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PREDICTION OF OXIDATION PRODUCT CONTENT IN BISON MUSCLES USING HYPERSPECTRAL IMAGING

Nuria Prieto[1], Md Mahmudul Hasan[2]; Muhammad Mudassir Arif Chaudhr[3]; Jitendra Paliwal[3], Argenis Rodas-Gonzalez*[2].

[1]Agriculture and Agri-Food Canada, Lacombe Research and Development Centre, Lacombe, Canada. [2]Food and Human Nutritional Sciences, University of Manitoba, Winnipeg, Canada; [3]Biosystems Engineering,

*Corresponding author: Argenis.RodasGonzalez@umanitoba.ca

I. INTRODUCTION

Bison meat is marketed most of them as frozen products due to its faster colour deterioration under aerobic packaged retail conditions, which limits its expansion in the retail market and puts it at a disadvantage before other meat commodities that are sold fresh (i.e., pork, beef, lamb, and ground beef) [1,2]. Bison muscles [*longissimus lumborum* (LL) and *psoas major* (PM)] early browning is caused by lipid [malondialdehyde (MDA) and 4-hydroxy-2-nonenal (HNE)] and protein [carbonyl (CAR)] oxidation products development during storage and retail display [2]. Thus, early determination of those components in meat portions would make it possible to designate muscle-specific technology or management to mitigate colour deterioration caused by those oxidation products and supply bison meat with desirable and stable colour. However, it could be challenging for purveyors and retailers to apply a rapid and reliable sorting technique. In this context, exploring a contactless and fast evaluation technique is necessary to sort the meat portion on a large scale at those processing and packaging facilities. Therefore, hyperspectral imaging (HSI) could be an alternative. Hence, the objective of this study was to predict the content of oxidation products in bison muscles using HSI with two wavelength ranges.

II. MATERIALS AND METHODS

Ten longissimus lumborum (striploins) and ten psoas major (tenderloins) muscles from A1 grade bison carcasses were collected within 48 h post-mortem. Each muscle portion was sub-sampled for the determination of MDA, HNE, CAR prior to 2 x 2 cm steaks being scanned by hyperspectral imaging in both the visible and near-infrared (Vis-NIR; 400-1000 nm) and short wave near-infrared (SWIR; 1000-2500 nm) regions (SPECIM Spectral Imaging Ltd., Oulu, Finland) [3]. The remaining muscle samples were divided into two parts, placed in vacuum packages and stored at 2°C for an ageing period of 7 and 14 d. At the end of each ageing period, muscles were removed from the vacuum packages, 2.5-cm thick steaks were obtained, and HSIs were acquired, followed by the determination of MDA, HNE and CAR contents [2]. After image acquisition, steaks were placed on a white polystyrene foam tray with a soaking pad and wrapped with polyvinyl chloride film, placed in retail display cabinet and used for HSIs acquisition again after the retail display period of 5 days, followed by determination of the aforementioned parameters. Partial least square regression (PLSR) was used for predicting the content of oxidation products in bison muscles using the image and spectral data information as independent variables. Internal full cross-validation was performed to avoid over-fitting the PLSR equations.

III. RESULTS AND DISCUSSION

As shown in Table 1, HSI was able to accurately predict MDA content in both the *longissimus lumborum* and *psoas major* muscles using the SWIR region (RPD: 3.16 and 3.34, respectively). Despite MDA having limited absorption in the near-infrared region [4], this lipid oxidation product could be indirectly predicted through structural and chemical changes in the sample resulting from lipid oxidation, which correlate with MDA production. Interestingly, slightly higher prediction accuracy was observed in both muscles when using the Vis-NIR region (RPD: 3.43 and 3.68, respectively). Although MDA itself does not exhibit strong absorbance in the visible spectrum [5], colour changes in meat due to lipid oxidation may have been captured by the visible spectra, thereby enabling an indirect prediction of MDA content. In contrast, HNE content could not be estimated with sufficient accuracy in both muscles using either the Vis-NIR or SWIR regions (RPD: 1.31-1.61). Similarly, lower predictive performance was found for CAR content in both muscles using the Vis-NIR region, and in the *psoas major* using the SWIR region (RPD: 1.28-1.89). However, HSI may still be suitable for CAR screening purposes in the *longissimus lumborum* using the SWIR region (RPD:

2.01). While NIR spectroscopy does not directly detect carbonyl functional groups (C=O) — due to their weak overtone and combination band signals in this region — oxidation-induced changes in protein structure may have affected the NIR spectra across the full wavelength range [6], contributing to the observed CAR screening ability.

Table 1. Prediction of the content of oxidation products in bison muscles by hyperspectral imaging.

	Longissimus lumborum					*Psoas major*				
	Mathematical treatment	T	R^2_{CAL}	$RMSE_{CV}$	RPD_{CV}	Mathematical treatment	T	R^2_{CAL}	$RMSE_{CV}$	RPD_{CV}
Vis-NIR (400-1000 nm)										
MDA	SNV-D SG1st	3	0.93	0.1328 mg/kg	3.43	SNV-D SG1st	3	0.94	0.1917 mg/kg	3.68
HNE	SNV-D SG2nd	1	0.60	3.9895 µM/g	1.53	SNV-D SG2nd	1	0.62	4.4343 µM/g	1.57
CAR	SNV-D SG2nd	1	0.43	0.8925 nmol/mg	1.28	SNV-D	4	0.77	0.6039 nmol/mg	1.89
SWIR (1000-2500 nm)										
MDA	SG1st	4	0.92	0.1443 mg/kg	3.16	SNV-D SG2nd	2	0.92	0.2078 mg/kg	3.34
HNE	SNV	3	0.49	4.6690 µM/g	1.31	SG2nd	1	0.64	4.2637 µM/g	1.61
CAR	SG1st	3	0.79	0.5697 nmol/mg	2.01	SG2nd	1	0.63	0.7205 nmol/mg	1.60

Vis-NIR: visible and near-infrared region; SWIR: short wave near-infrared region; MDA: malondialdehyde; HNE: 4-hydroxy-2-nonenal; CAR: carbonyl; SNV: standard normal variate; SNV-D: standard normal variate and detrend; SG1st: Savitzky–Golay first-order derivative; SG2nd: Savitzky–Golay second-order derivative; T: number of PLS terms utilized in the calibration equation; R^2_{CAL}: coefficient of determination of calibration; $RMSE_{CV}$: root mean square error of cross-validation; RPD_{CV}: ratio of performance deviation calculated as SD/$RMSE_{CV}$.

IV. CONCLUSION

These findings demonstrate that HSI has a strong potential for accurately predicting MDA content in bison muscles. While prediction of HNE and CAR content by HSI was less accurate overall, the SWIR region showed some potential for CAR screening in the *longissimus lumborum*.These results highlight the value of HSI as a non-destructive tool for assessing lipid and protein oxidation in bison muscles.

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