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Volatile compound characterization of modified atmosphere packaged ground beef held under temperature abuse

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ABSTRACT

The effect of modified atmosphere packaging (MAP) on headspace volatile compounds of raw ground beef, as profiled by solid phase microextraction (SPME), was studied. Raw ground beef patties (81:19 lean:fat) were packaged in high oxygen MAP (80% O_2, 20% CO_2) or carbon monoxide MAP (COMAP) (69.6% N_2, 0.4% CO, and 30% CO_2) atmospheres. Packages were stored at 22 °C under continuous fluorescent lighting (1530 lux). Package headspace was sampled over a three consecutive day trial by SPME and then analyzed by gas chromatography/mass spectrometry. In total, 20 volatile compounds were separately identified in the headspace of COMAP and high oxygen MAP packages; the progression of time evidenced development of known spoilage-associated compounds including several hydrocarbons and hexanal. The identification of compounds in similar relative abundance in both package types suggest their development via alternative oxidation and non-oxidation pathways.

1. Introduction

The market introduction of several MAP designs has generated a battery of scientifically or publically founded food safety issues that remain partially unresolved (Cornforth & Hunt, 2008; European Commission, 2001). The accomplishments of COMAP in amending the shortcomings of traditional polyvinyl chloride overwrap packaging have found limited commercial success as a result of a cautious public reception related to carbon monoxide exposure (European Commission 2001; McMillin, 2008). Conversely, the use of high oxygen MAP retains concerns related to the accelerated oxidation of meat pigments and formation of undesirable lean color—as well as those related to human health—such as consumption of hazardous oxidation byproducts (Greene, Hsin, & Zipser, 1971; John et al. 2005; Mancini & Hunt, 2005). Recent sensory evaluation of beef cooked after storage in high oxygen MAP was rated lower in consumer scores for juiciness, flavor, and overall liking versus beef from traditional skin (low-oxygen) packaging (Geesink, Robertson, & Ball, 2015). Further discussion as to the myriad issues surrounding MAP and meat packaging technologies is beyond the scope of this manuscript (for an excellent up-to-date overview of the topic see Sofos et al. 2012).

Although research characterizing the shelf-life and quality influences of high oxygen (80% O_2, 20% CO_2) and COMAP systems (69.6% N_2, 0.4% CO, and 30% CO_2) have received extensive attention (Cornforth & Hunt, 2008; McMillin, 2008), little is understood regarding the formation of volatile compounds under these packaging conditions (Insausti, Goni, Petri, Gorraiz, & Purroy, 2002). That the Food and Drug Administration has designated the use of low-levels of carbon-monoxide gas in the retail packaging of meat as generally recognized as safe should urge the scientific community to immediately answer any remaining questions pertaining to the use of CO and food safety (Tarantino, 2004). A significant disadvantage of CO-MAP is that a preserved cherry-red color in meat due to the formation of carboxymyoglobin has been associated by consumers with the masking of visual spoilage indicators (Sorheim, Nissen, & Nesbakken, 2001). A greater understanding of the processes involved in each package type will enhance the information available to formulate and address public concern. Particularly, knowledge regarding the volatile composition of meat in various package types will provide valuable information about

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the production of metabolites and development of compounds that may be detrimental to meat quality or human health.

To our knowledge, investigation into the volatile odor composition of raw meat packaged under COMAP has not been conducted. Similarly, parallel exploration into high oxygen MAP is limited and that which does exist does not incorporate solid phase microextraction (SPME) into a complete gas chromatography mass spectrometry (GC/MS) analytical system (Insausti et al. 2002). The combination of SPME with GC-MS as an analytical tool to describe ground beef volatile composition has been previously demonstrated (Perez, Rojo, Gonzalez, & Lorenzo, 2008; Watanabe, Ueda, Higuchi, & Shiba, 2008). However, SPME-GC-MS has not previous to this study been applied to the investigation of spoiled-state ground beef volatile profile.

The purpose of this study was to refine a method aimed to quantify and characterize the headspace volatile composition of high-oxygen and COMAP ground beef over time. A temperature abuse model was used to accelerate spoilage and accommodate the development of volatile compounds related to meat spoilage (Limbo, Torri, Sinelli, Franzetti, & Casiraghi, 2010). The methods developed and data obtained from this study will be of primary importance in several areas of meat research, particularly in areas related to the development and understanding of compounds that are either beneficial or harmful to not only food quality, but human health. Such an understanding may be useful in ameliorating the public concern of package types that possess known shelf-life advantages.

2. Materials and methods

2.1. Product and packaging

Fresh, coarsely ground beef (81% lean, 19% fat) was obtained from commercial fed-beef processors located in northern Texas immediately after its release from the company's “test and hold” program, and transported to Texas Tech University Gordon W. Davis Meat Science Laboratory (Lubbock, TX, U.S.A.) for preparation. The ground beef chubs were held at 0–2 °C for a period of 5–7 days in total darkness prior to packaging. On day 0 of the trial, coarsely ground beef was placed in a mixer (machine name KFM-110, model #A80 Koch Supplies, Inc., Kansas City, MO, U.S.A.) and blended, prior to finely grinding with a 3.2 mm grind plate attached to a commercial meat grinder (model 346SS Manual Feed Grinder, Biro Manufacturing Company, Marblehead, OH, U.S.A.), The finely ground beef was transferred to a patty forming machine (model 54, Hollymatic Corp., LaGrange, IL, U.S.A.) and portioned into 150 g patties of uniform thickness prior to packaging. Koch fm-110.

Single ground beef patties were placed in 25.4 × 15.2 × 7.6 cm white polypropylene trays (Cryovac Sealed Air Corp., Duncan, SC.,U.S.A., Oxygen Transfer Rate (OTR) = < 0.1 cc oxygen/tray/24 h at 22.8 °C and 0% relative humidity (RH); Moisture Vapor Transmission = 2.0 g water vapor/645.2 cm2/24 h at 37.8 °C and 100% RH) and sealed with a high barrier film (LID 1050, Cryovac, Inc.; OTR ≤ 25 cc oxygen/m2/24 h at 22.8 °C and 100% RH; MVT ≤ 0.1 g water vapor/645.2 cm2/24 h at 4.4 °C and 100% RH). Packages were flushed with either high oxygen (80% O2/20% CO2) or carbon monoxide (0.4% CO/30% CO2/69.6% N2) and sealed using a tray sealing machine (model CV.VG-S, G., Mondini, Brescia, Italy). The gas mixtures were obtained via a gas mixer (Checkmate 9900, PBI Dansensor, Glen Rock, NJ, U.S.A.) or from locally purchased (Airgas Inc., Lubbock, TX, U.S.A.) premixed compressed gas cylinders (ultra high purity). Gas mixture levels were evaluated using a headspace analyzer (model 333 Pac Check, Mocon, Minneapolis, MN, U.S.A.) on MAP packages not containing ground beef patties; these packages were discarded following testing and not included in the analytical trials. Packaging ensued if all values were within ±0.5% of the targeted O2, N2, and CO2 levels and 0.4% CO was measured in the carbon monoxide MAP gas blend with less than 0.5% residual O2 present.

Nine packages were produced for each packaging treatment (high oxygen MAP and COMAP) for evaluation over a three day period (days 0, 1, and 2; n = 3 packages per day). As indicated by Limbo et al. (2010), storage at greater than ideal temperatures accelerates the spoilage processes seen in ground beef. As such, all packages were stored at 22 °C under continuous fluorescent lighting (1530 lux) prior to volatile composition analysis. Each MAP package provided a single evaluation and was discarded following the volatile evaluation. An identical but separate set of high-oxygen and CO-MAP packages that did not contain meat were prepared, subjected to study parameters, and sampled. The headspace of these high-oxygen and CO-MAP packages were sampled in identical fashion to each treatment package in order to determine headspace volatile formation due to packaging material (data not shown).

2.2. Solid phase microextraction (SPME)

The atmosphere of each package was sampled at each interval by an SPME technique using Supelco SPME 85 μm Carboxen/PDMS Stableflex Fiber Assembly (Sigma Aldrich, St. Louis, MO, U.S.A). Selection of Carboxen/PDMS as the chosen fiber type was determined through literature review of fiber types employed successfully by other research teams in the analysis of raw, cooked, or simulated beef volatiles (Machiels & Istasse, 2003; Moon, Cliff, & Li-Chan, 2006; Perez et al. 2008; Watanabe et al., 2008). Solid phase microextraction fibers were individually placed in a single SPME fiber holder for manual injection (Supelco, Bellefonte, PA, U.S.A.) and preconditioned in the injector port of the GC at 300 °C for 30 min. Prior to sampling, a rubber foam septum was placed on the package film to prevent leakage of headspace or equilibration with the outside environment (Rotabakk, Wyller, Lekang, & Sivertsvik, 2008; Sharma et al. 2011). The SPME sheath containing the needle was then inserted through the septum; the SPME needle was exposed to the headspace of the package for a 40 min sampling time at a sampling temperature of 22 °C. At the end of the sampling time, the fiber was removed and immediately placed into the injector port of the GC for a desorption period of 3 min at a temperature of 250 °C. Each package was discarded following headspace sampling. Optimal extraction conditions of volatile compounds were determined through preliminary testing of intersecting times and temperature conditions respective to both sampling and desorption (data not shown).

2.3. GC/MS analysis

Characterization and quantification of volatile compounds was performed on a GC (model 6890A, Agilent Technologies, Santa Clara, CA, U.S.A.) linked with mass spectrometer (MS; model 5975B VLMSD, Agilent Technologies). A GC capillary column (forte BPX5, SGE) was used for analytical separation with helium as the carrier gas at a flow rate of 3.9 mL/min. The GC injection port was operated in splitless mode at a temperature of 250 °C. The GC oven temperature was operated at an isothermal run at 32 °C for 5 min followed by 8 °C/min ramp to 100 °C, then 12 °C/min ramp to 225 °C, and finally held at 225 °C for 5 min. The MS was run with an electron multiplier voltage of 1376 V, source temperature of 230 °C, quadrupole temperature of 150 °C, mass range m/z of 16–500, and scan rate of 3.0 scans/sec.

Volatile components were initially identified using a previously purchased MS library (Wiley 7th Edition Library for Mass