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NON-INVASIVE NEAR INFRARED SPECTROSCOPY (NIRS) FOR ON-LINE SODIUM CONTENT PREDICTION IN DRY-CURED HAM SLICES: DEVELOPMENT OF TEMPERATURE-COMPENSATED MODELS

M. Isabel Campos[1,2], Gregorio Antolín[1†] Luis Debán[2], Rafael Pardo[2]

[1] CARTIF Technology Center, Agrifood and Processes Division, Parque Tecnológico de Boecillo, 205. Valladolid, Spain. marcam@cartif.es

[2] Analytical Chemistry Department, Faculty of Sciences, University of Valladolid. Spain.

ABSTRACT

Sodium plays a vital role in cured meats by contributing to microbial stability, texture, and flavor. However, excessive sodium intake is associated with health risks, making accurate monitoring essential. This study explores the potential of near-infrared spectroscopy (NIRS) as an online analytical tool for predicting sodium content in dry-cured ham slices. Implementing salt monitoring directly on the slicing line allows for real-time control of product characteristics without compromising production speed. Additionally, it supports consumers in selecting products with appropriate salt levels. The study also examines the effect of temperature variations on model performance, as such fluctuations can significantly influence spectral data accuracy.

METHODOLOGY

Analytical technique: **NEAR INFRARED SPECTROSCOPY (NIRS)**
Accurate, fast and low cost per measurement. Non-destructive and non-invasive, without sample pre-treatment or reagents.

Equipment: Fourier Transform NIR spectrometer model Matrix-F emission provided with a non-contact probe Q-412/AF with two tungsten sources (Bruker Optik). Spectral data processing was carried out using OPUS™(V 7.0) software.

Reference method: Inductively Coupled Plasma Atomic Emission Spectrophotometry (ICP–AES) with a 720-ES Varian spectrometer. Quantification was performed based upon calibration curves produced from 1000 ppm standards of in 0.5 M nitric acid. The means of two determinations, were expressed as g sodium/100 g wet matter.

NIRS Methodology

In the experimental design, key factors such as sample temperature, sodium variability, and measurement area were considered. Three temperature ranges were established between −12 and +20 °C. Sliced dry-cured ham samples were scanned in the spectral range of 12,000 to 4000 cm^{-1} after removing the plastic packaging to avoid interference, and at different sample temperatures. Spectra were collected with a wavenumber resolution of 16 cm^{-1}.

RESULTS

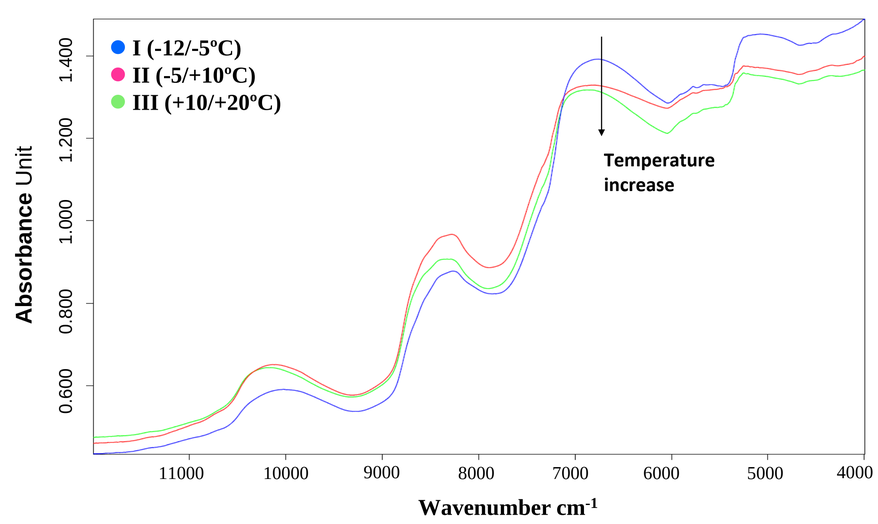
Statistical overview of sodium content (% wet matter) in three sample sets by spectral measurement temperature range

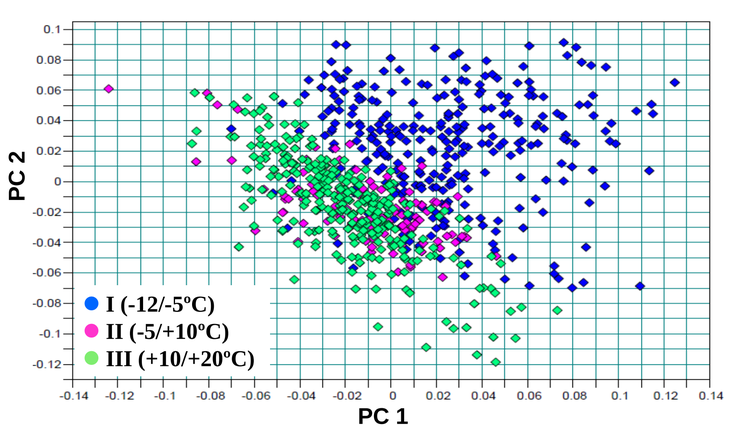
Temperature range	No. Samples	Mean	Range	SD
I (-12/-5ºC)	291	2.00	1.21-3.10	0.45
II (-5/+10ºC)	107	2.11	1.27-3.10	0.40
III (+10/+20ºC)	291	1.98	1.21-3.10	0.43

SD, Standard Deviation; CV, Coefficient of Variation (SD * 100/mean)

Prediction models: Multivariate models relating the multi-wavelength spectral response to the analyte concentration were developed using partial-least squares regression (PLSR). An internal full cross-validation method was used to determine the optimal number of factors in the regression models in order to avoid overfitting.

Average NIR spectra of dry-cured ham slices in three temperature ranges

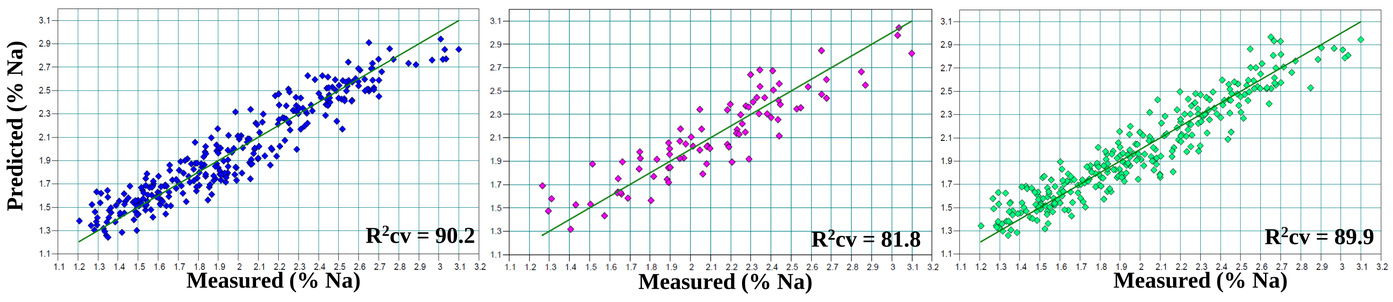




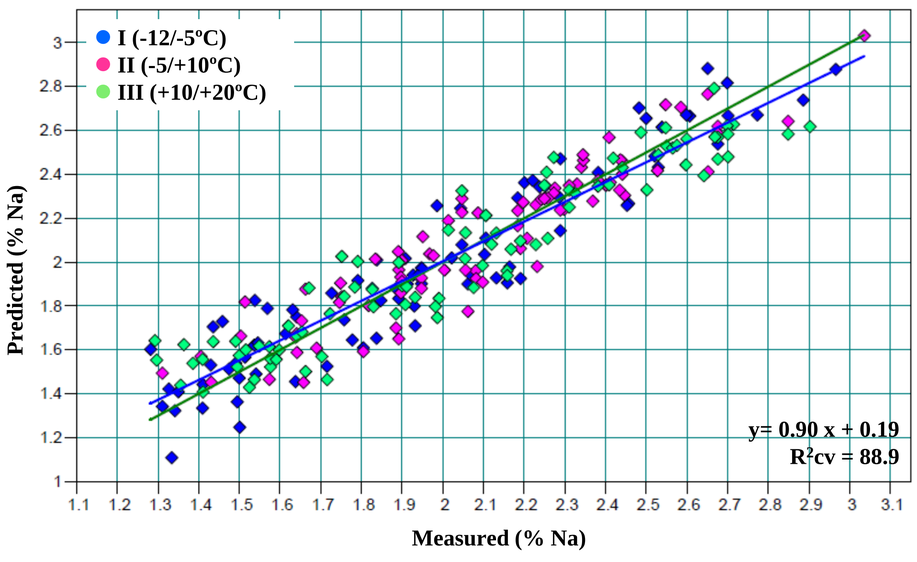
Principal component score plot of the NIR spectra of dry-cured ham slices grouped according to sodium content

Those spectra collected within the same temperature range tend to group together. There is a clear separation between ranges I (blue colour) and III (green colour), due to the large difference between temperatures, in the NIR spectra this variation induces changes in the conformation of the molecules. In the spectra range II (pink colour), the temperature was taken before being irradiated by the laser, it is understandable that they overlap with group III, the heating shifts the spectra towards this group.

Depending on the spectra used in calibration (cross-validation) and external validation, two types of models were constructed: **local and global temperature models.**



The **local models** are sensitive to temperature deviations beyond the range in which they were developed, the **global model** demonstrates superior performance, achieving a 90% adjustment with more accurate results, making it a more versatile option for packaging lines. **This work confirms the feasibility of integrating NIRS technology for real-time sodium monitoring.**



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