EVALUATING THE EFFECTS OF STORAGE TIME ON GAS FORMATION FROM RETAIL GROUND MEAT

By

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EVALUATING THE EFFECTS OF STORAGE TIME ON GAS FORMATION

FROM RETAIL GROUND MEAT

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Abstract: The objective of this study was to evaluate greenhouse gas emissions (GHG), specifically carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from raw and cooked ground beef. Shoulder clods were ground, formed into loaves, and displayed in a retail case. Following the retail display, the samples were collected for GHG analysis from raw and cooked samples (n = 4 replications). The samples were aged to either 7 or 14 d. Following aging, ground beef loaves were displayed under retail conditions for 3 days. Displayed samples were stored under dark at 4 °C (4, 8, and 11 days) to simulate meat storage conditions at home. Samples were cooked to 71.1 °C. Aerobic samples were sealed with atmospheric oxygen, and anaerobic samples were flushed with 100% nitrogen gas. During retail display, objective color measurements of a^* were recorded. Total plate count was conducted on days 4, 8, and 11. The aerobic condition had greater CO_2, CH_4, and N_2O formation compared with the anaerobic condition. Dark storage time had a significant effect on CO_2 formation, but not on CH_4 and N_2O. Aging time increased CO_2 and CH_4 formation ($P < 0.05$); however, the aging time had no effect on N_2O formation. Raw meat had greater greenhouse gas formation than cooked meat. Bacterial characterization identified *Carnobacterium divergens*, *Hafnia alvei*, *Lactobacillus sakei*, *Lactobacillus sakei*, and *Yersinia enterocolitica*. N_2O gas production was lesser from aged product, and cooked products had greater gas formation. The results suggest that incubation conditions, aging time, and storage time can impact GHG formation of ground beef products.

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INTRODUCTION

Enhancing the food system's efficiencies is critical with the anticipated increase in global population combined with the need to source safe, healthy, and sustainable food. This tasks agriculturists and scientists to seek out new technologies and methods to prevent food waste. The demand for animal proteins will rise drastically with an expected 3.5% increase in global Gross Domestic Product (GDP) and combined with a 34% world population increase by 2030 (Fiala, 2008). Not only are developing countries now able to afford more meat, but their rates of consumption are also predicted to increase. The total global protein demand, accounting for a population of 7.3 billion, is 202 million tons (Henchion et al., 2017). However, with an increase in the production and consumption of animal proteins, the issue of increased food waste, particularly meat waste, possesses a potential negative economic and environmental impact.

It has been estimated in the United States, Canada, Australia, and New Zealand, that approximately 22% of total meat and poultry production is discarded annually (Gunders, 2012). Wastage of meat can result from a variety of factors, including losses during fabrication and processing, cooking or serving a larger portion than is consumed, expiration or over-purchase in the home or in food service, or from a lack of marketability due to discoloration or inability to fulfill color expectations for consumers. A recent report suggests that in 2020 the United States meat industry wasted 5.8 metric tons of meat due to discoloration (Maia Research Analysis, 2020).

Meat discoloration can occur from various of factors such as higher retail display case temperature, muscle-specific differences in stability, lipid oxidation, microbial growth, and exposure to oxygen (Ramanathan et al., 2020; Mancini & Hunt, 2005). As a result, discolored meat is typically marked down, reground, or thrown into a landfill. It was reported in 2019 that meat waste due to discoloration resulted in a loss of $3 billion in the United States and $14.2 billion in loss globally (Maia Research Analysis, 2020).

While there are substantial economic impacts of meat loss, there is also a potential for irreversible environmental impacts. Various packaging types have made substantial progress in extending meat color in a retail setting. Recently, companies have started thinking about reducing the use of plastic in their packaging. For example, Perdue Farms® has made a switch to water dissolving biodegradable foam tray, and several other companies have replaced Sytrofoam™ trays with recycled cardboard (Kavilanz, 2020). However, meat wastage can substantially contribute to greenhouse gas production in landfills.

The Environmental Protection Agency reported that landfill gas, a natural byproduct from the breakdown of organic matter, is composed of 50% methane and 50% carbon dioxide and 15.1% of total human methane production comes from municipal waste (United States Environmental Protection Agency, 2018). In comparison, various studies have determined that pork production has generated 668 million tons of CO_2 equivalent, broiler chicken production accounts for 343 million tons of CO_2 equivalent, and beef accounts for 2.9 gigatonnes of CO_2 equivalent from the production lifecycle (MacLeod et al. 2013, Suszkiw, 2019). However, there is limited knowledge on the impact of meat waste on greenhouse gas production.

The objectives of this study were to determine the combined effects of aging, storage condition, and meat state (either raw or cooked) on greenhouse gas formation, specifically carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from ground beef loaves. We anticipate the results will add missing details of greenhouse gas formation from meat in the life cycle analysis and also could bring greater awareness to consumers about meat waste.

CHAPTER II

REVIEW OF LITERATURE

Food Waste and Environmental and Energy Impact

Food waste is defined as food appropriated for human consumption that is discarded. It can occur at the pre-harvest level in fruit and vegetables, post-harvest steps, such as processing, transport, over-purchase, or at the consumer level, and it can post detrimental environmental and energy impacts (Food and Agriculture Organization, 2013).

The United States Department of Agriculture Economic Research Service has estimated that 133 billion pounds out of the 430 billion pounds of edible food produced in the United States were not consumed in 2010. The retail and consumer losses were 43 and 90 billion pounds, respectively (Buzby et al., 2019). These losses are valued at over $161.6 billion USD, with the highest monetary losses resulting from meat, poultry, and fish (Buzby et al., 2019). Consumers in the United States are losing approximately 1% of their average disposable income, essentially losing 0.80 pounds of food per day, equivalent to almost $1 a day (Buzby et al., 2019). The Food and Agriculture Organization of the United Nations has estimated one-third of global food production deemed for human consumption is wasted every year (Food and Agriculture Organization, 2013). With the pressing need to feed an expected 9 billion people by the year 2050, the world cannot afford the massive amount of food waste, nor the environmental and energy impacts it can bring.

Wastage varies across the world with differing climates, soil types, economies, and food waste types. The overall quantity of wastage is not equally matched across the world. Bluewater footprints and carbon footprints have to be considered with varying threat levels globally. Bluewater footprints focus on the freshwater utilized to make a product, industrial or agricultural, while the carbon footprints broadly reference carbon production in greenhouse gases, whether they be from agricultural, industrial, or residential production (Hoekstra et al., 2011, Environmental Protection Agency, 2020).

Global food waste ranks as the third-highest total carbon footprint in the world and is only surpassed by the total carbon footprints of the United States and China (Food and Agriculture Organization, 2015). The highest contributor to the Food Supply Chain-Food Waste carbon footprint, specifically evaluating carbon footprint equivalents from all stages of the supply chain such as production, processing, or retail, was found at the consumer level. The average carbon footprint from food waste is about 500 kg CO_2 per capita per year (Food and Agricultural Organization, 2013). Global water footprints in 2007, based on consumption and withdrawals, revealed the blue water footprint was approximately 250 km^3, and compared to all other countries sampled, the blue water usage from food waste alone had the highest water footprint (Food and Agricultural

Organization, 2013). When focusing on arable land, land available for crops or suitable for grazing, food wastage in 2007 was at almost 1.4 billion hectares, almost equivalent to 28% of total global agriculture land (Food and Agricultural Organization, 2013). With such losses, the potential for irreversible global environmental impacts could be faced (Food and Agriculture Organization, 2015).

Meat Waste

Meat is a nutrient-dense food. With an expected annual Gross Domestic Product (GDP) increase of 3.5% and a 34% world population increase by the year 2030, it has been predicted the demand for animal proteins will also drastically rise. For example, beef is anticipated to have a 32% increase in demand, pork 73%, and chicken 110% by 2030 (Fiala, 2008). It has been estimated that in the United States, Canada, Australia, and New Zealand, 22% of total meat production is wasted annually (Gunders, 2012). Wastage of meat can result from a variety of factors, including cooking or serving a larger portion than is consumed, expiration or over-purchase in the home or in food service, or from a lack of marketability due to discoloration. Globally, total meat loss due to discoloration or lacking color expectations for consumers for 2020 is anticipated to be over 5.8 metric tons (Maia Research Analysis, 2020).

Meat discoloration can occur from a variety of factors such as higher retail display case temperature, muscle-specific differences in stability, lipid oxidation, microbial growth, and exposure to oxygen (Elroy et al., 2015; Mitacek et al., 2019;

Mancini & Hunt, 2005). It was reported in 2019 that meat waste due to discoloration resulted in a loss of $3 billion in the United States and $14.2 billion in loss globally (Maia Research Analysis, 2020).

Meat waste also poses a threat to the environment. Greenhouse gases are emitted throughout animal life cycles during production and processing. Since meat is organic, its wastage can result in greenhouse gases. While packaging studies and packaging types have made substantial progress in extending meat color in a retail setting, meat and its packaging are still piling up in landfills. However, Perdue Farms has made the switch to water dissolving biodegradable foam tray, and several other companies have replaced Sytrofoam™ trays with recycled cardboard (Kavilanz, 2020). Despite these efforts, meat wastage can substantially contribute to greenhouse gas production in landfills.

The estimated water footprint of meat was predicted to be almost one-third of the total agricultural water footprint, taking into account the production of feed, transportation, and yields of the animal (Gerbens-Leenes et al., 2013). Using beef as an example, applying the average dressing percentages and carcass weights, the estimated water usage in processing one beef carcass is 11 L per kilogram of boneless beef (Legesse et al., 2018). If annual meat waste is applied at 22% combined with the estimated demand for beef in metric tons by the year 2027, the world would lose not only 12,090 metric tons of beef but would also be wasting over 860 million liters of water just in processing (Organization of Economic Co-operation Development and the Food and Agricultural Organization, 2018, Fiala, 2008).

Recent research has utilized artificial intelligence and eye-tracking technology to study consumer purchasing behavior to analyze time spent looking at the nutritional information, labeling claims, or the product as a whole. Samant and Seo (2016) reported participants with a high-level understanding of a meat product looked at sustainability and processing claims for longer amounts of time compared to those without any prior knowledge. Preferences and background knowledge can span gender, socioeconomic factors, as well as region or country of purchase. For example, in a Portuguese experiment, it was observed that females had a significantly higher attraction to beef steaks with less external fat compared to males (Banovic et al., 2016), and further research could prove significant to a greater understanding of global consumer habits.

Greenhouse Gas Formation

Greenhouse gases can be defined as gases that trap heat in the atmosphere, and their typical composition consists of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases such as hydrofluorocarbons, and each can pose different environmental threats or have specific effects (Environmental Protection Agency, 2020). The Environmental Protection Agency has reported that landfill gas, a natural byproduct from the breakdown of organic matter, is composed of 50% methane and 50% carbon dioxide, and 15.1% of total human methane production comes from municipal waste (United States Environmental Protection Agency, 2018). Many food items will produce a variety of greenhouse gases. The most commonly produced gases and those that are seen in the greatest volumes are CO_2, CH_4, and N_2O. Considering a full life cycle analysis for greenhouse gas formation, emissions from food wastage have been estimated to be approximately 2.7 gigatons of CO_2 equivalent or Gt CO_2e (Food and Agriculture Organization, 2014). Although the focus of previous research was on all food types, limited knowledge is currently available on the impact of meat on greenhouse gas formation.

CO_2 is already present in the atmosphere; however, with human-related emissions, including the emissions from the breakdown of organic matter from food waste, emissions have been on a steady incline, increasing 5.8% from 1990 to 2018 (Environmental Protection Agency, 2020). In 2018, CH_4 accounted for approximately 9.5% of all United States greenhouse gas emissions from human activities; however, manure, livestock, wetlands, and wastewater are large contributors to total CH_4 emissions (Environmental Protection Agency, 2020). Pertaining to wetlands, manure, or food waste, bacteria breaking down the organic materials in the absence of oxygen will also produce methane. N_2O accounts for approximately 6.5% of the United States greenhouse gas emissions from human activities, and can result from various agricultural fertilizers, manure management, or soil management, along with fuel combustion (Environmental Protection Agency, 2020).

The Environmental Protection Agency has stated that food is the largest category of waste in municipal landfills, where food waste emits a medley of greenhouse gases. In 2017 alone, only 6.3% of the 41 million tons of food wasted were used for composting

(Environmental Protection Agency, 2020). A visual of gas resulting from food waste in a landfill would be similar to tying food in a plastic bag; the nutrients are never returned to the soil, and the rotting food can produce CH_4 gas (Environmental Protection Agency, 2020).

When analyzing gas formation from municipal waste, temperature can also play an effect on the amounts of gas produced. A study observing the production of methane and nitrous oxide from compost consisting of municipal food waste at set temperatures of 40, 55, and 67 °C found carbon dioxide equivalents from methane were higher than from nitrous oxide except for the composts run at 67 °C (Ermolaev et al., 2015). In another study, utilizing the EX-ACT, a model to account for multiple environmental practices, greenhouse gases, and carbon pools, it was found in those developing countries that processing, transport, and storage inefficiencies were responsible for the food waste. This suggests that their supply chain was more responsible for gas contribution in municipal waste, compared to more developed nations whose gases are a result of excess at the consumer and retail level (Galford et al., 2020).

NASA's Global Climate Change has observed a simple molecule in the atmosphere, the hydroxyl O.H. radical can act as a self-recycling detergent in the atmosphere (Gray, 2018). CH_4's current atmospheric lifecycle is estimated to be nine years, but the lifecycle can be cut down and regulated by this detergent. Nitrogen oxides aid the detergent in the self-recycling process, as the breakdown of methane products react with the nitrogen oxides for the O.H. to be recycled back into the atmosphere (Gray, 2018). However, Global Warming Potentials (GWP) should be considered when calculating the given effect of gases in the atmosphere as it allows the comparison of different gases. A larger GWP is indicative that a given gas warms the Earth more compared to CO_2, typically measured over a time span of 100 years (Environmental Protection Agency, 2020). Since CO_2 is a reference gas, its GWP will remain at a constant of 1, and its increase in concentration can last thousands of years. CH_4's GWP is 28-36 over 100 years due to its ability to absorb energy greatly, and N_2O's GWP is 265-298 times that of CO2, remaining in the atmosphere for over 100 years (Environmental Protection Agency, 2020).

The Environmental Protection Agency has reported greenhouse gases (GHG) trap outgoing energy produced by the Earth and retain heat in the atmosphere which can disrupt the radiative balance of the Earth (Environmental Protection Agency, 2020). Greenhouse gases have the potential to alter climate and weather patterns, which is more commonly referred to as global warming (Environmental Protection Agency, 2020). With a minuscule change in overall global temperature, it has been predicted that sea levels could rise, population displacement and a disruption of the food supply could occur, as well as increased chances for flooding and infectious diseases (Feldscher, 2011).

Bacteria in Meat

Spoilage bacteria assist in the breakdown of organic matter and can produce greenhouse gases. More specifically, carbon, nitrogen, and hydrogen atoms in organic matter are utilized by bacteria in the decomposition process (Utah State University, 2020). During decomposition, energy can be released through heat from oxidation of carbon. When materials are piled onto each other the temperature can range from 72.2-77.7 °C. A previous study observing temperature and moisture variations effect on the lag phase of the bacterial growth curve found higher temperatures, in this case, 30 °C, produced shorter lag periods even though it was not ideal for growth (Nicola & Baath, 2019). However, if higher temperatures were investigated, there may have been a much shorter lag phase, as the USDA's Food Safety and Inspection Service reports temperatures above 60 °C will destroy bacteria (United States Department of Agriculture Food Safety and Inspection Service, 2013). With temperatures exceeding 60 °C, it is possible to destroy bacteria's growth that can assist in protein decomposition. However, thermophilic bacteria, which can withstand temperatures of over 80 °C, will breakdown proteins and can sustain growth in a landfill environment (Suzuki et al., 2006).

Animal-based proteins are much more difficult to degrade. Incineration has previously been used to dispose meat products; however, some researchers have suggested shifting focus to thermophilic bacteria to assist in meat breakdown. Prions, extracellular matrix proteins, and keratins can be difficult to break down, and across multiple industries, their rigid structures resist proteases, but thermophilic bacteria are capable of breaking down their structural composition. With an elevated temperature range in which thermophiles thrive, proteins can be weakened and are made more susceptible to break down, and specific microbes with strong proteolytic activity spread bacterial toxins over the proteins and can break through the extracellular matrix (Suzuki et al., 2006). Potential use for thermophilic degradative enzymes could decompose other pathways or mechanisms and could even be used in the treatment of neurological degenerative diseases (Suzuki et al., 2006).

When landfills reach their capacity, they are typically capped with a layer of clay, reducing the amount of water let in and oxygen exposure, creating an anaerobic environment. Anaerobic conditions can greatly slow decomposition, and with the CH_4 gas produced being trapped by the clay barrier, it must be burned or released to avoid hazards from its flammable and explosive properties (Utah State University, 2020). The production of CH_4 and CO_2 can result from fermentative microbes, referred to as acidogens, hydrogen producing acetogens, and methane producing methanogens. For hydrolysis and acidogenesis, sugars, amino acids, and fatty acids are results from microbial degradation of biopolymers that are metabolized by fermentation products and other enzymes from microbial species and can be fermented to produce carbon dioxide and hydrogen (Food and Agriculture Organization, 1997). Through anaerobic digestion, methanogens can produce methane utilizing acetate or hydrogen or carbon dioxide, and if they utilize hydrogen or carbon dioxide for their production, they can limit atmospheric carbon dioxide production (Food and Agriculture Organization, 1997). Through secretion of enzymes and hydrolyzing of polymeric materials, acetogenic bacteria will convert volatile fatty acids to hydrogen, CO_2, or acetic acid, and methanogens will convert the previous products to either CH_4 or CO_2 (Food and Agriculture Organization, 1997).

Greenhouse Gas Quantification

While various studies have determined GHG emissions throughout meat animal and poultry production life cycles (MacLeod et al., 2013, Suszkiw 2019) there is limited knowledge on the impact of meat waste alone on GHG production. The greenhouse gas emission quantification differs across sectors, such as from industry or natural resources. There are several approved methods to measure and analyze gas composition. Direct emissions are defined as those of carbon dioxide from combustion fossil fuels as well as those of non-combustion from process emissions (Environmental Protection Agency, 2008). Indirect emissions are measured as carbon dioxide emissions from the generation of electricity by the specific sector (Environmental Protection Agency, 2008).

Out of all sectors measured for GHG emissions food and beverage ranked sixth, with fossil fuel combustion and electricity posing the highest CO_2 emission, and non-combustion for CH_4 emissions (Environmental Protection Agency, 2008). Utilizing fuel consumption from estimated and purchased electricity for production combined with emission factor data, the combustion, non-combustion, and purchased electricity gas generation was calculated. The data revealed over 50 million metric tons of CO_2 equivalents from fossil fuel combustion and purchased electricity was barely under 50 million metric tons of CO_2 equivalent (MMTCO2E) (Environmental Protection Agency, 2008).

To quantify soil GHG emissions, a study by the University of Vermont calculated greenhouse gas emissions and tested the carbon storage capabilities of soil from a variety of farms in Vermont. With manure present, N_2O and CO_2 emissions were increased with little impact from tillage, and high impact from temperature and nitrate levels in the soil (Goeschel, 2016). Farms selected varied in their soil management practices, including aerated, non-aerated, to-till, conventional, strip, vertical, and conventional tillage (Goeschel, 2016). This study utilized a 1412 infrared-photoacoustic-spectroscopy gas analyzer, and it was found that manure injection increased N_2O fluxes and aeration decreased them, and no-till decreased CO_2 the most (Goeschel, 2016).

Another method of GHG quantification revolves around metrics and calculations of GWP. The CO_2 equivalent is also a metric used to compare gas emissions based on their GWP and convert amounts of gases to MMTCO2E. The GWP of CH_4 is 28-36 and would indicate 1 million metric tons of CH_4 is equivalent to 25-36 metric tons of CO_2 (Eurostat, 2017). The GWP of N_2O is 265-298 times that of CO_2 and would be equivalent to 265-298 metric tons of CO_2 (Eurostat, 2017).

The Varian gas chromatograph, a method for reading specific headspace concentration of any sample, manufactured by Agilent Technologies, has two methods of quantifying GHG emissions. The first method consists of single-channel that utilizes dual detectors for analysis of CO_2, CH_4, N_2O and sulfur hexafluoride (SF6) in samples (Wang, 2010). The second method uses two channels and three detectors for wide concentration levels, allowing for lower levels of CO_2 to be converted to CH_4 and higher levels to remain as CO_2 in the samples (Wang, 2010).

The objectives of this study were to determine the effects of aging, storage condition, and meat state, either raw or cooked, on greenhouse gas formation, specifically carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from ground beef loaves. More specifically, the objectives were:

(1) to determine the effects of aerobic and anaerobic conditions on greenhouse gas formation from raw ground beef loaves

(2) to compare greenhouse gas formation from raw and cooked ground beef when incubated at aerobic conditions.

CHAPTER III

MATERIALS AND METHODS

Product Collection and Storage

A flow-chart showing sample allocation is included in Figure 1. Eight beef shoulder clods (clods are considered a large muscle system and include *infraspinatus*, *teres major*, and *triceps brachii,* IMPS 114, North American Meat Processors Association, 2002) were purchased from Creekstone Farms in Arkansas City, Kansas. Clods were transported on ice to the Food and Agricultural Products Center at Oklahoma State University. The samples were purchased within 3 d of harvest and remained in vacuum bags in dark storage at 4 °C until 7 d postmortem. Of the eight clods, four clods were randomly assigned to 7-d aging, and the remaining four were assigned to 14-d aging.

Grinding and Packaging

After 7 or 14 d aging, four clods packaged were opened, cut into chunks, and coarsely ground with a ½-inch stainless steel grinder plate (BIRO Model meat grinder, Biro Manufacturing Co., Marblehead, OH). Proximate analysis was performed with a FOSS FoodScan™ (FOSS Analytics North America, in Eden Prairie, MN). The ground samples were hand-mixed to ensure lean and fat particles did not congregate. After the desired protein fat ratio average was met (85% lean), meat from each clod was finely ground with a $^{3}/_{16}$-inch grinder plate.

Fine ground samples were hand-formed into eight loaves (approximate weight was 454 g; Mettler-Toledo scale, Mettler-Toledo, Columbus, OH). Meatloaves were placed into Styrofoam™ trays wrapped with a polyvinyl chloride (PVC) (oxygen-permeable polyvinyl chloride fresh meat film; 15,500 to 16,275 cm^3 O2/ m2/24 h at 23°C, E-Z Wrap Crystal Clear Polyvinyl Chloride Wrapping Film, Koch Supplies, Kansas City, MO) and heat sealed (Intertek Heat Seal, model 600A, Intertek USA Inc., Houston, TX).

pH

The pH of the ground clods was measured on day 7 and 14 using a Hanna pH meter (model HI 99163, Hanna Instruments Inc., Smithfield, RI) by inserting the pH meter. The pH measurements were recorded in triplicates and averaged for statistical analysis.

Retail Display and Instrumental Color Analysis

Packaged trays were placed in a coffin style retail case (Hussmann IM1SL, Bridgeton MO) set at 2.5°C (average temperature of 3.13°C; EL-USB-2-LCD temperature data logger, LASCAR Electronics Erie, PA). The product remained in the case for three days. The retail case was lit with Philips LED T8 Lamps (model number 9290011240B-453597, Niles, OH).

Instrumental color readings were recorded in three random locations on the product's surface every 24 h of retail display (0, 1, 2, and 3 d) using a HunterLab MiniScan spectrophotometer (HunterLab MiniScan®E.Z. spectrophotometer, model 4500L, Reston, VA). CIE L^* and a^* values were measured to represent lightness and redness. A greater L^* value indicates a lighter product, and a greater a^* values indicate a redder product. The instrument was standardized with white and black tiles before use.

Sample Preparation for Greenhouse Gas Analysis

After 7- or 14-day aging (Figure 1) and 3 days of retail display, each loaf was divided into three sections and assigned to 4, 8, and 11 days for storage in Ziploc® bags (to simulate storage of meat in the refrigerator at home). The days (4, 8, and 11) represent from the initial fine grind. The samples assigned to 4, 8, and 11 days were utilized for raw meat greenhouse gas analysis.

For cooking, approximately sixteen 100 g patties were hand-formed from the eight loaves and cooked to an internal temperature of 71.1 °C using a George Foreman Grill (Model GRP99 B, Beachwood, OH). The internal temperature was monitored using a meat thermometer (Alpha Grillers, Instant Read Thermometer, Anchorage, AK). The cooked patties were allowed to cool at 21.5 °C (room temperature) for 1 h. Five grams of cooked patties that contain both interior and exterior meat were placed in 20 mL glass vials headspace vials (Thermo Scientific™, Waltham, MA). Tubes were sealed with atmospheric oxygen and were left at 21.5 °C to incubate for 24 h ± 0.50 h before analysis.

The raw product from the loaves after 4, 8, and 11 days of storage, also comprised of a combination of interior and exterior meat, was weighed into either 5 g samples for gas readings or 11 g samples for aerobic plate count analysis. The meat samples were placed in vials and flushed with either nitrogen (to create anaerobic condition) or atmospheric condition. Nitrogen vials were flushed with certified 100% nitrogen (Stillwater gas, Stillwater, OK) gas for 30 s. Once gas tubes had been sealed and flushed, they were placed in a Ziploc® baggie as designated and were left to incubate at 21.5 °C for 24 h ± 0.50 h.

After incubation, cooked and raw tubes were analyzed using a headspace analyzer (Agilent Technologies Inc., Santa Clara, CA), to determine carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Standard tubes were filled with 10% and 4% CO_2 gas combinations, and ambient air was also utilized for standardization against the samples being read.

Total Aerobic Plate Count

The samples assigned to d 4, 8, and 11 were utilized for total aerobic plate count (APC). The samples were taken from vials incubated at 21.5 °C for 24 h ± 0.50 h. After open each vial, 10 g samples from each treatment were homogenized in 90 mL of sterile

0.1% peptone water in a sterile stomacher bag and paddled for 30 sec at 230 rpm utilizing a Stomacher 400 Circulator (Seward Laboratory Systems Inc., in Bohemia, NY). Microbial growth was determined by plating 1 mL of the sample homogenate (3M™ Petrifilm™ Aerobic Count Plate, St. Paul, MN, USA). The plates were incubated for 48 h at 37 °C and then counted, reporting the colony-forming units (CFU) per cm^2. Plates were counted in accordance with the 3M™ Petrifilm™ Aerobic Count Plate Interpretation Guide.

Statistical Analysis

The data were analyzed based on the objectives. A split-split-plot design was utilized to determine the effects of incubation conditions (aerobic vs. anaerobic) and effects of raw and cooked ground beef on greenhouse gas formation.

Objective 1: The whole plot consists of eight shoulder clods randomly assigned to either 7 or 14 aging periods (n = 4 at each aging period) and ground beef loaves were repeatedly measured to determine color during retail display. Within the subplot, ground beef loaves were assigned to raw and cooked patties. Within the sub-sub plot, raw and cooked samples were assigned to 4, 8, and 11 days of dark storage at 4 C. During dark storage, samples were collected at each dark storage time point for greenhouse gas emission analysis. The fixed effects for the whole plot consist of aging period and the random effect included error A (aging x unit). The fixed effects for the subplot was raw or cooked and the random effect was error B (aging x state x unit). The fixed effects for subsubplot include aging, state, dark storage, and their interactions. The unspecified residual error was used for the subsubplot random effect.

Objective 2: The whole plot consists of eight should clod randomly assigned to either 7 or 14 aging periods (n = 4 at each aging period) and ground beef loaves were repeatedly measured to determine color during retail display. Within the subplot, raw samples were assigned to 4, 8, and 11 days of dark storage at 4 °C. During dark storage, samples were collected at each dark storage time point for greenhouse gas emission analysis. Within the subplot, raw ground beef samples were incubated at either aerobic or anaerobic conditions. The fixed effects for whole plot consist of aging period and random effect included error A (aging x unit). The fixed effects for subplot was dark storage time and the random effect was error B (aging x dark storage x unit). The fixed effects for subsubplot include aging, incubation conditions, dark storage, and their interactions. The unspecified residual error was used for the subsubplot random effect.

For both objectives, Type-3 tests were performed using the Mixed Procedure of SAS (SAS 9.3; SAS Inst. Inc., Cary, NC). Least squares mean for the highest-order interactions determined to be significant will be presented. Least squares means were separated using the PDIFF option and were considered significant at $P < 0.05$.

CHAPTER IV

RESULTS

Proximate Analysis and pH

There were no differences (*P* > 0.05) in the fat, protein, or moisture percentages between 7- and 14-days aged products (Table 1). The pH values on day 14 was greater (*P* < 0.05) than that of day 7 (Table 1).

Color Analysis

For 7 days aged, retail day 0 and 1 were significantly different (*P* < 0.05) from d 2 and 3 (Table 2).

Total Aerobic Plate Count and Microbial Classification

There were no differences in APC between 14 d aged patties that were stored for 4 d and the 14 d aged and stored for 8 d. However, samples stored for 11 d had greater (*P* < 0.05) APC than 4 and 8 d (Table 3).

Bacteria in ground beef samples were characterized using a proteomic based approach (MALDI-Biotyper). Following bacteria were characterized under the aerobic condition: *Carnobacterium divergens (*very large amount), *Hafnia alvei* and *Lactobacillus sakei (*small amounts), *Lactobacillus sakei and Yersinia enterocolitica (trace amount)* (Table 4). However, no anaerobic bacterial growth was detected in the culture.

Effects of incubation condition (aerobic or anaerobic) on greenhouse formation

Table 6 indicates a significant difference between dark storage d 4 and 8 for CO_2. However, there was no difference in CO_2 formation between dark storage 8 and 11. There were no differences observed for CH_4 and N_2O among dark storage time (Table 6).

Aging time had an effect on CO_2 and CH_4 formation ($P < 0.05$); however, the aging time had no effect on N_2O formation (Table 7). The aerobic condition had greater CO_2, CH_4, and N_2O formation compared with the anaerobic condition (Table 8). There was a storage time and incubation time interaction for carbon dioxide (Table 9). Aerobic condition on day 4 had greater CO_2 formation than an anaerobic condition on day 4. In both aerobic and anaerobic conditions, dark storage time increased CO_2 formation.

There was aging time and dark storage time interaction for CO_2 formation (Table 10). Ground beef aged for 7 days and displayed for 4 d had greater ($P < 0.05$) CO_2 formation than aged 14 d and stored for 4 d. In both d 7 and 14 aging, dark storage time increased CO_2 formation.

There was an aging time and condition of incubation interaction for CO_2, CH_4 formation (Table 10). Ground beef aged 14 days and under aerobic conditions had greater ($P < 0.05$) CO_2 and CH_4 formation than aged 14 d and anaerobic condition. Aging time did not increase CO_2 and CH_4 formation under anaerobic conditions but increased for the aerobic condition.

There was a dark storage x aging x incubation condition interaction resulted for nitrous oxide formation. Ground beef aged for 7 days, stored for 4 days and incubated at aerobic condition had lower N_2O than ground beef aged for 14 days and stored for 4 days under aerobic condition. Ground beef aged for 14 days, stored for 4 days and incubated at aerobic condition had greater N_2O than ground beef aged for 14 days and stored for 11 days under aerobic condition.

Greenhouse gas formation from raw and cooked ground beef

The raw ground beef had lower CH4 than cooked when aged for 7 d. However, raw ground beef when aged for 14 d had greater CH4 formation than 7 d aged. There was a storage time x aging interaction resulted for N2O. When aged 14 d, there was no effect on storage time. However, the dark storage of 11 d had greater N2O compared with dark storage of 4 d for 7 d aged samples. Interestingly, cooked ground beef stored for 8 or 11 d had greater than 4 d stored samples.

CHAPTER V

DISCUSSION

Effects of incubation conditions on greenhouse gas emissions from raw ground beef

With the effects of aging, storage day, and anaerobic and aerobic conditions, various results were seen in levels of gas production of CO_2, CH_4, and N_2O. It was hypothesized that anaerobic conditions would produce greater gas levels as the Environmental Protection Agency reported in anaerobic bioreactor landfills with moisture in the waste, as with the moisture of raw meat samples, biodegradation would occur anaerobically and produce greenhouse gases (Environmental Protection Agency, 2019). However, for CO_2, CH_4, and N_2O, aerobically conditioned samples produced greater levels of gas.

Anaerobic samples were flushed with 100% nitrogen gas. Pure nitrogen has been found to be bactericidal with *Pseudomonas* and *Bacillus*, common bacteria found in meat, and with the death of these bacteria, degradation and gas production during decomposition could have been reduced (Munsch-Alatossava, P., & Alatossava, T., 2014). With the bactericidal capabilities of the nitrogen gas, the chances for growth and multiplication of these bacteria were very low. APC of this study revealed no significant differences ($P > 0.05$) in the aerobic or anaerobic conditions between the conditions of aging period 7 and period 14, but the production between anaerobic 7 and 14 as well as aerobic 7 and 14 was statistically different ($P < 0.05$). Samples were anaerobically analyzed by the Oklahoma Animal Disease Diagnostic Laboratory and had no growth detected, while aerobic samples produced bacteria from a range of trace to very large (Table 4). Bacterial decomposition and no growth detected in anaerobic samples imply that the samples' state and bacterial community can play a large part in greenhouse gas production and is an indicator as to why the aerobic samples actually produced significantly higher levels of gas.

It was also observed the shortest aging time had greater gas production compared to the second and longer aging treatment in the production of CO_2. Although the mechanistic basis for lower gas production with aging time is not clear, it has well documented that an increased aging period will change metabolites (Mitacek et al., 2019) and increase proteolysis (Nair et al., 2018). Therefore, differences in the metabolite profile have favored less for gas production.

Greenhouse gas formation from raw and cooked ground beef

In the current research, cooked meat had lower greenhouse gas formation. The USDA recommended cooking temperature to destroy bacteria present on the meat product could significantly affect total gas production and gas formulation (Wagner Jr., 2008). The raw state was significantly higher in all gases except for CH_4. The current research suggests that raw meat waste can contribute more to greenhouse formation than cooked meat.

Addressing food safety, the USDA designates the “danger zone” of meat to be between a temperature of 4.44 ° and 60 °C, and the bacteria found on the meat products at these temperatures can double in amount every 20 minutes with nutrients permitting (United States Department of Agriculture Food Safety and Inspection Service, 2011). When vials were incubated at room temperature, the meat both cooked and raw did have the potential for this great level of bacterial growth, however, with bacteria being destroyed by the cooking process, it is evident that raw product would have a greater amount of GHG formation resulting from high levels of bacteria.

For storage of leftover raw and cooked products, the meat in this study was identically stored in a walk-in cooler at 4 °C until it was taken out for its next pull day. The USDA instructs post-cooking, meat should be cooled again and refrigerated within 2 hours, which was performed in this study (United States Department of Agriculture Food Safety and Inspection Service, 2011). However, in future studies, cooked meat could be left out of the refrigerator to reintroduce bacteria to the product and imitate garbage conditions in order to see if this could affect gas production and have significant effects on all greenhouse gases that were analyzed in this study.

CHAPTER VI

CONCLUSION

With the need to feed the growing population with healthy and high-quality meat products, meat waste, and energy expenditures in its creation have to be reduced. The results of this study indicated that raw product in aerobic conditions produced higher levels of greenhouse gases (GHG) compared to anaerobic conditions and that raw product had greater gas formation compared to cooked products. Characterizing the factors influence greenhouse gas formation may help to minimize the impact of greenhouse gases on environment.

Figure 1: Summary of various treatment allocations

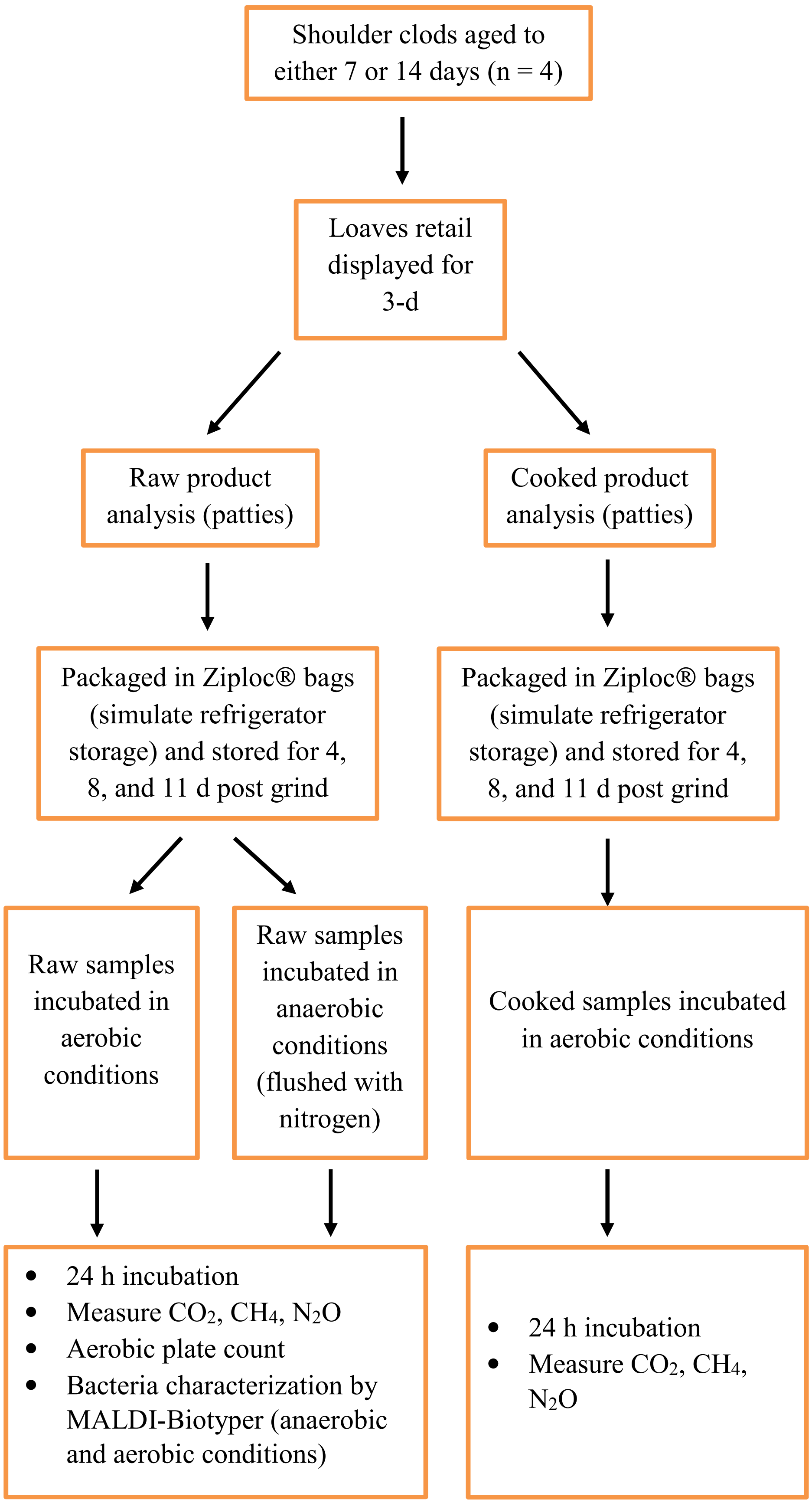

Figure 2: Pictorial representation of days allocation

Shoulder clod (n = 8)

Shoulder clod aged 7 d

(n = 4)

Shoulder clod aged 14 d

(n = 4)

7-day aging, followed by 3 days of retail display (red in retail, green in dark storage)

1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11

14-day aging, followed by 3 days of retail display (red in retail, green in dark storage)

1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11

Table 1. Effects of aging on fat, protein, moisture, and pH from ground beef loaves.

Aging	**Fat (%)**	**Protein (%)**	**Moisture (%)**	**pH**
7	17.12	18.20	64.42	5.55[a]
14	15.70	18.35	62.21	5.76[b]

[1]Aging: 7- and 14-d postmortem aged shoulder clods

Standard error: fat - 1.01, protein - 0.28, moisture - 0.71, pH - 0.03

Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 2. Effects of retail display time and aging on *a** values from ground beef loaves.

	Aging[2]	
Retail Display[1]	**7**	**14**
0	33.79[d]	33.09[d]
1	24.46[c]	33.09[d]
2	20.96[ab]	21.66[b]
3	17.65	18.51[b]

[1]Display: represents the displays of ground beef loaves in the retail display case
[2]Postmortem aging time
A greater *a** value indicates more red color
n = 4 shoulder clods with 2 loaves per clod
Standard error of retail display × aging: 1.23
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 3. Effects of storage, aging, and incubation conditions on total aerobic plate count formation from ground beef loaves.

		Storage[1]		
Aging[2]	**Condition[3]**	**4**	**8**	**11**
7	**Anaerobic**	7.22	7.48	7.25
7	**Aerobic**	7.23	7.46	7.27
14	**Anaerobic**	4.98[a]	5.08[ab]	6.78[bc]
14	**Aerobic**	4.92[a]	5.07[ab]	6.02[abc]

[1]Storage: samples of beef contained in airtight Ziploc® baggies 4-, 8-, and 11-days' post grind
[2]Aging: 7 and 14 d postmortem aged shoulder clods
[3]Condition: anaerobic- flushed with 100% nitrogen gas, aerobic- sealed with atmospheric oxygen
Unit: colony-forming units (CFU)
n= 4 shoulder clods with 2 loaves per clod
Standard error of storage × aging × condition: 0.73
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 4. Anaerobic and aerobic bacterial quantification and identification.

Condition	Organism ID
Aerobic	*Carnobacterium divergens/+5*
Aerobic	*Hafnia alvei, Lactobacillus sakei/*+2
Aerobic	*Carnobacterium divergens, Lactobacillus sakei/*+2
Aerobic	*Yersinia enterocolitica/*+1
Anaerobic	N/A
Anaerobic	N/A

Muscle sample: 4 samples, 2 analyzed as anaerobic, 2 as aerobic
Condition: anaerobic- flushed with 100% nitrogen gas, aerobic- sealed with atmospheric oxygen
Amount*: 0= no growth detected, +1= trace, +2= small, +3= medium, +4= large, +5= very large
Unit: colony forming units (CFU)
n= 4 shoulder clods

Table 5. Effects of storage time on carbon dioxide, methane, and nitrous oxide gas formation from ground beef loaves.

Storage	**Carbon Dioxide**	**Methane**	**Nitrous Oxide**
4	92,591[a]	3.18	0.52
8	117,329[b]	2.65[a]	0.54[a]
11	124,660[b]	2.66[a]	0.33[a]

[1]Storage: samples of beef contained in airtight Ziploc® baggies 4-, 8-, and 11-days' post grind
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error: carbon dioxide- 4,555.33, methane- 0.33, nitrous oxide- 0.15
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 6. Effects of aging time on carbon dioxide, methane, and nitrous oxide gas formation from ground beef loaves.

Age	Carbon Dioxide	Methane	Nitrous Oxide
7	139,207[a]	1.77[a]	0.15
14	83,847[b]	3.89[b]	0.15

[1]Aging: 7- and 14-d postmortem aged shoulder clods
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error: carbon dioxide- 4,729.13, methane- 0.37, nitrous oxide- 0.15
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 7. Effects of incubation conditions on carbon dioxide, methane, and nitrous oxide gas formation from ground beef loaves.

Condition	Carbon Dioxide	Methane	Nitrous Oxide
Anaerobic	50,480[a]	0.80[a]	0.30[a]
Aerobic	172,574[b]	4.86[b]	0.63[b]

[1]Condition: anaerobic- flushed with 100% nitrogen gas, aerobic- sealed with atmospheric oxygen

Unit: parts per million (ppm)

n= 4 shoulder clods with 2 loaves per clod

Standard error: carbon dioxide- 3995.60, methane- 0.33, nitrous oxide- 0.14

Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 8. Effects of storage, aging, and incubation condition on carbon dioxide gas formation from ground beef loaves.

		Storage[1]		
Aging[2]	**Condition[3]**	**4**	**8**	**11**
7	**Anaerobic**	65,340^{b}	81,264^{bc}	81,059^{bc}
7	**Aerobic**	178,695^{e}	221,996^{f}	206,884^{f}
14	**Anaerobic**	22,253^{a}	18,725^{a}	34,237^{a}
14	**Aerobic**	104,078^{c}	147,329^{d}	176,460^{e}

[1]Storage: samples of beef contained in airtight Ziploc® baggies 4-, 8-, and 11-days post grind
[2]Aging: 7 and 14 d postmortem aged shoulder clods
[3]Condition: anaerobic- flushed with 100% nitrogen gas, aerobic- sealed with atmospheric oxygen
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error of storage × aging × condition: 16,369.99
Least squares mean with different letters are significantly different ($P < 0.05$)

Table 9. Effects of aging and incubation condition on methane gas formation from ground beef loaves.

	Condition[2]	
Aging[1]	**Anaerobic**	**Aerobic**
7	0.48[a]	3.07[b]
14	1.13[a]	6.64[c]

[1]Aging: 7- and 14-d postmortem aged shoulder clods
[2]Condition: anaerobic- flushed with 100% nitrogen gas, aerobic- sealed with atmospheric oxygen
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error aging × condition: 0.43
Least squares mean with different letters are significantly different ($P < 0.05$)

Table 10. Effects of storage, aging, and incubation condition on nitrous oxide gas formation from ground beef loaves.

		Storage[1]		
Aging[2]	**Condition[3]**	**4**	**8**	**11**
7	**Anaerobic**	0.11[a]	0.71[bc]	0.18[a]
7	**Aerobic**	0.47[abc]	0.82[cd]	0.50[abc]
14	**Anaerobic**	0.21[abc]	0.51[abc]	0.09[a]
14	**Aerobic**	1.31[d]	0.01[a]	0.55[abc]

[1]Storage: samples of beef contained in airtight Ziploc® baggies 4-, 8-, and 11-days post grind

[2]Aging: 7 and 14 d postmortem aged shoulder clods

[3]Condition: anaerobic- flushed with 100% nitrogen gas, aerobic- sealed with atmospheric oxygen

Unit: parts per million (ppm)

n= 4 shoulder clods with 2 loaves per clod

Standard error of display × aging × condition: 0.22

Least squares means with different letters are significantly different ($P < 0.05$)

Table 11. Effects of storage time on carbon dioxide, methane, and nitrous oxide gas formation from ground beef loaves.

Storage	Carbon Dioxide	Methane	Nitrous Oxide
4	73,822[a]	4.96[a]	0.68[a]
8	139,071[b]	4.43[b]	1.44[b]
11	152,485[c]	4.29[b]	0.98[a]

[1]Storage: samples of beef contained in airtight Ziploc® baggies 4-, 8-, and 11-days post grind
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error: carbon dioxide- 5,814.97, methane- 0.32, nitrous oxide- 0.28
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 12. Effects of aging time on carbon dioxide, methane, and nitrous oxide gas formation from ground beef loaves.

Age	Carbon Dioxide	Methane	Nitrous Oxide
7	94,916[a]	3.69[a]	1.45[b]
14	148,670[b]	5.43[b]	0.62[a]

[1]Aging: 7- and 14-d postmortem aged shoulder clods
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error: carbon dioxide- 6,506.75, methane- 0.37, nitrous oxide- 0.31
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 13. Effects of incubation conditions on carbon dioxide, methane, and nitrous oxide gas formation from ground beef loaves.

State	Carbon Dioxide	Methane	Nitrous Oxide
Cooked	71,025[a]	4.26[a]	0.63[a]
Raw	172,560[b]	4.86[a]	1.44[b]

[1]State: cooked- 71.1°C, raw- raw ground product
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error: carbon dioxide- 6,506.74, methane- 0.31, nitrous oxide- 0.32
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 14. Effects of storage and aging on carbon dioxide gas formation from ground beef loaves.

	Aging[2]	
Storage[1]	**7**	**14**
4	91,871[b]	55,772[a]
8	182,238[d]	95,904[b]
11	171,899[d]	133,072[c]

[1]Storage: samples of beef contained in airtight Ziploc® baggies 4-, 8-, and 11-days post grind
[2]Aging: 7 and 14 d postmortem aged shoulder clods
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error of display × aging: 8,223.24
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 15. Effects of display and incubation conditions on carbon dioxide gas formation from ground beef loaves.

	State[2]	
Storage[1]	**Cooked**	**Raw**
4	6,271[a]	141,372[d]
8	94,012[b]	184,129[e]
11	112,792[c]	192,179[e]

[1]Storage: samples of beef contained in airtight Ziploc® baggies 4-, 8-, and 11-days post grind
[2]State: cooked- 71.1°C, raw- raw ground product
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error of display × condition: 8,223.45
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 16. Effects of storage, aging, and incubation states on carbon dioxide gas formation from ground beef loaves.

			Storage[1]	
Aging[2]	**State[3]**	**4**	**8**	**11**
7	**Cooked**	5,048[a]	143,155[e]	136,631[de]
7	**Raw**	17,895[fg]	221,321[h]	207,437[gh]
14	**Cooked**	7,494[a]	44,870[b]	89,224[c]
14	**Raw**	104,050[cd]	146,938[ef]	176,920[fg]

[1]Storage: samples of beef contained in airtight Ziploc® baggies 4-, 8-, and 11-days post grind
[2]Aging: 7 and 14 d postmortem aged shoulder clods
[3]State: cooked- 71.1°C, raw- raw ground product
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error of display × aging × condition: 11,628.41
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 17. Effects of aging and incubation state on methane gas formation from ground beef loaves.

	State[2]	
Aging[1]	**Cooked**	**Raw**
7	4.32[b]	3.07[a]
14	4.21[b]	6.64[c]

[1]Aging: 7- and 14-d postmortem aged shoulder clods
[2]State: cooked- 71.1°C, raw- raw ground product
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error of aging × condition: 0.42
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 18. Effects of storage and aging on nitrous oxide gas formation from ground beef loaves.

	Aging[2]	
Storage[1]	**7**	**14**
4	0.46[a]	0.90[a]
8	2.46[c]	0.41[a]
11	1.43[b]	0.54[a]

[1]Storage: samples of beef contained in airtight Ziploc® baggies 4-, 8-, and 11-days post grind
[2]Aging: 7 and 14 d postmortem aged shoulder clods
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error of display × aging: 0.36
Least square means within a column with different letters are significantly different ($P < 0.05$)

Table 19. Effects of storage and incubation state on nitrous oxide gas formation from ground beef loaves.

	State[2]	
Storage[1]	**Cooked**	**Raw**
4	0.46[a]	0.89[ab]
8	2.41[c]	0.46[a]
11	1.45[b]	0.52[ab]

[1]Storage: samples of beef contained in airtight Ziploc® baggies 4-, 8-, and 11-days post grind
[2]State: cooked- 71.1°C, raw- raw ground product
Unit: parts per million (ppm)
n= 4 shoulder clods with 2 loaves per clod
Standard error of display × condition: 0.36
Least square means within a column with different letters are significantly different ($P < 0.05$)

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Education:

Completed the requirements for the Master of Science in Food Science at Oklahoma State University, Stillwater, Oklahoma in May, 2021.

Completed the requirements for the Bachelor of Science in Food Science at Oklahoma State University, Stillwater, Oklahoma in May, 2019.

Experience: Graduate Research and Teaching Assistant

Professional Memberships: American Meat Science Association, Institute of Food Technologists, Research Chef's Association