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UNIVERSAL METHOD FOR ASSESSMENT OF ULTIMATE PH IN RED MEAT BASED ON NEAR-INFRARED SPECTROSCOPY (NIRS)

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I. INTRODUCTION

Muscle pH is a critical criterion used globally in meat quality assessment systems as it strongly correlates with key quality attributes like water-holding capacity, colour, and tenderness. It is frequently used in quality grading systems to segregate low and high value carcasses and to meet food safety requirements. Near-InfraRed Spectroscopy (NIRS) has been investigated as a non-invasive method to assess pH in meat. It is non-invasive, fast and can be implemented at several stages of meat processing plant enabling the automation of pH assessment during processing. Independent studies have demonstrated the value of NIRS on assessment of pH, but most of them focused on specific conditions (e.g., a single type of instrument). This study investigates the hypothesis that NIRS can provide a universal assessment of pH in red meat that is independent of instrument, species, muscle type and conditions of measurement (e.g., pre- or post-rigor). The outcome of the study contributes to adoption of pH assessed by NIRS as a universal tool for assessment of red meat.

II. MATERIALS AND METHODS

A total of 6 datasets from different experiments and using different NIRS instruments across species (beef, lamb, and venison) and muscles were used for modelling. As each instrument has its unique features such as wavelength, resolution, and meat surface area analysed, an identical range was considered across all the devices (i.e., 81 wavelengths between 700 and 1100 nm) to ensure comparability. Using a database constituted of 2,414 pH measures (Table 1), a predictive model was developed using Convolutional Neural Network (CNN). Data were split into calibration (n=1195) and test (n=1219). The calibration dataset was then split into training (n=839) and validation (n=356) sets, considering similar samples across experiments in terms of species and muscle types for each dataset.

Table 1 - Instrument and data description used for model development.

Instrument	N	Characteristic	Description	Comment
Labspec	208	Benchtop Instrument	Spectral range: 350–2500 nm; a spectral resolution of 3 nm at 700 nm; 10 nm at 1400 nm and 2100 nm. Area illuminated: ⌀ 25 mm, area viewed: ⌀ 15 mm	Australia/Beef (plant 1), post-rigor
Labspec	95			Australia/Beef (plant 2), post-rigor
Labspec	44			Lamb, post-rigor
KES	779	Benchtop Instrument with a fibre optic probe	Spectral range: 400-1700, spectral resolution 5nm.	NZ/Beef, post and pre-rigor [1]
Hyperspectral imaging	991	Linescan imaging system	235 wavebands; spectral range: 550 nm to 1700 nm; spectral resolution of 5 nm. Stand-off: variable	Several species (beef, lamb and venison), post-rigor [2]
Indigo	297	Handheld	Spectral range: 700-1100 nm	Beef, post-rigor
Total	**2,414**			

III. RESULTS AND DISCUSSION

The performance summary of the developed CNN model is presented in Table 2, where the training dataset for ultimate pH yielded a high R^2 value of 0.93, a low SEP of 0.08, and a slope of 0.89. The validation and test datasets resulted very satisfactory R^2 of 0.79 and 0.71, respectively but much lower RPD values as compared to the training dataset, which could indicate slight over-optimisation of the model. The result shows that all sources of variation were modelled including species, types of instrument and conditions of measurements demonstrating that NIRS is capable to produce a universal measure of pH in meat.

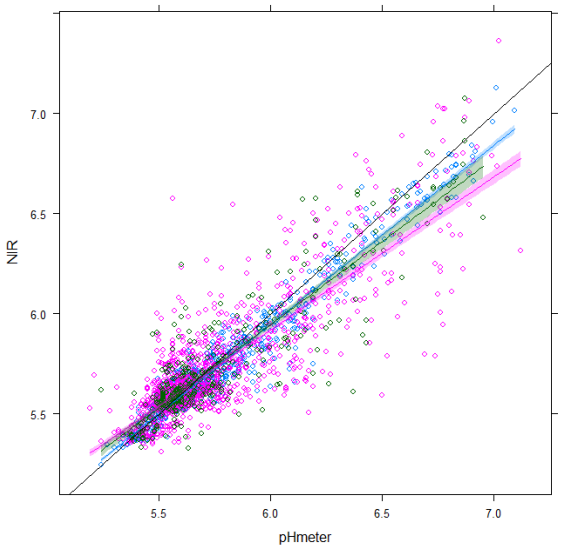


Figure 1 - Relationship between the pH_{24} reference data and those predicted by NIRS in meat samples for prediction (blue) and validation (pink) models.

Table 2 - Statistics of regression models for ultimate muscle pH.

	Calibration	Validation	Test
N	839	356	1219
R^2	0.93	0.79	0.71
Slope	0.89	0.83	0.76
SEP	0.08	0.16	0.18
Bias	0.03	0.01	0.02
RPD	4.11	2.18	1.86
RMSE	0.08	0.16	0.18

N: number of samples; R^2: coefficient of determination for calibration; SEP: Standard Error of Prediction ; RPD = Residual Prediction Deviation calculated as SD after outliers' removal/ standard error of cross-validation; RMSE: Root Mean Square Error.

IV. CONCLUSION

The current model was developed based on a large dataset with various types of samples and NIRS-based instruments to represent the typical variations found in meat plants, allowing it to generalise across a range of NIRS-based instruments worldwide. The study demonstrates that is possible to utilize data of multiple sources to develop a universal NIRS calibration for pH.The results show that NIRS can be used as a universal measure of pH in meat, but further development is required to reduce the impact of sources of variation (e.g. instruments) in the accuracy of the measurments.

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