Research Article

Received: 28 August 2017 | Revised: 11 January 2018 | Accepted article published: 6 February 2018 | Published online in Wiley Online Library:

(wileyonlinelibrary.com) DOI 10.1002/jsfa.8944

Near-infrared spectroscopy-based analysis to study sensory parameters on pork loins as affected by cooking methods and conditions

Alberto González-Mohino,[a*] Teresa Antequera,[a] Sonia Ventanas,[a] Daniel Caballero,[a] Jorge Mir-Bel[b] and Trinidad Pérez-Palacios[a]

Abstract

BACKGROUND: The main objectives of this study were to evaluate the use of near infrared spectroscopy (NIRS) to classify pork loins under different methods and cooking conditions, and to predict sensory attributes of this product.

RESULTS: Samples were oven cooked at two temperatures (150 and 180 °C) for different times (45, 60 and 75 min) and confit cooked for different times (120, 180 and 240 min). All cooked loin samples were subjected to a Quantitative Descriptive Analysis by a trained panel. For classification, principal component analysis was performed based on the NIRS database, showing a good discrimination between loins samples subjected to different cooking conditions. Regarding prediction, a data mining technique (multiple linear regression) was applied on a database constructed with data from NIRS and sensory analysis.

CONCLUSION: The correlation coefficient and the mean absolute error obtained suggest that the calculated prediction equations of this study are valid to predict the changes in the sensory attributes depending on the cooking method and conditions used for pork loins.

Keywords: near-infrared spectroscopy (NIRS); Quantitative Descriptive Analysis (QDA); multiple linear regression (MLR); temperature; time; pork loin

INTRODUCTION

During cooking, there are important changes in meat products depending on the cooking method used, as well as on the cooking temperature and time.[1–3] The automatic control of these changes would allow the attainment of optimal points of cooking without the subjective criterion of who cooks, which supposes an important improvement in restoration and in the domestic area.

Sensory evaluation has been extensively applied in many pork studies, particularly as a control quality tool. Using sensory evaluation makes it possible to obtain valid and essential information related to the sensory profile of a particular product or to consumers' preferences.[4–7] Among the different sensory techniques available for the scientists, Quantitative Descriptive Analysis (QDA)® [8] is one of the most widely applied in meat products.[9–12] Data obtained by means of QDA are reliable and give valuable information about sensory quality of meat products.[13] However, QDA is a time-consuming technique, and it requires the use of a panel that needs to be trained.

Consequently, some people have tried to predict sensory traits of meat products as a function of data obtained from rapid and automatic techniques. In this sense, near-infrared spectroscopy (NIRS) could be an appropriate choice, since it has been mostly applied to predict major components (water, protein and fat) in different products.[14–16] This technique has also been used to predict more specific quality parameters in food. Focusing on meat and meat products, different physicochemical parameters (pH, instrumental colour, fat, and drip loss) and sensory traits (tenderness and juiciness) have been predicted in dry-cured loin and hams by means of NIRS.[17–19] In addition, it has been used to predict the degree of lipid oxidation in rabbit meat stored under refrigeration.[20] Moreover, Klaypradit *et al.*[21] used NIRS to estimate the fat content, the fatty acid composition and the level of lipid oxidation in different fish species. In addition, Alamprese and Casiraghi[16] allowed the authentication of fish fillets by means of NIRS. There also are some studies focused on analysing quality characteristics of cooked meat by using NIRS.[22–24]

As a predictive method, the use of the data mining technique instead of the usual statistical tools could be a significant step forward within this scientific and technological backdrop. In fact, there is a growing interest in the use of the data mining technique, allowing a major ease in data collection over networks.[25]

* *Correspondence to: A González-Mohino, Department of Food Technology, Research Institute of Meat and Meat Product, University of Extremadura, Avenida de la Universidad S/N, 10003, Cáceres, Spain. E-mail: albertogj@unex.es*

a *Department of Food Technology, Research Institute of Meat and Meat Product, University of Extremadura, Avenida de la Universidad S/N, Cáceres, Spain*

b *Food Technology, Faculty of Veterinary, University of Zaragoza, C/ Miguel de Servet, Zaragoza, Spain*

The data mining technique has been applied in food technology to monitor the process of beer fermentation,[26] to predict quality traits in beef[27] or oxidation status in menhaden fish oil.[21] In meat products, data mining was applied to estimate the quality traits.[17,19,28] However, the use of a fast and automatic methodology with the data mining technique has not been used to predict quality characteristics in cooked meat products.

Taking all these aspects into consideration, the main objective of this work was to evaluate the feasibility of the NIRS technique to characterize cooked loins by means of (i) the classification of the loins depending on the cooking method (oven and confit) and the cooking conditions (time and temperature), (ii) analysing the relationship between sensory and NIRS data, and (iii) the prediction of sensory attributes of cooked samples as a function of NIRS data applying data mining techniques.

MATERIALS AND METHODS

Experimental design

Commercial fresh pork loins were bought in a local Spanish supermarket (Mercadona, Spain). Two different cooking treatments were applied: oven and confit. Eighteen pieces of pork loins (400 ± 20 g) were oven cooked at two temperatures (150 and 180 °C) and at three different times (45, 60 and 75 min) for each temperature. Three loins were oven cooked in different days for each temperature–time treatment. Nine pieces of pork loins (400 ± 20 g) were confit cooked at 70 °C and at three different times (120, 180 and 240 min) in extra-virgin olive oil (Hacendado, Spain) on different days.

First, sensory analysis was carried out on all cooked samples. Then, cooked samples were minced and the NIRS technique was applied in quintuplicate. The temperature of pork loins during cooking was recorded using a thermometer probe (Testo 735-2, Lenzkirch, Germany). Figure 1 shows the experimental design in detail.

Sensory evaluation of loin samples

Cooked loin samples were subjected to a descriptive sensory evaluation, particularly QDA.[8] Twelve trained panellists (five male and seven female, range age 24–39 years old) were used for this purpose. All of them were staff at the Meat and Meat Products Research Institute (IProCar) of the University of Extremadura. Samples were evaluated during three sessions (two sessions for oven-cooked samples and one for confit-cooked ones) with three products tasted per session. After cooking, the cooked samples were refrigerated for 24 h until sensory evaluation. Then, loins were sliced using a slicer meat machine TGI 300 OMS S.r.l. (TGI, Jerago con Orago, Italy) (slice samples of 2 mm and 5 g). Just before the evaluation, samples were heated for 10 s in a 600 W microwave oven. Samples (one slice per plate) were served on glass plates with a glass of mineral water and a piece of unsalted cracker to follow the rinsing protocol between samples. Evaluations were developed in tasting rooms designed according to the UNE-EN-ISO 8589:2010 regulation. All sessions were conducted at room temperature (20–22 °C) in a sensory room equipped with white fluorescent light. The serving order of the samples was randomized according to the Williams Latin square design. FIZZ software 2.20 C version (Sensory Analysis and Computer Test Management) (Biosystèmes, Couternon, France, 2002) was used for collecting the data.

Attributes used in this study were selected based on the previous experience of the authors in sensory evaluation of meat products[29,30] and according to a tasting evaluation of the cooked samples in a previous pilot study. The following attributes were chosen: brown colour and brightness for appearance, overall odour and cooked pork odour for odour, overall flavour and cooked pork flavour for flavour, and tenderness (effort required to bite through sample and to convert it to a swallowable state), juiciness (impression of lubricated food during chewing), fibrousness (extent to which fibres are perceived during chewing) and chewiness (number of chews or time of chewing required to masticate the product) for texture. A 10 cm unstructured scale was used for attributes scoring, and verbal anchors were fixed as 'little' to 'very much' for all evaluated attributes, except for brown colour (from 'light brown' to 'dark brown'), and for tenderness (from 'soft' to 'hard').

Near-infrared spectroscopy analysis procedure

After cooking, samples from each treatment were minced and analysed by NIRS (FOODSCAN lab, Foss, Hillerod, Denmark) using a wavelength range of 850–1048 nm. Each sample was analysed in quintuplicate. First, spectral data were imported from *.nirs* to *.jcamp* extension by using WinIsi III (Foss, Hillerod, Denmark), in order to allow extraction of numerical data from the near-infrared spectra. Then, the noise was eliminated by Unscrambler v. 10.4.1 (Camo Software, Oslo, Norway) with the filter MSC, removing the outlier spectra. Figure 2 shows the near-infrared spectra before (Fig. 2a) and after (Fig. 2b) removing the outlier spectra. Finally, mean values for bandwidth each 10 nm were calculated from the near-infrared spectra. Therefore, for each spectrum, 20 values were obtained and gathered in a database.

Data analysis

The data analysis was carried out as shown in Fig. 3. The cooked samples were first analysed by NIRS. The absorbance values obtained from this determination (spectral data) were used for classification purposes. A QDA was also carried out on the cooked samples. The sensory data were recorded and statistically analysed. Finally, a database was constructed with spectral and sensory data with prediction aims.

Cooking conditions effect on sensory characteristics

Sensory data (average attribute over 11 assessors) were analysed by the Kruskal–Wallis test followed by the Mann–Whitney *U* test when significant differences ($P \leq 0.05$) were found. The effect of cooking temperature (150 or 180 °C) and time (45, 60, or 75 min) were tested in oven-cooked samples. For confit samples, only time effect was analysed (120, 180, or 240 min). The IBM SPSS v.22 (IBM Co., New York, New York, USA) statistics software package was used to carry out the former analysis.

Classification

Principal components analysis (PCA) was applied on NIRS data. In this case, PCA was carried out in order to evaluate the ability of NIRS to discriminate between cooked samples as a function of cooking temperature, cooking time and both together; that is, the combined effect of temperature and time of cooking. XLSTAT software (Addinsoft Pearson Edition 2014, Addinsoft, Paris, France) was used to carry out the PCA analysis.

Moreover, a database with results from sensory and NIRS analyses was constructed.

PCA was also applied on a database constructed with both NIRS and sensory data, in order to evaluate the samples distribution

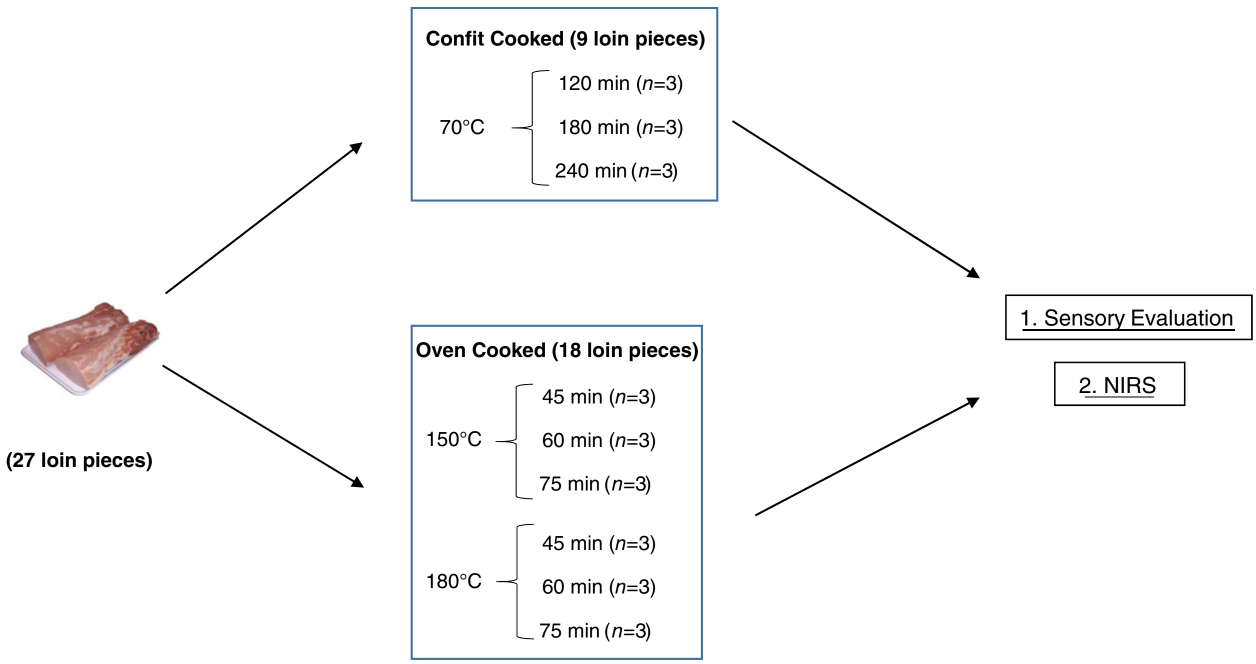

Figure 1. Experimental design.

as well as the relationship between sensory and NIRS variables. XLSTAT software (Addinsoft Pearson Edition 2014, Addinsoft, Paris, France) was also used in this case.

Prediction

Predictive techniques of data mining were used in this study by using the free software Waikato Environment for Knowledge Analysis (WEKA; http://www.cs.waikato.ac.nz/ml/weka). WEKA is a tool that allows the use of a collection of machine-learning algorithms for data analysis tasks.

Among these tasks, the main groups in data mining are descriptive and predictive techniques. In this study, predictive techniques were applied; these allow that future models can be predicted from current data by trend analysis.[31,32]

Multiple linear regression (MLR), as a data mining technique, was performed on this database to obtain prediction equations of sensory attributes as a function of the absorbance values.

MLR models the linear relationship between a dependent variable (target) and one or several independent variables (predictors). This technique provided a linear regression equation, which could be used to predict future values.[33] The M5 method was applied for attribute selection, and a ridge value of 1.0×10^{-4}. This method is based on removing the independent variable with the smallest standardized coefficient. Then, the independent variable is dropped if the result is improved. This was repeated until no improvement was observed in the estimation of the error.

The correlation coefficient R was used for evaluating the accuracy of fit of the prediction, according to other authors,[34,35] using the following equation:

$$R = \sqrt{\frac{\sum_{i=1}^{n} \left(f_i - \bar{y}\right)^2}{\sum_{i=1}^{n} \left(y_i - \bar{y}\right)^2}}$$

where f_i is the predictive value, y_i is the real value and $\bar{y}$ is the average value.

Rules given by Colton[36] were used to evaluate R values: $R = 0 - 0.25$ indicates very low correlation, $R = 0.25 - 0.5$ indicates low correlation, $R = 0.5 - 0.75$ indicates acceptable correlation and$R = 0.75 - 1$ indicates high correlation.

Additionally, the mean absolute error (MAE) was used to validate the prediction results.[37] MAE is calculated using the following equation:

$$\mathrm{MAE} = \frac{1}{n} \sum_{i=1}^{n} \left| \mathrm{f}_i - y_i \right|$$

where f_i is the predicted value and y_i is the real value.

RESULTS AND DISCUSSION

Sensory profiles

Oven-cooked loins

The sensory profile of oven-cooked loins is shown in Fig. 4 and Table 1. Sensory attributes of oven-cooked loins at 150 °C are displayed in Fig. 4a and b, whereas sensory attributes of oven-cooked samples at 180 °C are presented in Fig. 4c and d.

Regarding the temperature effect in oven-cooked loins, panellists detected significant differences ($P < 0.05$) in brown colour, brightness, tenderness, juiciness, fibrousness, and chewiness. However, the evaluated odour and flavour attributes were not significantly ($P > 0.05$) influenced by the temperatures studied. Loins oven cooked at 180 °C were browner (1.83 ± 1.44 for 150 °C, and 2.75 ± 0.75 for 180 °C), brighter (0.79 ± 0.62 for 150 °C, and 2.75 ± 0.75 for 180 °C), and juicier (1.89 ± 0.79 for 150 °C, and 2.76 ± 1.28 for 180 °C), easier to chew (6.77 ± 1.08 for 150 °C, and 4.55 ± 1.01 for 180 °C), less fibrous (7.06 ± 0.68 for 150 °C, and 5.79 ± 1.17 for 180 °C), and less tender (6.34 ± 1.08 for 150 °C, and 4.21 ± 1.12 for 180 °C) compared with those oven cooked at 150 °C. These results revealed an important effect of oven cooking temperature on sensory attributes of pork loins. Previous studies have found that modifications in cooking temperature affected

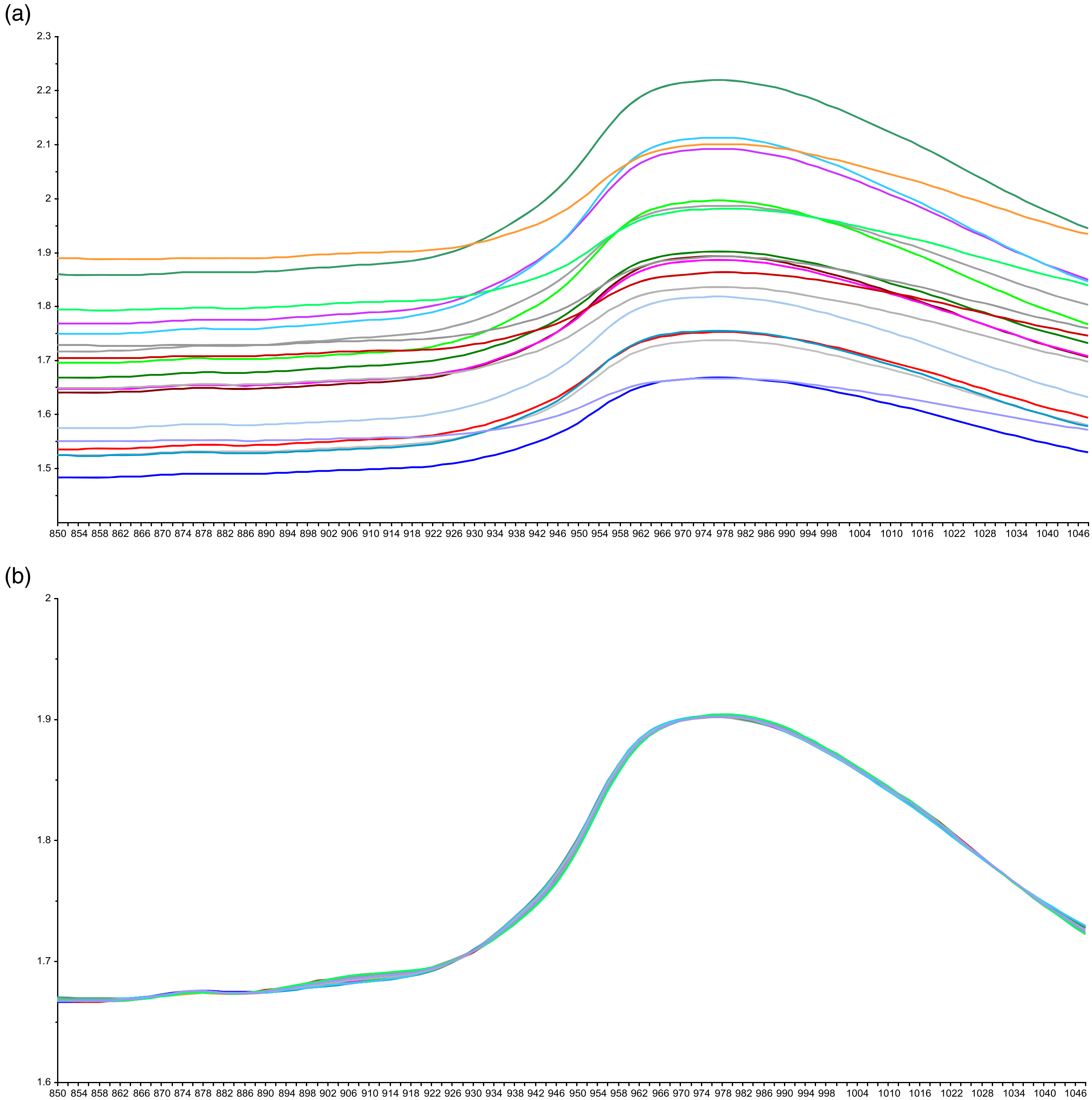

Figure 2. Spectra obtained (a) before and (b) after removing the outlier and noise.

sensory attributes such as juiciness, odour, flavour or tenderness in pork loins.[38]

Moreover, similar to the results of this study, others also reported not significant differences in odour and flavour attributes due to the oven cooking temperature.[29,39] For appearance attributes, panellists described samples oven cooked at the highest temperature (180 °C) the brownest, probably owing to the occurrence of Maillard reactions and thus the accumulation of melanoidins on the pork surface.[40] Regarding the tenderness results, the findings described in previous studies were in agreement with those reported in here, as increasing the oven cooking temperature led to more tender pork loins.[38,41] Cooking has a great influence on meat tenderness as a result of denaturation of myofibrillar components, resulting in collagen solubilization and alteration, leading to more tender meat.[42]

Time of oven cooking significantly influenced all attributes studied except cooked pork odour, overall flavour and chewiness in loins oven cooked at 150 °C (Table 1). Regarding appearance attributes, samples oven cooked for 60 min displayed the highest scores for brown colour, whereas those oven cooked for 45 min were significantly the brightest. Decreasing in brightness due to time of cooking could be explained by the loss of water associated with the cooking procedure.[43] Heat induces protein denaturation during meat cooking, leading to less water being entrapped within the protein structures held by capillary forces.[35] For overall odour, samples cooking for 45 and 60 min

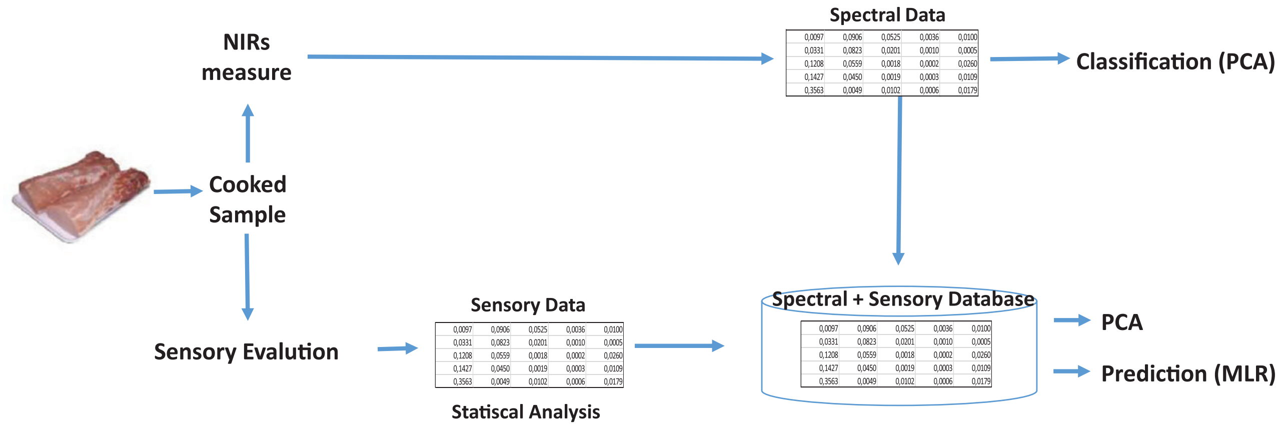

Figure 3. Data analysis.

displayed significantly higher scores than those cooked for 75 min. Regarding texture, tenderness was significantly lower in samples oven cooked for 60 min than those cooked for 45 min, but for 75 min the scores for this attribute significantly increased compared with 60 min. Moreover, increasing the time of cooking at 150 °C significantly decreased the juiciness of samples and increased the fibrousness. Increasing the time of cooking led to a higher dehydration of meat,[29] contributing to a decrease in the juiciness perception, which mainly depends on the water and fat content in meat,[35] and to increase the fibrousness perception since the meat fibres likely were more intensely perceived during loins consumption. Finally, for cooked pork flavour, samples oven cooked for 60 min significantly displayed the highest scores for this attribute compared with those cooked for 45 and 75 min. Flavour perception, among other factors, depends on the amount of flavour compounds formed, the rate of release of flavour compounds from the food matrices during consumption and the ability of these compounds to reach the receptors in the olfactory and oral epithelium. Cooking induces volatile compound generation in meat, mainly derived from lipid oxidation and Maillard reactions.[44] Moreover, fat could influence the release of volatile compounds from the food matrix to the environment and the mouth, mainly by retaining nonpolar compounds.[45] Regarding food composition, water and fat content and physical state of fat determine the rate of volatile compounds release and thus their perception.

In relation to loins oven cooked at 180 °C, time of cooking significantly influenced the brightness, tenderness, juiciness, fibrousness, chewiness, and overall flavour attributes. First, brightness was significantly influenced by the time effect, showing the highest scores for samples oven cooked for 45 and 60 min compared with those oven cooked for 75 min, likely due to the loss of water during cooking.[44] Regarding texture parameters, tenderness displayed higher scores when the time of cooking increased, with samples oven cooked for 60 and 75 min being significantly the most tender. Similar results were obtained for fibrousness, with the loins oven cooked for 75 min being significantly the most fibrous. Furthermore, juiciness was significantly higher in loins oven cooked for 45 min, compared with those cooked for 60 and 75 min. Similarly to the result reported for samples oven cooked at 150 °C, the phenomenon of dehydration influenced loins oven cooked at 180 °C, showing a decrease in the juiciness perception (29). Chewiness presented the highest values in oven cooked samples during 60 min. The loss of water and the modification of myofibrils and collagen caused by the cooking process and previously discussed could explain the former results regarding texture attributes and the effect of cooking time. Finally, overall cooked flavour displayed significant differences between samples cooked for 75 min and those cooked during 45 and 60 min. Accordingly, for the results found at 150 °C, the flavour perception decreased when loins were cooked for the longest period of time (75 min).

Confit-cooked loins

The sensory profile of confit-cooked loins is shown in Fig. 4e and f and Table 1.

Time of cooking revealed a significant effect in all attributes studied except for cooked pork flavour and fibrousness. Concerning appearance attributes, increasing the time of cooking significantly increased brown colour but decreased brightness. Myoglobin oxidation and loss of water could explain the results of colour and brightness respectively. Cooking meat produced a denaturation and oxidation of myoglobin, causing an alteration of meat colour, changing from red to brown.[46] Cooked pork odour received higher scores when the time of cooking increased, with the loins confit cooked for 240 min displaying the highest values for this attribute. Similar results were obtained for overall odour. A higher odour compounds generation with time of cooking was expected. Similarly, others have described a great influence of time and temperature of cooking on odour intensity perception.[29,47] Regarding texture parameters, tenderness was significantly lower in samples oven cooked for 180 min than those cooked for 120 and 240 min. In addition, increasing the time of cooking significantly decreased the juiciness of samples, similar to the results reported in previous studies.[48] Chewiness showed the highest scores in loins cooked for 120 and 180 min, compared with samples cooked for 240 min. Texture attributes and particularly juiciness depends on the water and fat content of samples.[29,35] Therefore, increasing the time of cooking increases the water loss, and thus the perceived juiciness decreases and the chewiness increases. Finally, similar to the results reported for oven-cooked loins at 180 °C, overall flavour displayed higher values in loins cooked for 120 and 180 min than the samples cooked for 240 min.

Once the influence of temperature and time of cooking in sensory attributes of oven and confit loins was shown and discussed, the capability of NIRS to differentiate these samples was tested.

Classification

The ability of NIRS for classifying samples cooked as a function of the temperature and time of cooking was evaluated by means of

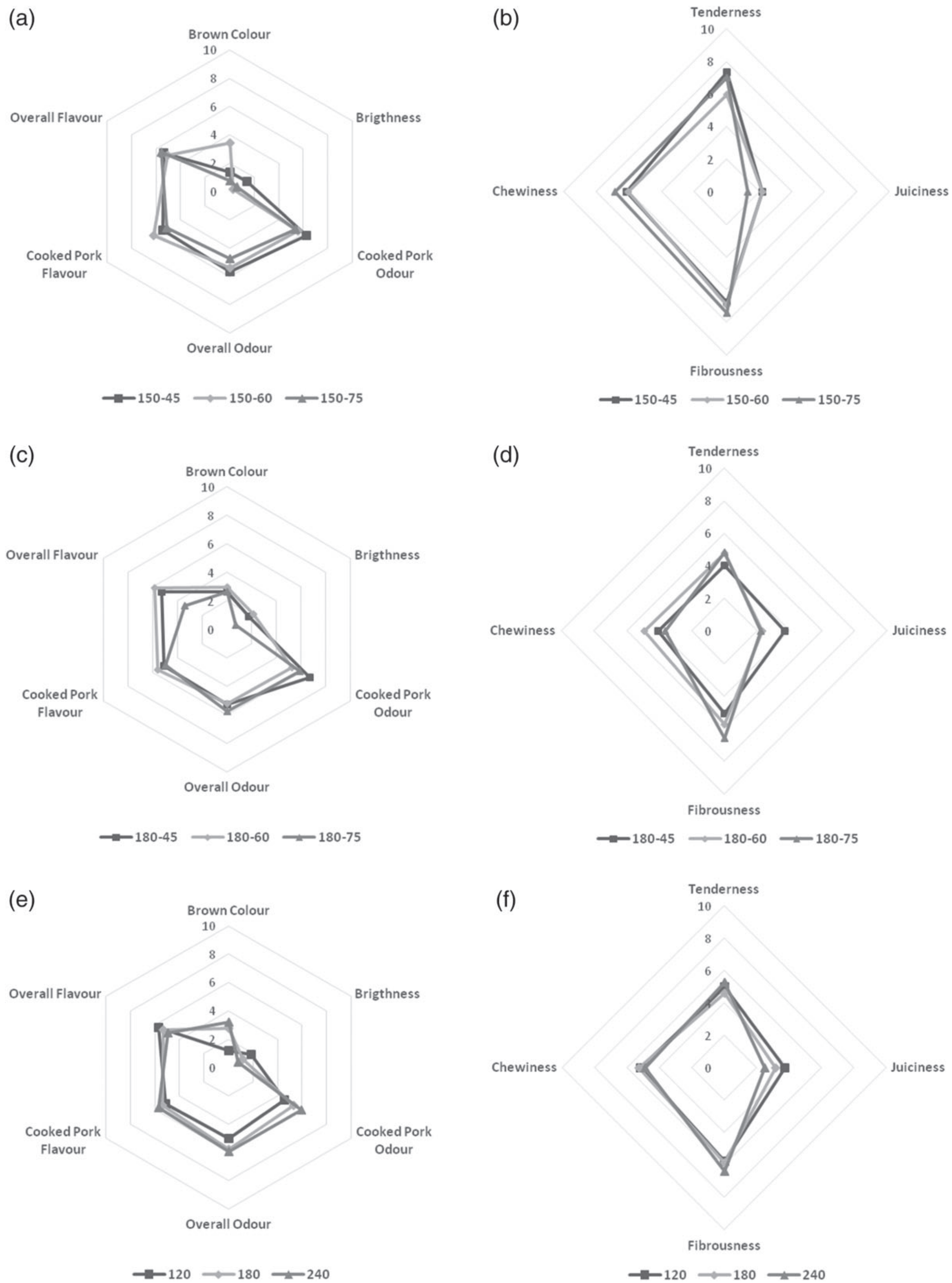

Figure 4. Results on sensory analysis for oven-cooked loins at (a, b) 150 °C (45, 60 and 75 min), (b, c) 180 °C (45, 60 and 75 min); (e, f) confit-cooked loins at 70 °C (120, 180 and 240 min). A: appearance, odour and flavour attributes. B: texture attributes. Attributes values within a 10 cm scale.

PCA (Fig. 5). First, score plots of PCA of NIRS data from oven-cooked samples at 150 and 180 °C are presented in Fig. 5a. The first two principal components accounted for 80.22% of the total variance (59.95% for PC1, and 20.27% for PC2). Most loins cooked at 150 °C were positioned in the two upper quadrants, and only three samples were found in the bottom right quadrant. Samples oven cooked at 180 °C were located in the two bottom quadrants, except for one situated in the upper right quadrant.

In relation to the cooking time effect, Fig. 5b shows the score plot of NIRS data from oven-cooked loins cooked at 150 °C for 45,

Table 1. Time effect for sensory attributes evaluated in oven- and confit-cooked loins (means values plus/minus standard deviation)

	Oven								
	150 °C			180 °C			Confit		
	45 min	60 min	75 min	45 min	60 min	75 min	120 min	180 min	240 min
Brown colour	1.36 ± 0.50^{b}	3.40 ± 1.41^{a}	0.74 ± 0.44^{c}	2.63 ± 0.72	2.96 ± 0.85	2.67 ± 0.68	1.21 ± 0.60^{b}	2.77 ± 0.97^{a}	3.22 ± 0.99^{a}
Brightness	1.44 ± 0.51^{a}	0.31 ± 0.22^{b}	0.60 ± 0.41^{b}	1.78 ± 0.76^{a}	2.11 ± 0.74^{a}	0.69 ± 0.32^{b}	1.86 ± 0.96^{a}	$1.15 \pm 0.93a^{b}$	0.79 ± 0.85^{b}
Cooked pork odour	6.26 ± 1.20	5.59 ± 1.49	5.36 ± 0.90	6.67 ± 0.94	5.25 ± 1.05	5.89 ± 0.86	4.58 ± 0.83^{c}	5.33 ± 0.88^{b}	5.96 ± 0.78^{a}
Overall odour	5.68 ± 0.92^{a}	5.41 ± 1.01^{a}	4.77 ± 0.75^{b}	5.27 ± 1.12	5.18 ± 1.04	5.72 ± 1.06	5.00 ± 0.87^{b}	5.76 ± 0.67^{a}	5.95 ± 0.89^{a}
Tenderness	7.33 ± 0.93^{a}	5.98 ± 0.84^{b}	6.99 ± 1.05^{a}	4.00 ± 0.83^{b}	4.79 ± 0.99^{a}	4.85 ± 1.05^{a}	5.00 ± 0.46^{a}	4.59 ± 0.67^{b}	5.30 ± 0.85^{a}
Juiciness	2.17 ± 0.85^{a}	2.21 ± 0.49^{a}	1.30 ± 0.66^{b}	3.72 ± 1.17^{a}	2.35 ± 1.31^{b}	2.22 ± 0.82^{b}	3.75 ± 0.98^{a}	3.15 ± 0.70b	2.52 ± 0.85^{c}
Fibrousness	6.79 ± 0.51^{b}	6.95 ± 0.73^{ba}	7.45 ± 0.64^{a}	5.07 ± 1.07^{b}	5.74 ± 0.96^{b}	6.57 ± 1.01^{a}	5.77 ± 0.64	5.86 ± 0.81	6.40 ± 0.99
Chewiness	6.15 ± 1.00	6.04 ± 1.02	6.84 ± 1.13	4.05 ± 1.04^{b}	4.92 ± 1.03^{a}	3.65 ± 0.90^{b}	5.17 ± 0.94^{a}	5.25 ± 0.75^{a}	4.88 ± 0.80^{b}
Cooked pork flavour	5.44 ± 0.93^{b}	6.19 ± 0.77^{a}	5.13 ± 1.04^{b}	5.10 ± 1.07	5.58 ± 1.07	5.00 ± 1.14	5.15 ± 0.91	5.40 ± 0.86	5.68 ± 1.01
Overall flavour	5.41 ± 0.71	5.07 ± 0.93	5.57 ± 0.60	5.31 ± 1.13^{a}	5.85 ± 1.07^{a}	3.40 ± 0.84^{b}	5.68 ± 1.00^{a}	5.3 ± 0.86^{ab}	4.92 ± 0.76^{b}

Different letters within the same row denote significant differences between means at $p < 0.05$.

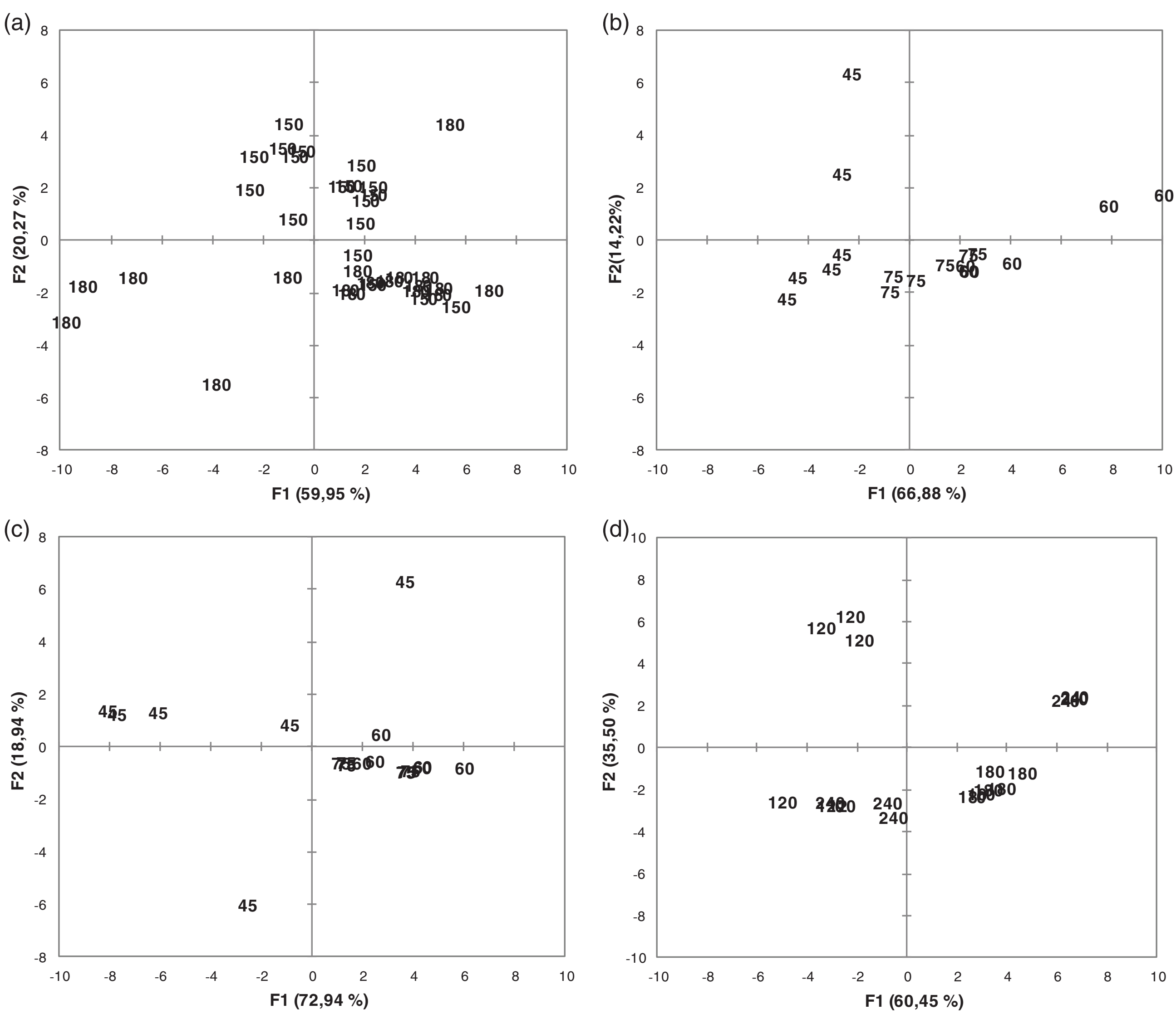

Figure 5. PCA of absorbance results (NIRS) with factor scores plot for the two first principal components: (a) effect of temperature (150 and 180 °C) on oven samples, (b) effect of time (45, 60 and 75 min) on oven samples at 150 °C; (c) effect of time (45, 60 and 75 min) on oven samples at 180 °C; (d) effect of time (120, 180 and 240 min) on confit samples at 70 °C.

60 and 75 min. The first two principal components accounted for 81.10% of the total variance (66.88% for PC1, and 14.22% for PC2). Samples cooked for 45 min were located in both left quadrants, and those samples cooked for 60 min were in the right quadrants, whereas samples oven cooked for 75 min were near to the centre point in the two lower quadrants, and close to some samples cooked for 60 min. A similar trend was found for loins oven cooked at 180 °C for 45, 60 and 75 min (Fig. 5c). However, in this case, samples oven cooked for 60 min were even closer to those cooked for 75 min.

Regarding the time effect for confit loins, Fig. 5d shows the score plots of PCA of NIRS data from samples confit cooked for 120, 180 and 240 min. The first two principal components accounted for 95.95% of the total variance (60.45% for PC1, and 35.50% for PC2). Pork loins cooked for 120 min were distributed in the left quadrants, and separated from samples confit cooked for 180 min, which were situated in the bottom right quadrant. Finally, loins confit cooked for 240 min were situated in the bottom left quadrant, near to the 120 min samples, and in the upper right quadrant.

These findings point out that NIRS enables differentiation of oven-cooked and confit-cooked loins under different conditions, particularly for samples cooked at different temperatures, whilst not being as accurate for samples cooked at different times.

Monin[49] proposed that NIRS was amongst the most promising techniques for large-scale meat quality evaluation, especially with respect to classification, and many studies support this conclusion. NIRS data as a classification model method have been used in multiple ways. Some reports have demonstrated the ability of NIRS to classify using different techniques of classification and combination between them. NIRS has been used to identify the geographical origins of lamb meat, showing a high classification rate,[50] to discriminate amongst species of fish to avoid fraudulent practices,[16] or to determine freshness using visible spectroscopy and NIRS (visible–NIRs) on Atlantic salmon[51] or even to control pig breeding.[18] Regarding pork meat, others have used NIRS to quantify water-holding capacity in pork loins,[52] to classify tenderness and juiciness with visible–NIRS results[53] and to predict pork quality using visible–NIRS data. All these studies obtained good results of classification using NIRS. The results of this work are shown to be valid for classifying pork loins, especially in oven-cooked samples for temperature and time effect.

First, relationships between sensory attributes and near-infrared spectral data were analysed by means of PCA, for both oven- and confit-cooked samples.

Figure 6a shows a PCA biplot (variables and samples) of sensory and NIRS data from ove-cooked samples. The first two principal components accounted for 82.54% of the total variance (54.52% for PC1, and 28.02% for PC2). Cooked meat flavour was positively correlated to PC1 and was located close to wavelengths of 860, 890, and 970 nm, while cooked meat odour was negatively associated to PC1 and near to wavelengths of 920, 1010, 1020, 1030, and1040 nm. Tenderness, chewiness, and fibrousness were positively associated to PC2, and were found close to wavelengths of 900 and 990 nm. Meanwhile, juiciness and brown colour were negatively related to PC2, and at the same time were near to wavelengths of 930 and 940 nm and 950 nm respectively.

Figure 6b displays another PCA biplot that was made using the data from NIRS and sensory data of confit-cooked loins. The two principal components accounted for 91.13% of the total variance (62.54% for PC1, and 28.59% for PC2).

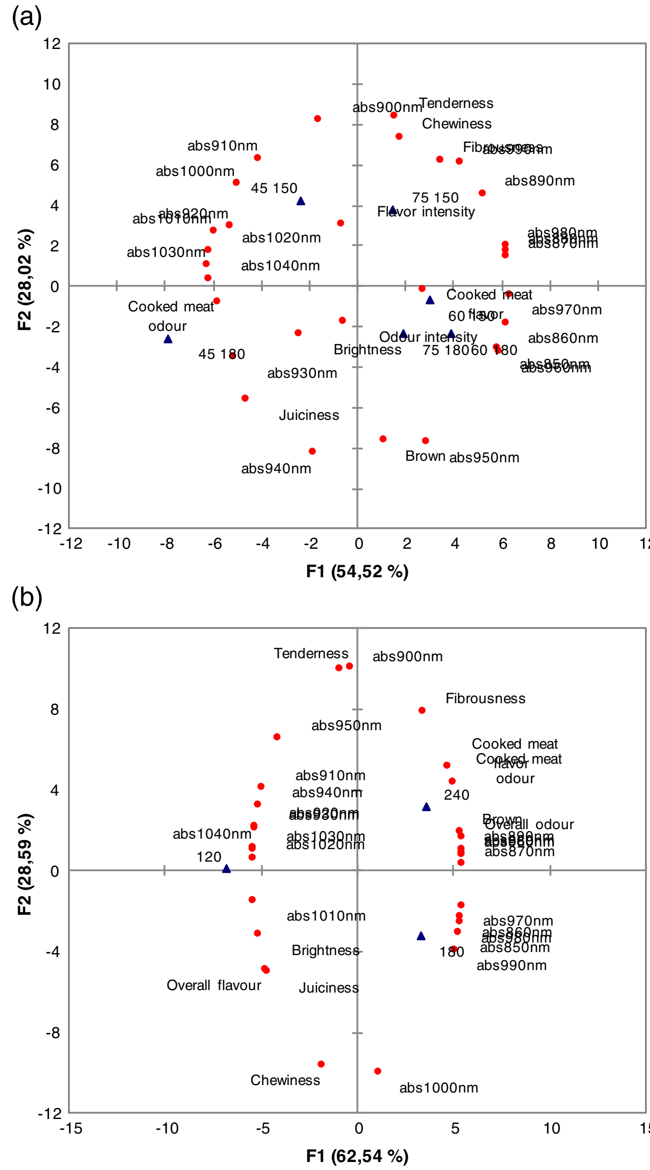

Figure 6. PCA of absorbance (NIRS) and sensory parameters results (QDA) with biplot for the two first principal components: (a) effect of temperature and time on oven samples at 150 °C and 180 °C for 45, 60 and 75 min; (b) effect of time on confit samples at 70 °C for 120, 180 and 240 min.

Brown colour and overall odour were positively related to PC1, and were found close to 870, 880, 890, and 960 nm. Tenderness was distributed near to wavelength 900 nm, and positively correlated to PC2, while chewiness was negatively associated to this principal component, close to a wavelength of 1000 nm. Finally, brightness was located in the left bottom quadrant, near to wavelength 1010 nm.

Prediction

Once the existence of relationships between sensory and NIRS data was reported, the predictive technique of data mining was applied in order to obtain prediction equations of sensory attributes as a function of NIRS absorbance. As an example, Eqn (1) shows the prediction equation for tenderness in oven-cooked loins:

$$\begin{aligned}\text{Tenderness} = &-220.882 \times \text{abs850nm} - 180.688 \times \text{abs860nm} + 35.058 \times \text{abs870nm} + 263.933 \times \text{abs880nm} + 1277.887\\ &\times \text{abs890nm} + 459.09 \times \text{abs900nm} + 280.220 \times \text{abs910nm} + 397.496 \times \text{abs920nm} - 212.099 \times \text{abs930nm}\\ &- 850.337 \times \text{abs940nm} - 242.246 \times \text{abs950nm} + 83.607 \times \text{abs960nm} + 300.075 \times \text{abs970nm} + 485.491\\ &\times \text{abs980nm} - 834.762 \times \text{abs990nm} - 1357.824 \times \text{abs1000nm} - 313.542 \times \text{abs1010nm} - 59.128\\ &\times \text{abs1020nm} + 105.598 \times \text{abs1030nm} + 301.756 \times \text{abs1040nm} + 835.295 \end{aligned} \quad (1)$$

Table 2. Correlation coefficient *R* and mean absolute error MAE of the prediction equations for sensory attributes of oven- and confit-cooked loins

	Oven		Confit	
	R (10 nm)	MAE (10 nm)	*R* (10 nm)	MAE (10 nm)
Brown colour	0.7290	0.9403	0.9770	1.1900
Brightness	0.3776	0.7382	0.9438	0.5933
Cooked pork odour	0.8539	0.4690	0.8900	0.7100
Overall odour	0.4641	0.8177	0.9820	0.5700
Tenderness	0.7249	0.4608	0.1891	0.3733
Juiciness	0.5624	0.6339	0.8589	0.6200
Fibrousness	0.5474	1.2816	0.6100	0.3900
Chewiness	0.6592	1.3887	0.6114	0.2200
Cooked pork flavour	0.3058	0.4575	0.8492	0.2700
Overall flavour	0.4258	1.0346	0.8660	0.3800

Table 2 shows the values of *R* and MAE for the prediction equations of each sensory attribute of oven- and confit-cooked loins.

In the case of oven-cooked samples, correlation coefficients of the prediction equation for six attributes were acceptable ($R > 0.5$; brown colour, cooked pork odour, tenderness, juiciness, fibrousness and chewiness), while correlation coefficients for the rest of attributes (brightness, overall odour, cooked pork flavour and overall flavour) were low. With regard to MAE, equations of all sensory attributes displayed appropriate values (<2).

For confit-cooked loins, equations for seven sensory attributes attained high correlation coefficients (brown colour, brightness, cooked pork odour, overall odour, juiciness, cooked pork flavour and overall flavour), acceptable for fibrousness and chewiness but very low for tenderness. Concerning MAE, all equations displayed appropriate values (<1).[31] It is also noted that confit-cooked samples obtained more accurate prediction results than oven-cooked samples. As previously reported, relationships between sensory and NIRS data were slightly higher in confit- than in oven-cooked loins. These findings point out the accuracy of both NIRS and data mining techniques for prediction of sensory attributes of cooked loins. This is in agreement with previous studies applying NIRS to cooked ham[22] and lamb meat[23,24] and using partial least square and partial least square regression. Besides that, some have proposed the use of NIRS to predict physicochemical parameters in pork meat products.[53,54]

The accuracy of MLR for prediction of physicochemical and sensory attributes of fresh and dry-cured meat products by means of magnetic resonance imaging has been previously reported.[36,55,56]

CONCLUSIONS

This study demonstrates the capability of the NIRS technique to distinguish among pork loins based on the cooking methods (oven and confit) and conditions (temperature and time). Additionally, the application of MLR, as a data mining technique, in a database with NIRS and sensory data enables a correct prediction for sensory attributes in oven- and particularly confit-cooked pork loins.

ACKNOWLEDGEMENTS

Alberto González-Mohino Jiménez thanks the Ministerio de Economía y Competitividad de Empleo for the 'Ayuda de Empleo Juvenil' (PEJ2014-A-33492). We wish to acknowledge the Animal Source Foodstuffs Innovation Service (SIPA) from the University of Extremadura for their direct contribution and support.

REFERENCES

1 James BJ and Yang SW, Effect of cooking method on the toughness of bovine M. semitendinosus. *Int J Food Eng* **8** https://doi.org/10.1515/1556-3758.276 (2012).
2 Oz F, Aksu MI and Turan M, The effects of different cooking methods on some quality criteria and mineral composition of beef steaks. *J Food Process Preserv* **41**:e13008 (2017).
3 Yang Z, Lu R, Song H, Zhang Y, Tang J and Zhou N, Effect of different cooking methods on the formation of aroma components and heterocyclic amines in pork loin. *J Food Process Preserv* **41**:e12981 (2017)
4 Aaslyng MD, Oksama M, Olsen EV, Bejerholm C, Baltzer M, Andersen G *et al.*, The impact of sensory quality of pork on consumer preference. *Meat Sci* **76**:61–73 (2007).
5 Nam Y-J, Choi Y-M, Jeong D-W and Kim B-C, Comparison of postmortem meat quality and consumer sensory characteristic evaluations, according to porcine quality classification. *Food Sci Biotechnol* **18**:307–311 (2009).
6 Juárez ME, Carlin SC, Rebollo F, Verdugo-Rodríguez A and Martínez-Gómez D, Sensory evaluation of cooked pork meat (M. bicepsfemoris) fed with and without ractopamine hydrochloride associated to age but not gender of the non-trained panelist. *J Anim Plant Sci* **26**:40–45 (2016).
7 Straadt IK, Aaslyng MD and Bertram HC, Sensory and consumer evaluation of pork loins from crossbreeds between Danish Landrace, Yorkshire, Duroc, Iberian and Mangalitza. *Meat Sci* **95**:27–35 (2013).
8 Stone H, Sidel J, Oliver S, Woolsey A and Singleton RC, Sensory evaluation by Quantitative Descriptive Analysis. *Food Technol* **28**:24–34 (1974).
9 Moeller SJ, Miller RK, Aldredge TL, Logan KE, Edwards KK, Zerby HN *et al.*, Trained sensory perception of pork eating quality as affected by fresh and cooked pork quality attributes and end-point cooked temperature. *Meat Sci* **85**:96–103 (2010).
10 Pérez-Palacios T, Antequera T, Durán ML, Caro A, Rodríguez PG and Palacios R, MRI-based analysis of feeding background effect on fresh Iberian ham. *Food Chem* **126**:1366–1372 (2011).
11 Roldan M, Antequera T, Armenteros M and Ruiz J, Effect of different temperature-time combinations on lipid and protein oxidation of sous-vide cooked lamb loins. *Food Chem* **149**:129–136 (2014).

12 Roldan M, Loebner J, Degen J, Henle T, Antequera T and Ruiz-Carrascal J, Advanced glycation end products, physico-chemical and sensory characteristics of cooked lamb loins affected by cooking method and addition of flavour precursors. *Food Chem* **168**:487–495 (2015).
13 García C and Carrapiso AI, La calidad sensorial del jamón Ibérico y su evaluación: la cala y la cata del jamón. In *Tecnología del Jamón Ibérico*, ed. by Ventanas J. Mundi Prensa, Madrid, pp. 391–418 (2001).
14 Cozzolino D, Murray I, Scaife JR and Paterson R, Study of dissected lamb muscles by visible and near infrared reflectance spectroscopy for composition assessment. *Anim Sci* **70**:417–423 (2000).
15 Sánchez MT, De la Haba MJ, Serrano I and Pérez-Marín D, Application of NIRS for nondestructive measurement of quality parameters in intact oranges during on-tree ripening and at harvest. *Food Analytical Methods* **6**:826–837 (2013).
16 Alamprese C and Casiraghi E, Application of FT-NIR and FT-IR spectroscopy to fish fillet authentication. *LWT–Food Sci Technol* **63**:720–725 (2015).
17 García-Rey RM, García-Olmo J, De Pedro E, Quiles-Zafra R and Luque de Castro MD, Prediction of texture and colour of dry-cured ham by visible and near infrared spectroscopy using a fiber optic probe. *Meat Sci* **70**:357–363 (2005).
18 Zamora-Rojas E, Garrido-Varo A, De Pedro-Sanz E, Guerrero-Ginel JE and Pérez-Marín D, Monitoring NIRS calibrations for use in routine meat analysis as part of Iberian pig-breeding programs. *Food Chem* **129**:1889–1897 (2011).
19 Monteiro Balage J, da Luz e Silva S, Abdalla Gomide C, de Nadai Bonin M and Figueira AC, Predicting pork quality using vis/NIR spectroscopy. *Meat Sci* **108**:37–43 (2015).
20 Cifuni GF, Contò M and Failla S, Potential use of visible reflectance spectra to predict lipid oxidation of rabbit meat. *J Food Eng* **169**:85–90 (2016).
21 Klaypradit W, Kerdpiboon S and Singh RK, Application of artificial neural networks to predict the oxidation of menhaden fish oil obtained from Fourier transform infrared spectroscopy method. *Food Bioprocess Technol* **4**:475–480 (2011).
22 Barbieri S, Soglia F, Palagano R, Tesini F, Bendini A, Petracci M *et al.*, 2016. Sensory and rapid instrumental methods as a combined tool for quality control of cooked ham. *Heliyon* **2**:e00202.
23 Kamruzzaman M, Elmasry G, Sun DW and Allen P, Non-destructive assessment of instrumental and sensory tenderness of lamb meat using NIR hyperspectral imaging. *Food Chem* **141**:389–396 (2013).
24 Andrés S, Murray I, Navajas EA, Fisher AV, Lambe NR and Bünger L, Prediction of sensory characteristics of lamb meat samples by near infrared reflectance spectroscopy. *Meat Sci* **76**:509–516 (2007).
25 Mitchell TM, Machine learning and data mining. *Commun ACM* **42**:30–36 (1999).
26 Grassi S, Amigo JM, Lyndgaard CB, Foschino R and Casiraghi E, Beer fermentation: monitoring of process parameters by FT-NIR and multivariate data analysis. *Food Chem* **155**:279–286 (2014).
27 Song YH, Kim SJ and Lee SK, Evaluation of ultrasound for prediction of carcass meat yield and meat quality in Korean native cattle (Hanwoo). *Asian–Australas J Anim Sci* **15**:591–595 (2002).
28 Caballero D, Antequera T, Caro A, Duran ML and Perez-Palacios T, Data mining on MRI-computational texture features to predict sensory characteristics in ham. *Food Bioprocess Technol* **9**:699–708 (2016).
29 Bejerholm C and Aaslyng MD, The influence of cooking technique and core temperature on results of a sensory analysis of pork – depending on the raw meat quality. *Food Quality and Preference* **15**:19–30 (2004).
30 Lorido L, Estévez M and Ventanas S, A novel approach to assess temporal sensory perception of muscle foods: application of a time–intensity technique to diverse Iberian meat products. *Meat Sci* **96**:385–393 (2014).
31 Witten IH and Frank E, *Data Mining: Practical Machine Learning Tools and Techniques with Java Implementations*. Morgan Kaufmann, San Francisco, CA (2005).
32 Wu X, Kumar V, Quinlan JR, Ghosh J, Yang Q, Motoda H *et al.*, Top 10 algorithms in data mining. *Knowledge and Information Systems* **14**:1–37 (2008).
33 Hastie T, Tibshirani R and Friedman JH, *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*. Springer, New York (2001).
34 Manzocco L, Anese M, Marzona S, Innocente N, Lagazio C and Nicoli MC, Monitoring dry-curing of S. Daniele ham by magnetic resonance imaging. *Food Chem* **141**:2246–2252 (2013).
35 Pérez-Palacios T, Caballero D, Antequera T, Durán ML, Ávila M and Caro A, Optimization of MRI acquisition and texture analysis to predict physico-chemical parameters of loins by data mining. *Food Bioprocess Technol* **10**:750–758 (2017).
36 Colton T, *Statistics in Medicine*. Little Brown and Co., New York (1974).
37 Hyndman RJ and Koehler AB, Another look at measures of forecast accuracy. *International Journal of Forecasting* **22**:679–688 (2006).
38 Aaslyng MD, Bejerholm C, Ertbjerg P, Bertram HC and Andersen HJ, Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. *Food Quality and Preference* **14**:277–288 (2003).
39 Moeller SJ, Miller RK, Edwards KK, Zerby HN, Logan KE, Aldredge TL *et al.*, Consumer perceptions of pork eating quality as affected by pork quality attributes and end-point cooked temperature. *Meat Sci* **84**:14–22 (2010).
40 Hodge JE, Dehydrated foods, chemistry of browning reactions in model systems. *J Agric Food Chem* **1**:928–943 (1953).
41 Simmons SL, Carr TR and McKelth FK, Effects of internal temperature and thickness on palatability of pork loin chops. *J Food Sci* **50**:313–315 (1985).
42 Christensen M, Purslow PP and Larsen LM, The effect of cooking temperature on mechanical properties of whole meat, single muscle fibres and perimysial connective tissue. *Meat Sci* **55**:301–307 (2000).
43 Heymann H, Hedrick HB, Karrasch MA, Eggeman MK and Ellersieck MR, Sensory and chemical characteristics of fresh pork roasts cooked to different endpoint temperatures. *J Food Sci* **55**:613–617 (1990).
44 Jeantet R, Croguennec T, Shuck P and Brulé G, Oxidación de los lípidos, in *Ciencias de los Alimentos, Volumen 1: Estabilización Biológica y Físico Química*, 1st edn. Editorial Acribia (2010).
45 Ventanas S, Estevez M, Andrés A and Ruiz J, Analysis of volatile compounds of Iberian dry-cured loins with different intramuscular fat contents using SPME-DED. *Meat Sci* **79**:172–180 (2008).
46 Hunt MC, Sørhelm O and Slinde E, Colour and heat denaturation of myoglobin forms in ground beef. *J Food Sci* **64**:847–851 (1999).
47 Del Pulgar JS, Roldan M and Ruiz-Carrascal J, Volatile compounds profile of sous-vide cooked pork cheeks as affected by cooking conditions (vacuum packaging, temperature and time). *Molecules* **18**:12538–12547 (2013).
48 Tornberg E, Effects of heat on meat proteins – implications on structure and quality of meat products. *Meat Sci* **70**:493–508 (2005).
49 Monin G, Recent methods for predicting quality of whole meat. *Meat Sci* **49**:S231–S243 (1998).
50 Sun S, Guo B, Wei Y and Fan M, Classification of geographical origins and prediction of δ^{13}C and δ^{15}N values of lamb meat by near infrared reflectance spectroscopy. *Food Chem* **135**:508–514 (2012).
51 Kimiya T, Sivertsen AH and Heia K, VIS/NIR spectroscopy for non-destructive freshness assessment of Atlantic salmon (*Salmo salar* L.) fillets. *J Food Eng* **116**:758–764 (2013).
52 Geesink GH, Schreutelkamp FH, Frankhuizen R, Vedder HW, Faber NM, Kranen RW *et al.*, Prediction of pork quality attributes from near infrared reflectance spectra. *Meat Sci* **65**:661–668 (2003).
53 Monteiro Balage J, da Luz e Silva S, Abdalla Gomide C, de Nadai Bonin M and Figueira AC, Predicting pork quality using vis/NIR spectroscopy. *Meat Sci* **108**:37–43 (2015).
54 Prieto N, Roehe R, Lavín P, Batten G and Andrés S, Application of near infrared reflectance spectroscopy to predict meat and meat products quality: a review. *Meat Sci* **83**:175–186 (2009).
55 Caballero D, Caro A, Rodríguez PG, Durán ML, del Mar Ávila M, Palacios R *et al.*, Modeling salt diffusion in Iberian ham by applying MRI and data mining. *J Food Eng* **189**:115–122 (2016).
56 Caballero D, Antequera T, Caro A, del Mar Ávila M, Rodríguez PG and Perez-Palacios T, Non-destructive analysis of sensory traits of dry-cured loins by MRI–computer vision techniques and data mining. *J Sci Food Agric* **97**:2942–2952.

