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INTEGRATION OF MICROBIAL LOADS AND SPOILAGE GAS SENSORS OF GROUND BEEF FROM LEAST - COST RAW MATERIAL SOURCES

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I. INTRODUCTION

The fed beef industry in the U.S. has faced a shortage of lean beef trimmings, forcing the use of different least-cost raw material sources to address these needs and enabling processors to balance economic efficiency with quality control in the ground beef production [1]. These alternatives include boneless trimmings-finely textured (BTFT), finely textured beef (FTB), imported (grass-fed) lean trimmings, and cow lean trimmings; all of which can present differences in product texture, color, appearance, and flavor. The primary alternatives considered in the industry are imported lean trimmings (mainly from Australia, New Zealand, and Canada) and cow lean trimmings, both of which have distinctive flavor and processing characteristics. Furthermore, BTFT and FTB are limited to maximum inclusion rates of 15% and 20% respectively [1]. Another important aspect to be considered is the microbial load they present and their influence on the shelf-life of the product, which poses a challenge in the ground beef production and preservation. Different methodologies have been used in the last few decades to monitor microbiological indicators such as Aerobic Counts (AC), Enterobacteriaceae (EB), Lactic Acid Bacteria (LAB), and Psychrotrophic Aerobic Counts (P-AC). However, these traditional methods lack the capability to deliver timely results and are labor-intensive. Over the last decade, spoilage gas sensors have been used as a solution to obtain real-time data and monitor the freshness of the product, increasing time efficiency and reducing food waste. To consider the sensors feasible for industry application, they must be easy to use, flexible, nondestructive, compatible with other packaging technologies, biodegradable, and of significant low cost [2]. Based on the needs and significance mentioned earlier, the objective of the study was to evaluate the use of a spoilage gas sensor as a rapid, non-destructive tool for estimating the shelf-life of ground beef from different least-cost raw material sources.

II. MATERIALS AND METHODS

Ground beef was processed using five different formulations from the least-cost raw material sources (BTFT, FTB, imported, and cow lean trimmings) and fed beef lean trimmings serving as control, each designed to evaluate the interaction between raw material composition and sensor performance under commercial like conditions. Each batch underwent a standard production workflow beginning with analysis using FOSS technology to determine the lean and fat content of the trimmings. Based on these values, samples were formulated accordingly, then subjected to a controlled grinding process. Following grinding, the ground beef was shaped into uniform loafs using a VEMAG forming system to ensure consistency across treatments. Each formed loaf was individually overwrapped with polyvinyl chloride (PVC) film, and spoilage gas sensors were placed directly inside the trays to enable continuous monitoring of freshness indicators. The packaged samples were then sealed inside a mother bag under a tri-gas modified atmosphere packaging (MAP) system (O_2, CO_2, and N_2), and stored under dark conditions for 12 days to simulate commercial-like storage. Sampling was conducted on day 0 (production day), day 6 of storage, and on day 12 (end of storage). For microbiological analysis, 10 g of sample were placed into sterile bags with 90 mL of Buffered Peptone Water (BPW) and stomached to obtain a homogenous sample. The following microbiological indicators were analyzed: AC, LAB, EB, and P-AC using the TEMPO enumeration system. Statistical analyses were conducted using R software to evaluate the effects of treatment and time on microbiological and sensor-based spoilage indicators. One-way ANOVAs were performed separately for each microbiological parameter and sensor measurement to assess the main effects of treatment and storage day. To evaluate the relationship between microbial spoilage and sensor output, linear regression models were fitted using microbial counts (log CFU/g) as the response variable and sensor values as the predictor. Regression models were built for each microbial group based on average values across storage days (0, 6, and 12).

III. RESULTS AND DISCUSSION

The interaction between ground beef treatment and storage day influenced LAB ($p = 0.018$). There were no further interaction or ground beef treatment effects for AC, EB, or PAC ($p > 0.05$). Storage day impacted AC, EB, and PAC counts ($p < 0.001$). These results indicate that microbial growth was primarily driven by storage duration, with some influence of treatment on LAB populations. Sensor output followed similar trends, showing consistent variation with both treatment and time ($p < 0.001$). Regression analyses using sensor data revealed moderate to strong adjusted R^2 values with microbial counts: 0.82 for lactic acid bacteria, 0.72 for aerobic counts, 0.62 for Enterobacteriaceae, and 0.61 for psychrotrophs.

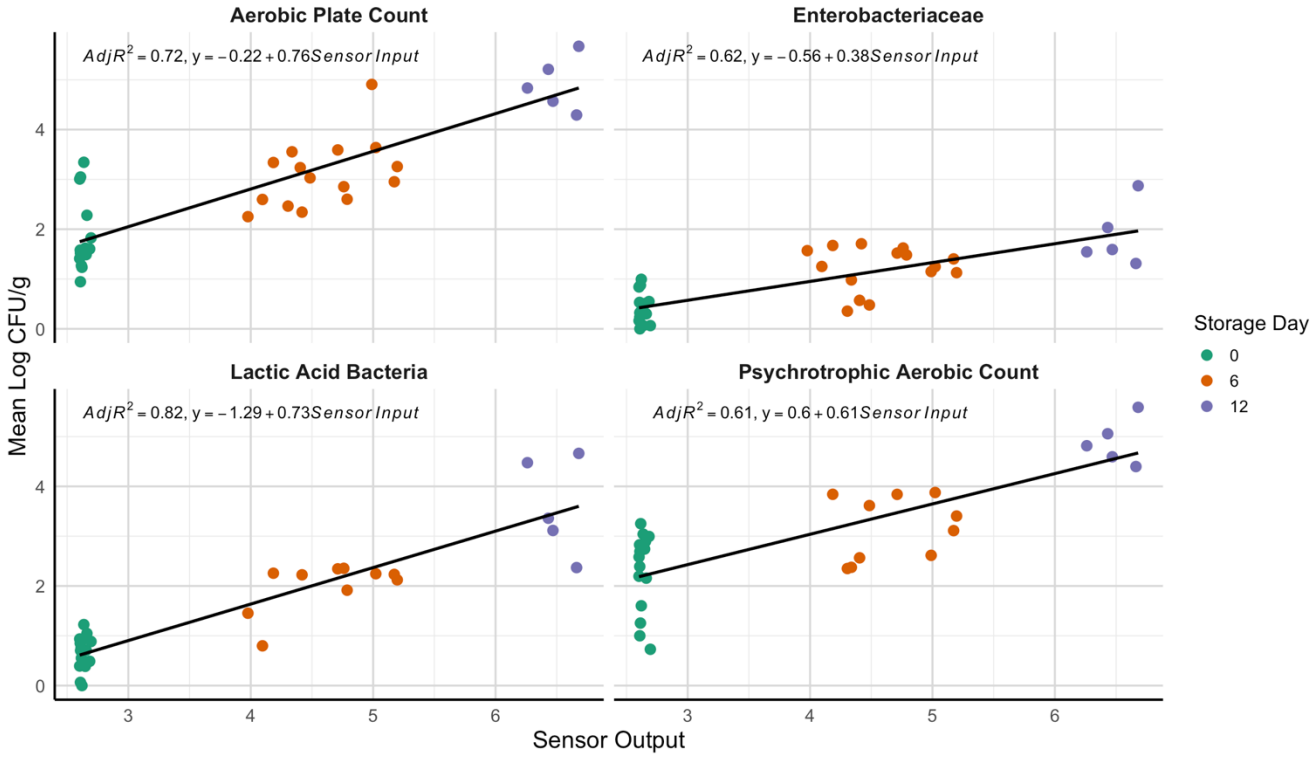


Figure 1. Regression between Spoilage Gas Sensor and Microbiological Measurements across three different sampling days.

IV. CONCLUSION

Regression analysis between sensor outputs and microbial counts demonstrated strong predictive relationships. These findings indicate that the sensor system effectively captured microbial trends during storage, supporting its potential as a reliable, non-destructive tool for monitoring spoilage progression in ground beef during refrigerated storage.

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