figures 1 and 2 and in Table II, are "normalized" to enable direct comparison. The "normalization" process converts data obtained

Table I. Effect of Vacuum on Sensory Attribute Intensity[a]

	treatment, ppm additive														
	SNO			ENO			EVO			ENA			EVA		
sensory descriptor	25[b]	50[b]	100[b]	25[b]	50[b]	100[b]	25[b]	50[b]	100[b]	25	50	100	25	50	100
Desirable Flavors															
cooked beef/brothy (CBB)	6.13	6.08	6.29	4.43	5.09	4.87	5.39	5.60	5.66	5.08	5.61	5.81	5.54	5.76	6.00
browned/caramel (BRC)	3.17	3.13	3.12	2.70	2.61	2.71	2.91	2.84	2.84	2.72	2.93	2.93	2.88	3.15	2.89
sweet (SWT)	1.36	1.36	1.38	1.04	1.16	1.03	1.18	1.28	1.14	1.16	1.36	1.31	1.25	1.25	1.30
Undesirable Flavors															
painty (PTY)	0.19	0.21	0.15	1.68	1.64	1.64	0.45	0.39	0.38	0.81	0.40	0.22	0.32	0.25	0.16
cardboard (CBD)	0.22	0.22	0.17	2.00	1.61	1.29	0.69	0.57	0.57	1.20	0.54	0.28	0.51	0.40	0.32
bitter (BTR)	0.43	0.45	0.42	0.83	0.79	0.66	0.71	0.71	0.53	0.76	0.60	0.49	0.60	0.63	0.47
sour (SOU)	0.52	0.58	0.47	1.11	0.89	0.86	0.78	0.65	0.58	0.84	0.69	0.54	0.74	0.60	0.52
Other Flavors															
cooked liver (CKL)	2.21	2.25	2.30	2.10	2.16	2.30	2.31	2.33	2.32	2.13	2.29	2.40	2.24	2.20	2.36
salty (STY)	1.46	1.49	1.46	1.28	1.40	1.34	1.40	1.39	1.38	1.37	1.38	1.47	1.41	1.43	1.37

[a] Descriptive sensory profiles of beef patties were generated by the Spectrum method described by Meilgaard et al. (1987). A 15-point universal intensity scale (Meilgaard et al., 1987) was used. SNO = standard, freshly cooked burger with no vacuum and no additives. ENO = 3 day cooked, stored patty. EVO = ENO maintained under vacuum. ENA = EVO containing equal amounts of additives (propyl gallate and EDTA) at the concentrations listed. EVA = ENO with the vacuum and additives. [b] While these samples did not contain additives, they are shown to reflect that each experiment (repetition) incorporated all five treatment groups.

by the various methods (e.g., sensory, gas chromatography, chemical) to a dimensionless form such that variables with different units may be plotted on the same grid. This permitted the clear visual comparison of data obtained from dosage to dosage and treatment to treatment.

Data normalization was accomplished by adjusting the magnitude of all off-flavor descriptors (painty, cardboard, sour, and bitter) and chemical markers (TBARS, propanol, butanol, pentenal, pentenol, hexanal, 2,3-octanedione, nonanal, and decanal) to a percentage of an anchor value itself represented by the maximum off-flavored sample, i.e., those stored for 3 days. Desirable flavor notes (cooked beef/brothy, browned/caramel, and sweet), which diminish during the progression of MFD, were normalized to their comparable anchor-value, i.e. the standard patties. All normalized data were presented along with their anchor values to facilitate acquisition of raw data by the reader.

The "SNO", "ENO", and "EVO" groups were never in contact with antioxidant or chelator. However, these data are presented as if the samples had been exposed to antioxidant and chelator since all five treatments ("SNO", "ENO", "EVO", "ENA", and "EVA") were presented to the panel at each session. These data and statistical results present a graphical rendering (Figure 3) of differences resulting among the experimental treatments (factor 1), the source animals, general week-to-week variability, and/or treatment dosage (factor 2).

RESULTS

Effect of Vacuum and Additives on the Sensory Attributes of Beef. Sensory data for two off-flavor descriptors, painty and cardboard (top), and two desirable flavor descriptors, cooked-beef/brothy and browned/caramel (bottom), are shown in Figure 1. Each descriptor is organized into five clusters of three bars each. From left-to-right the clusters represent the five treatment groups, i.e., the "SNO" or standard, the "ENO" or 3-day MFD sample, the "EVO" or 3-day MFD patties maintained under vacuum, the "ENA" or the 3-day MFD samples containing the different levels (25, 50, and 100 ppm) of additives, and the "EVA" or 3-day MFD patties maintained under vacuum and containing additive.

The complete sensory data in Table I and the normalized data of selected descriptors in Figure 1 (verified by ANOVA) show that storage of beef patties in a vacuum ("EVO" cluster) was quite efficient in retarding the development of off-flavor such as painty, cardboard (Figure 1; Table I), bitter, and sour (Table I) and retards the loss of desirable flavors such as cooked beef/brothy, browned/caramel (Figure 1; Table I), and sweet (Table I) as a result

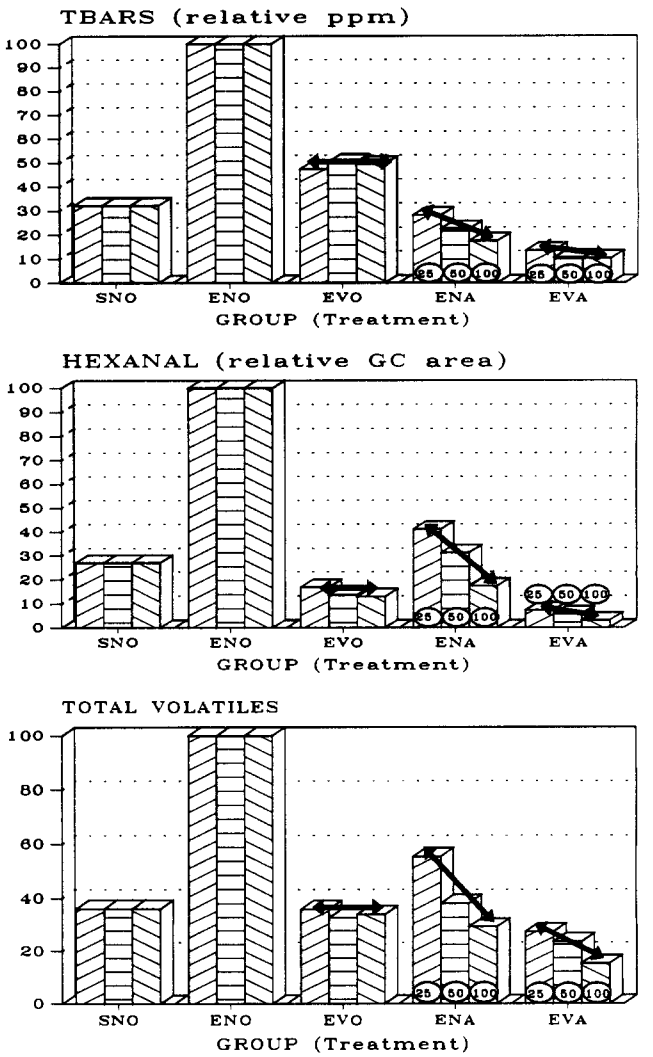

Figure 2. Effect of vacuum (V) and additives (A) on cooked-beef volatiles. This graph is similar to Figure 1 except that it represents the level of the chemical and instrumental markers of beef flavor. The bars in each cluster (from left to right) represent the descriptor intensity at a given concentration of 25, 50, or 100 ppm each of propyl gallate (antioxidant) and EDTA (chelator). Since all five groups were examined at each repetition, both the additive containing and the comparable nonadditive control group are listed at the representative additive concentration (see explanation in text).

Table II. Effect of Vacuum and Additive on Beef Volatiles

	anchor			treatment[c] ppm of additive									
						EVO			ENA			EVA		
descriptor	25[d]	50[d]	100[d]	SNO av	ENO all	25[d]	50[d]	100[d]	25	50	100	25	50	100
TBARS (ppm)	12.8	14.4	12.7	32.2	100.0	47.5	62.4	49.6	28.3	22.6	17.6	13.6	10.6	10.3
pentanol[a]	10.7	13.1	8.3	26.1	100.0	31.0	30.4	27.4	35.1	14.8	12.2	12.0	8.4	5.0
hexanal[a]	102.2	143.0	84.6	27.1	100.0	16.9	13.7	13.0	41.2	21.3	17.4	5.4	0.8	9.1
2,3-octanedione[a]	14.1	26.3	12.8	32.6	100.0	36.2	26.2	28.7	30.0	20.3	16.9	25.5	11.9	7.4
total[a,b]	212.1	300.9	159.8	36.2	100.0	36.0	32.8	34.1	55.4	38.1	29.2	27.2	23.5	15.2

[a] All anchor numbers are presented as computer-generated area counts in thousands. The anchor is represented by the maximum area under the curve for the off-flavored chemical marker, i.e., the patties stored for 3 days. Anchor values are presented for all descriptors to facilitate recalculation of raw data by the reader. [b] Represent the total volatiles which include propanol, butanol, pentenal, pentenol, hexanal, 2,3-octanedione, nonanal, and decanal. [c] SNO = standard, freshly cooked burger with no vacuum and no additives. ENO = 3 day cooked/stored patty. EVO = ENO maintained under vacuum. ENA = EVO containing equal amounts of additives (propyl gallate and EDTA) at the concentrations listed. EVA = ENO with the vacuum and additives. [d] While these samples did not contain additives, they are shown to reflect that each experiment (repetition) incorporated all five treatment groups.

Table III. Pearson Correlation Coefficients of Beef Sensory Attributes[a]

	CBB	PTY	SER	BRC	CKL	CBB	SOU	SWT	BTR
CBB	1.0000								
PTY	−0.5556	1.0000							
SER	0.0596	−0.1039	1.0000						
BRC	0.5700	−0.2995	0.0604	1.0000					
CKL	0.1920	−0.0093	0.0433	0.1835	1.0000				
CBD	−0.5869	0.7875	−0.0635	−0.3503	−0.1147	1.0000			
SOU	−0.4269	0.3968	0.2964	−0.4478	−0.1978	0.4076	1.0000		
SWT	0.4078	−0.3754	0.0700	0.4009	0.1859	−0.4179	−0.3359	1.0000	
BTR	−0.4643	0.2496	0.2410	−0.2562	−0.1781	0.3223	0.6186	−0.3297	1.0000

[a] Numbers are Pearson correlation coefficients (additive) determined from 393 separate observations of raw data. None of the additives were significantly different than zero. Abbreviations define the sensory descriptor as follows: CBB = cooked beef/brothy, PTY = painty, SER = serum/raw, BRC = browned/caramel, CKL = cooked liver, CBD = cardboard, SOU = sour, SWT = sweet, and BTR = bitter.

of 3-day storage. The addition of antioxidant/chelator mixture to the patties retarded the development of off-flavors and the deterioration of desirable flavors in a dose dependent manner (see "ENA" Figure 1 and Table I). A synergistic, dose-dependent response resulted when vacuum storage was coupled to the addition of the antioxidant/chelator mixture ("EVA" in Figure 1 and Table I).

Effect of Vacuum and Additives on the Chemical and Instrumental Attributes of Beef. Data obtained for TBARS levels and GC–volatiles show a pattern similar to that of undesirable sensory descriptors. For example, vacuum storage, "EVO" (Figure 2; Table II), significantly retards the production of the chemical markers of rancidity. The addition of antioxidant and chelator mixture shows a dose-dependent protection against the development of rancidity ("ENA"; Figure 2 and Table II). There is a synergistic and dose-dependent response of beef markers of rancidity development to the combination of vacuum storage and antioxidant/chelator mixture addition ("EVA"; Figure 2 and Table II).

Statistical Evaluation of the Data. Statistical analysis of raw sensory data include 363 separate observations. The data show strong correlations (Table III), both negative and positive, among many of the descriptors. Values greater than 0.4 are very highly correlated ($P < 0.001$) while values greater than 0.3 and less than 0.4 are highly correlated ($P < 0.01$). Therefore, examination of the correlation coefficients in the column labeled "CBB" (cooked beef/brothy) reveal that "PTY", "CBD", "SOU", and "BTR" (painty, cardboard, sour, and bitter, respectively) have a strong negative correlation with "CBB" while "BRC" and "SWT" have a strong positive correlation with "CBB". The strongest positive correlations are between the aromatic off-flavor descriptors "CBD" and "PTY" (0.7875) and the off-flavor tastes "BTR" and "SOU" (0.6186).

Principal factor analysis, a multivariate statistical method that yields an empirical summary of patterns of correlation(s) among variables, was used to reduce a large number of variables into a number of "factors". In this study, the factors were generated to permit graphical depiction of the correlations among the experimental treatments and the chemical, instrumental, and sensory attributes of beef patties (Figure 3). Because of the large number of variable combinations in this study, the factors were presented on two fully superimposable plots (Figure 3, left and right); the left-hand plot shows the factor distribution of the treatments whereas the right-hand plot shows the distribution of the sensory and chemical/instrumental attributes.

The curved–dashed line in the left-hand plot indicates the trend of the treatments. This trend is from a most desirable flavor region located in the lower right of the grid to the region of more undesirable flavor in the upper portion of the grid. The desirable flavor region is represented by the triangle defined by the coordinates of "SNO 1–3" (standard patties). The undesirable flavor region is represented by "ENO 1–3" (3-day MFD patties). When the 3-day MFD patties ("ENO 1–3") are stored under vacuum ("EVO 1–3"), the coordinates approach that of the standard, fresh-cooked patties (near the XY intercept). Examination of the PFA factors derived from the patties containing the propyl gallate/EDTA (antioxidant/chelator) mixture, "ENA 1–3", show an interesting spread. The patties containing 25 ppm move from the area occupied by the undesirable "ENO" group down toward the more desirable patty region ("SNO 1–3"). As the concentration of the additive is raised from 25 to 50 and 100 ppm (ENA-1, ENA-2, and ENA-3, respectively), the PFA factors approach that of the standard patties. Combining vacuum storage with the portioned addition of additive ("EVA 1–3") yields a factor distribution that reflects the dose-dependent response of additives alone with the added downward response of vacuum, i.e., a synergistic response.

The right-hand graph shows the factor distribution for the chemical, instrumental, and sensory attributes. The

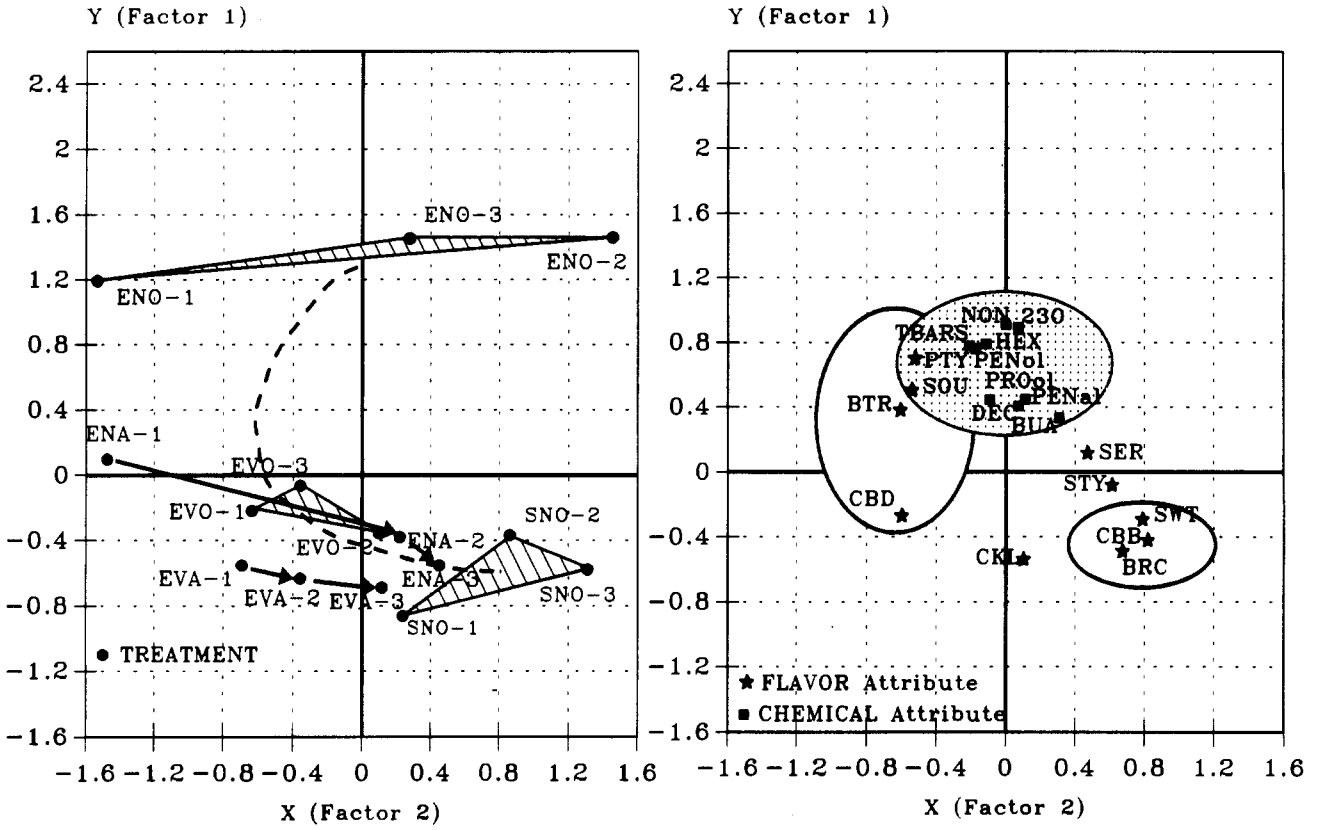

Figure 3. Factor analysis. A principal factor analysis was performed on all raw data to develop the factor solution. The factor scores for all experimental treatments, sensory flavor attributes and chemical and instrumental attributes are plotted for comparison of distribution within the grid. The graph on the left represents the coordinate distribution of the treatment data while the graph on the right represents the coordinate distribution of the flavor (stars) and the chemical (squares) attributes using the same *XY* coordinates. The numbers −1, −2, and −3 following the abbreviation for the treatment represent the 25, 50, and 100 ppm group of experimentals and controls. The curved–dashed line represents an eyeball judgement of the trend of the data. Volatiles and sensory attributes are represented as follows: Volatiles: NON = nonanal, 23O = 2,3-octanedione, HEX = hexanal, TBARS = thiobarbituric acid reactive substances, PROol = propanol, PENol = pentenol, PENal = pentenal, DEC = decanol, and BUA = butanol. Sensory descriptors: SOU = sour, PTY = painty, BTR = bitter, CBD = cardboard, CKL = cooked liver, STY = salty, SER = serumy, SWT = sweet, CBB = cooked beef/brothy, and BRC = browned/caramel.

off-flavor chemical markers, e.g. TBARS and GC–volatiles, cluster in the same region of the grid as do the off-flavor treatments described above. On the other hand, the flavor attributes show a bifunctional clustering dependent upon their flavor response. For example, "PTY", "SOU", "BTR", and "CBD" all cluster in the area of the grid associated with the off-flavor treatments, the off-flavor chemical marker (TBARS), and the off-flavor lipid volatiles (NON, 23O, HEX, PENol, PROol, PENal, DEC, and BUA). "SWT", "CBB", and "BRC" cluster in the area of the grid associated with desirable freshly cooked patties.

SUMMARY AND CONCLUSIONS

Many of the compounds identified in meat are products of free-radical reactions generated as a result of lipid oxidation; these compounds generated during cooking and subsequent refrigerated-storage play an important role in the development of the distinctive flavor character of meats (Shahidi et al., 1986). Hornstein and Crow (1960) and others (Sink, 1979; Wassermann, 1979) suggested that the fat portion of meat contributed to the unique flavor that characterizes meat of one species from that of another, such as beef, pork, lamb, etc. It is generally accepted that the development of rancidity in meat, and the loss of desirable flavors is via free-radical mechanisms mediated through lipid oxidation (Asghar et al., 1988; St. Angelo et al., 1988; Spanier, 1992; Spanier et al., 1992a,b). As lipids oxidize, they produce many secondary reaction products, such as alcohols, hydrocarbons, ketones, fatty acids, and aldehydes, each capable of supplying a different aroma, and collectively, several different aromas (Wassermann and Talley, 1968; Forss, 1972; Frankel, 1984; Gasser and Grosch, 1988; MacLeod and Ames, 1986), thereby affecting food flavor, usually in a negative manner. While lipid peroxidation is considered the primary means of flavor deterioration in muscle foods, there are divergent opinions regarding the mechanism of initiation of the peroxidative events. Lipid oxidation has been ascribed to the catalytic effect of both free and bound iron (Pearson et al., 1977; Igene et al., 1979), to iron in both the ferrous and ferric state (Minotti and Aust, 1987), to enzymatic processes (Svingen et al., 1979; McDonald and Hultin, 1987), and to changes in the ground state of molecular oxygen (Chan, 1987; Foote, 1985). The experiments performed in this investigation were designed to examine several of these mechanisms and the structure–activity relationship of these mechanisms to food flavor.

Multivariate results may be generated from data in systems having several mechanisms, e.g. those mechanisms responsible for initiation of lipid peroxidation. Factor analysis is designed to simplify the relationships that exist in a multivariate data set by isolating and identifying redundancies. The basic relationships or similarities between the variables used in the factor analysis are typically determined using Pearson correlation coefficients (Table III). Data generated in experiments such as those described above show that numerous mechanisms do exist. For example, the initiation of flavor deterioration by iron,

verified by analyses of variance, is demonstrated by the raw data (Figures 1 and 2) and the statistical results seen for the use of the chelator, EDTA, and an antioxidant, propyl gallate (PG) mixture (Figure 3). In this case, the data distributes, and the factors cluster, in a manner consistent with the addition of several levels of EDTA/PG (Figure 3). Exclusion of molecular oxygen shows an effect different from that of EDTA/PG (Figures 1–3). A synergistic effect is seen by the combined use of oxygen exclusion with chelator/antioxidant (Figure 1–3). Independent use of EDTA and PG shows that this chelator and antioxidant, respectively, exert independent effects (St. Angelo et al., 1992). Therefore, factor analysis can illustrate that several mechanisms (variables) affect the flavor quality of beef derived from lipid oxidation.

Multivariate statistical procedures, such as those used in this study, offer advantages over univariate statistical procedures in that they are better able to deal with many variables simultaneously and thereby uncover relationships that could not be seen when examining the variables one by one. Factor analysis, representing multicollinear structures, reflects the degree of covariance and not strict membership in one group or another. Thus with factor analysis it was possible to find stimuli whose response patterns were the result of more than one underlying process. Information obtained from such statistical evaluation of model systems will augment the understanding of the mechanisms initiating flavor decline as well as the complex responses of flavor components to different situations, such as different postmortem conditioning procedures, cooking means, and cooking/storage situations. More importantly, the knowledge generated from these models will permit food scientists to formulate better management methods to maintain and enhance food flavor and help to develop better predictive, adaptive, or management methods for enhancing flavor quality.

ACKNOWLEDGMENT

Materials contained in this paper were presented in preliminary form in 1989 at the 50th annual meeting of the IFT held in Chicago, IL. We thank Dr. Brian Vinyard for his comments and assistance in some of the statistical analysis of the data set. We also thank Dr. Harold P. Dupuy, Dr. Karen L. Bett, Mr. Larry Boihem, Mr. Maurice Brett, Mr. James Miller, Ms. Donna Sullen, and Mrs. Carolyn Vinnett for their technical assistance and discussions during various portions of this study. We are grateful to Drs. B. Vinyard, K. Ehrlich, and Roy Teranishi for participating in the preliminary review of the manuscript as well as in some discussions of our experimental data.

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Received for review March 23, 1992. Revised manuscript received May 26, 1992. Accepted June 15, 1992.

Registry No. PG, 121-79-9; EDTA·4Na, 64-02-8; NON, 124-19-6; 23*O*, 585-25-1; HEX, 66-25-1; PROol, 71-23-8; PENol, 11098-57-0; PENal, 31424-04-1; DEC, 112-30-1; BUA, 71-36-3; oxygen, 7782-44-7.