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DEVELOPMENT OF A METHODOLOGY TO DIFFERENTIATE BETWEEN MEAT PREPARATIONS AND MEAT PRODUCTS BY ANALYSING THE VISIBLE AND NEAR-INFRARED SPECTRA BEFORE AND AFTER HIGH-PRESSURE PROCESSING

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I. INTRODUCTION

In the European Union, classification of Meat Derivatives (MD) into *Meat preparations* and *Meat products* is essential because it determines which additives are permitted in each food category [1, 2]. EC Regulation [3] establishes these definitions: '*Meat preparations means fresh meat,… which has undergone processes insufficient to modify the internal muscle fibre structure of the meat and thus to eliminate the characteristics of fresh meat*' and '*Meat products means processed products…, so that the cut surface shows that the product no longer has the characteristics of fresh meat*'. However, no regulation defines the objective parameters to be measured to evaluate the alterations of the internal muscle fibre structure and the characteristics of fresh meat. Histological methods are used to differentiate between *Meat preparations* and *Meat products,* but they are not robust enough to classify MD accurately [4]. This makes it difficult to objectively classify MD that fall into a 'grey zone' or transition zone between *Meat preparations* and *Meat products*. Several studies have shown that the high pressure (HP) processing effect, i.e., increase of reflectance and lightness, is higher in the 'meat matrices' that preserve the characteristics of fresh meat than in those in which the proteins are already denatured by thermal treatment [5], drying [6], and a combination of acidification and drying [7] or fermentation and drying [8]. The aim of this study was to develop a methodology to classify objectively MD into *Meat preparations* and *Meat products* through Discriminant Analysis of the reflectance spectra before (CT) and after high pressure (HP) processing. The hypothesis is that changes in the visible (Vis) and near-infrared (NIR) reflectance spectra caused by HP processing are directly related to the degree of preservation of the '*characteristics of the fresh meat*' of the MD.

II. MATERIALS AND METHODS

The MD used to develop classification models were chosen to maximize the market's variability and representativeness and were grouped into two classification categories. The **Fresh** (n= 76) category included MD classified clearly and unequivocally as fresh meat, minced meat, and meat preparations, i.e., *'that maintain the characteristics of fresh meat'*. It comprised whole muscles (n= 39; pork, chicken, turkey and beef), minced meats (n= 24; different pH and up to 0.9% added salt) and meat-preparation models (n= 13; minced pork muscles, different pHs, added paprika). The **Product** (n= 83) category included MD classified clearly and unequivocally as meat products, i.e., *'that have lost the characteristics of fresh meat on the cut surface'*. It comprised commercial cooked meat products (n= 27; T_{core} >65 ºC): pork and turkey hams, bacon and cooked sausages (pork, chicken and turkey); dry-cured meat products (n= 26; a_w <0.92): dry-cured hams and fermented sausages, and models of cooked meat products (n= 30; different salt levels, pH and cooking T). Two samples of each MD were randomly assigned to CT and HP treatments. HP samples were treated at 600 MPa (holding time= 6 min, water T= 10 ºC) with a Wave-6000 (Hiperbaric, Burgos, Spain). Spectral reflectance was measured: Vis (400-700 nm; 10 nm) with a Spectrophotometer Konica Minolta CM-600d (ITA Aquateknica S.A., Valencia, Spain) and NIR (740-1070 nm; 10 nm) with a SCiO spectrometer (Consumer Physics, Hod HaSharon, Israel). The sample mean spectra were calculated (Vis-CT, Vis-HP, NIR-CT and NIR-HP). The first derivative of the mean spectra was calculated with the finite difference method using the symmetric derivative formula. A Discriminant Analysis to predict membership in a category (Fresh and Product) was carried out with JMP® (v.16.0.0; SAS Institute Inc. 2021-2022). Data (sample spectra) were divided, proportionally within each classification category, into Training or calibration data set (n = 101; Fresh: n = 49 and Product: n = 52) and Test or validation data set (n = 58; Fresh: n = 27 and Product: n = 31).

III. RESULTS AND DISCUSSION

Spectra in Fig. 1A-B show a significant increase in reflectance after HP processing in the Fresh category (blue lines). In contrast, no changes are observed in the Product category (red lines), except for a slight reflectance increase in HP dry-Cured products (black lines). Similar differences are observed in the first derivative (Fig. 1C-D). Results in Table 2 show that all the developed models correctly classified 100% of the samples into the two categories. These models can be used to classify those samples that raise doubts whether they have characteristics of fresh meat and to obtain a predicted classification category with an estimated probability (*P*). However, before applying a classification model to problem samples, an acceptance threshold value for the estimated probability has to be agreed upon.

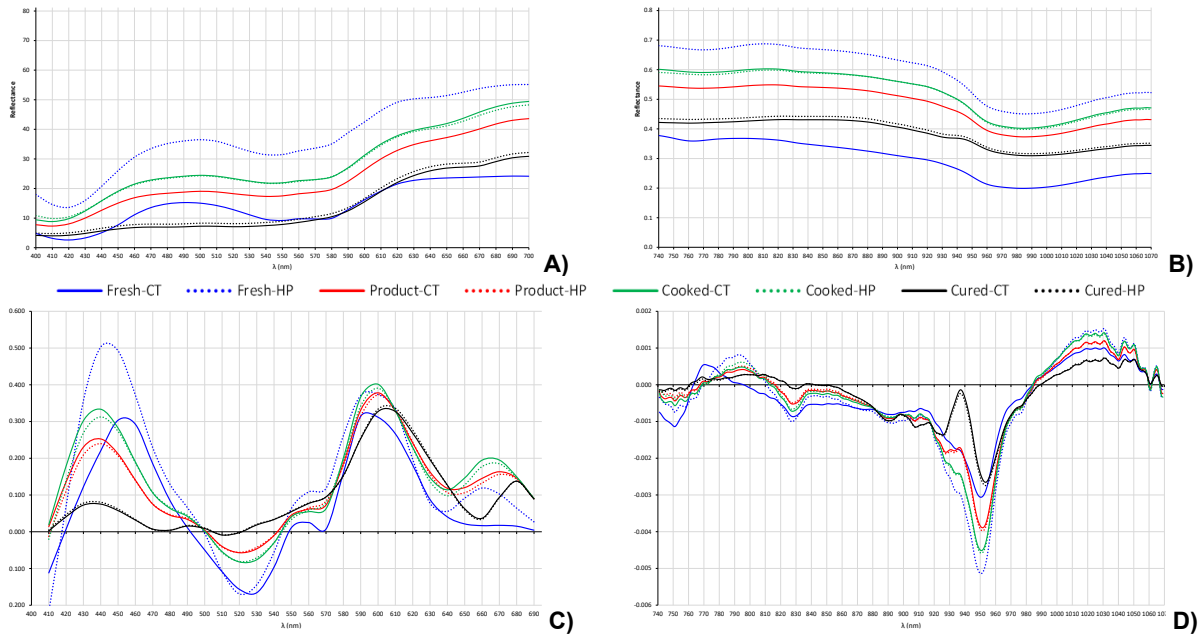


Figure 1. Reflectance mean spectra, raw: **A)** Vis, **B)** NIR, and first derivative: **C)** Vis and **D)** NIR of CT and HP samples for categories Fresh and Product (which, in turn, is split into Cooked and dry-Cured products).

Table 2. Performance of the developed models for discrimination between the Fresh and Product categories.

Reflectance spectra	Data Pre-treatment	Model fitting procedure	Data set	Entropy RSquare[a]	Predicted Rate[b]	
					Fresh	Product
Vis CT&HP (62 covariates)	None (raw)	Linear Discriminant Analysis (Canonical Variable)	Training	1.0000	1.00	1.00
			Validation	1.0000	1.00	1.00
NIR CT&HP (662 covariates)		Wide Linear Discriminant Analysis (Principal Component Analysis + Canonical Variable)	Training	0.9984	1.00	1.00
			Validation	0.9997	1.00	1.00
Vis CT&HP & NIR CT&HP (724 cv.)			Training	1.0000	1.00	1.00
			Validation	1.0000	1.00	1.00
Vis CT&HP (58 covariates)	First derivative	Linear Discriminant Analysis (Canonical Variable)	Training	1.0000	1.00	1.00
			Validation	1.0000	1.00	1.00
NIR CT&HP (658 covariates)		Wide Linear Discriminant Analysis (Principal Component Analysis + Canonical Variable)	Training	1.0000	1.00	1.00
			Validation	1.0000	1.00	1.00
Vis CT&HP & NIR CT&HP (716 cv.)			Training	1.0000	1.00	1.00
			Validation	1.0000	1.00	1.00

[a] Entropy RSquare: measure of fit. An Entropy RSquare value of 1 indicates that the classifications are perfectly predicted.
[b] Predicted rate: rate of actual by predicted counts for each level of the classification (categorical) variable.

IV. CONCLUSION

The developed methodology, based on analyzing reflectance spectra before and after HP processing, has proven useful to differentiate between meat preparations and meat products. The methodology features simplicity in sample preparation and analysis and speed in obtaining results. Nonetheless, further work is needed for standardization and interlaboratory validation.

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