HYPERSPECTRAL IMAGING CAN BE A RAPID TOOL TO MONITOR WEIGHT LOSS AND QUALITY CHANGES DURING DRY-AGING OF BEEF

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I. INTRODUCTION

Dry-aging is a processing technique used to enhance the flavor and eating quality of meat. This process involves various changes such as weight loss, oxidation, and microbial activities, which play a significant role in shaping the flavor of dry-aged meat [1]. Understanding the evolution of these parameters during the dry-aging process and developing a non-invasive method to accurately predict meat quality and flavor intensity is essential to optimize processing strategies. This will help to produce dry-aged meat with consistent and guaranteed quality, resulting in a more satisfying eating experience. This study aimed to apply hyperspectral imaging (HSI) to monitor the weight loss, moisture content, pH, instrumental color and lipid oxidation level during dry-aging of beef for up to 21 days.

II. MATERIALS AND METHODS

Twenty-four striploins from dairy-beef crossbred yearling calves (~12 months, n=12) and 2-year-old cattle were obtained at 48 h post-mortem, cut into four sections, and assigned to in-bag dry-aging (BD) for 0, 7, 14, and 21 days at 2°C and 75% relative humidity. The weight losses during BD were recorded. At each time point, steaks were taken from each section and determined for pH and instrumental color (Lightness, redness, chroma, and hue angle) according to the previous study by Zhang et al [2]. The same steaks were then analyzed by HSI as described below. The moisture content (freeze-drying) and thiobarbituric acid reactive substances (TBARS) values of these steaks were also determined [2]. A linescan HSI system was used in this study which included a translation stage, an illumination system, and a hyperspectral camera [3]. The hybrid camera sampled 235 wavebands with a spectral range of 550nm to 1700nm and a spectral resolution of 5 nm. A linear translation speed of 11.1mm/s was chosen to ensure square pixels in the image. The stand-off distance between the sample and the lens was set to ~ 370mm. Each hyperspectral image was calibrated with white and dark reference measurements for obtaining the reflectance values. One hyperspectral image was acquired for each sample on day 0, 7, 14, and 21. A total of 96 images (24 samples × 4 ageing times) were captured. Raw hyperspectral images were subjected to data pre-processing and multivariate analysis using R and Python. Hyperspectral images were cleaned to remove background pixels and averaged into a single spectrum per sample. The obtained raw spectral data was pre-processed using standard normal variate (SNV) transformation followed by Savitzky-Golay (SG) smoothing (window size=5) to remove any baseline effects and enhance signal-to-noise ratio (SNR) [4]. The pre-processed spectral data along with the reference data was subjected to PLSR analysis to develop and validate prediction models for individual attributes, using the repeated double cross-validation (rdCV) method [5].

III. RESULTS AND DISCUSSION

Table 1 illustrates the results of PLSR models for various dry-aged beef quality attributes using rdcv strategy. Weight loss model showed the best performance, yielding a R^2 of 0.92 and SEP of 0.03% followed by moisture content, redness, chroma, yellowness and hue angle models. pH and TBARS values showed poor results which could be related to less variability in pH across samples and absence of spectral peaks associated with TBARS. Selectivity ratio (SR) plots showed that weight loss model was governed by 3 major peaks: 789nm which could be related OH 3rd overtone or an absorption band produced by deoxymyoglobin, 1036nm and 1390nm which could be due to OH 2nd overtone related to water. Moisture model had a major peak around 1376nm related OH 2nd overtone [6]. All color related models including redness, chroma, yellowness and hue angle showed major peaks around 818nm related to OH 3rd overtone or deoxymyoglobin, 1400nm related to water and 1540nm which is highly overlapped and influenced by water (OH) and protein (N-H and C-N stretching) bands [7].

Table 1. PLSR model results using repeated double cross-validation strategy.

Attributes	n	R^2	No. of PLS Components	SEP
Weight loss	96	0.92	4	0.03
Moisture (freeze-dry)	96	0.78	3	1.55
Redness	96	0.75	3	1.80
Chroma	96	0.72	2	2.09
Yellowness	96	0.61	2	1.13
Hue angle	96	0.59	3	1.78
pH	96	0.34	6	0.07
TBARS	96	0.33	2	0.08

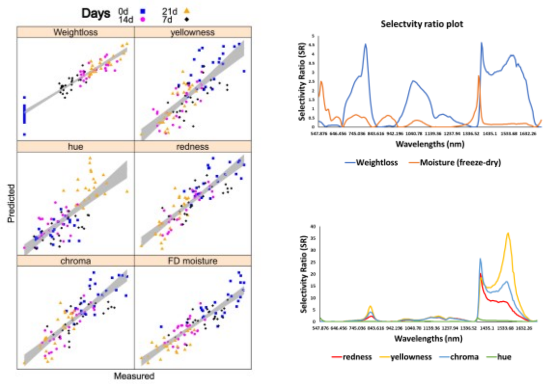

Figure 1. Prediction plots (left) and Selectivity Ratio (SR) plots (right) for quality attributes of dry-aged beef for 0, 7, 14, and 21 days.

IV. CONCLUSION

The results showed that HSI can be used to predict dry-aged beef's quality attributes including weight loss, moisture content, and color throughout the aging time up to 21 days. Further exploration revealed that models were majorly utilizing chemical information related to water in weight loss and moisture models whereas color parameters were predicted by a combination of color pigment (myoglobin) and water and/or protein. HSI was able to overcome the heterogeneity of meat samples and could be a potential tool for real-time, rapid, and non-invasive assessment of dry-aged beef quality for consistently high-quality product.

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