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Can NIR Replace a Panel of Tasters in Sensory Analysis of Dry-Cured Bísaro Loin?

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Abstract: This study involved a comprehensive examination of sensory attributes in Bísaro dry-cured loins, including odor, androsterone, scatol, color, fat color, hardness, juiciness, chewiness, flavor intensity, and flavor persistence. Analysis of 40 samples revealed a wide variation in these attributes, ensuring a robust margin for multivariate calibration purposes. The respective near-infrared (NIR) spectra unveil distinct peaks associated with significant components such as protein, lipid, and water. Support Vector Regression (SVR) models were methodically calibrated for all sensory attributes, with optimal results using multiplicative scattering correction pre-treatment, MinMax normalization, and radial base kernel (non-linear SVR model). The predictive models exhibited acceptable results, characterized by R-squared values close to 1 (0.9616 - 0.9955) and low RMSE values (0.0400 – 0.1031). The prediction set's relative standard deviation (RSD) remained under 5%. Comparisons with prior research revealed significant improvements in prediction accuracy, particularly when considering attributes like pig aroma, hardness, fat color, and flavor intensity. This research underscores the potential of advanced analytical techniques to improve the precision of sensory evaluations in food quality assessment.

Keywords: dry-cured Bísaro loin; NIR analysis; sensory attributes; non-linear SVR models

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1. Introduction

In this modern digital age, consumers are more active in the search for specific information about the nutritional content and sensory properties of food. Several scientific research works aim to provide outcomes related to quality control (QC), technological processing, traceability, and authenticity in food products. In the case of meat products and their derivatives, exception is not applied. Pork is one of the most traditionally consumed meats in the world and is known for its quality attributes. In Portugal, there exist three native pig breeds: the Bísaro, the Malhado de Alcobaça, and the Alentejano [1]. Bísaro represents a breed of autochthonous Portuguese pigs with Celtic origins and a part of Portugal's biological, economic, and cultural heritage [2]. It is typically

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produced in a semi-extensive system, with its dietary management relying on locally available agricultural resources [3]. In addition, the Bísaro breed is known for the quality of the meat and fat from these animals, used for the manufacture of various products of excellence and specific qualities that hold designations such as: Protected Geographical Indication (PGI) and Protected Designation of Origin (PDO). The products that currently enjoy the PGI designation are: Salpicão de Salpicão de Vinhais, Chouriça de carne de Vinhais, Alheira de Vinhais, Butelo de Vinhais, Chouriça Doce de Vinhais, Chouriço Azedo de Vinhais and Presunto Bísaro de Vinhais. The product with PDO is the Carne de Bísaro Transmontano [4]. Most of these products undergo traditional meat preservation methods, such as salting, drying, or smoking. Some examples are typical Mediterranean dry-cured meat processing characterized by dry salting, no smoking, and long drying process, while brine salting and smoking are used in continental parts of Europe [5]. The specific regional conditions for the application of these methods together with the typicality of raw material (genetic type, feed, rearing system, etc) makes it possible to obtain particularly diverse dry-cured products. Dry-cured Bísaro loin currently lacks recognition under any of these quality labels; however, due to its characteristics, it has the potential to also be a product in this list of products.

Generally, pork quality depends on factors intrinsic and extrinsic to the animal. Intrinsic factors include age, weight at slaughter, sex, genetics, physiological state. While, extrinsic factors to the animal involve housing system, feeding techniques, handling, sanitary and environmental conditions, transportation, pre-slaughter techniques, slaughter, post-mortem, and meat processing [6]. However, quality of meat products from Iberian pigs strongly depends upon breed and rearing system, which includes a number of different lines, causing a great heterogeneity within the same breed. Meat products for overall acceptance depend to a large extent on their flavor, which is mainly determined by taste and odor compounds [7]. In dry-cured products, the key attributes are markedly affected by the ripening process, complex chemical and biochemical changes in the main components of raw meat which contribute to their characteristic aroma and flavor [8]. Indeed, the information provided to consumers on the impact on health or any other quality aspect can significantly influence their acceptance of meat products [9]. Moreover, consumer expectations regarding with the perception of safety associated with processed meat, animal welfare, processing techniques, and the preservation of traditional production methods [10], denote the importance of utilizing an autochthonous breed, such as the Bísaro, in order to add value to the product. These characteristics, in the classic way, are usually determined by mechanical, physico-chemical measurements and sensory analysis most of them are invasive, expensive, and time-consuming [11]. So, it is essential to conduct rapid assessment all the meat and meat products quality traits, through physical and sensory tests, to ascertain whether the product aligns with the final consumer demands [12]. In this sense, the use of alternative techniques, such as computed tomography (CT) [13], magnetic resonance imaging (MRI) [11] hyperspectral imaging (HIS) or near infrared spectroscopy (NIR) [14,15] are increasingly gaining priority due to prompt, easy to use and minimal pre-processing requirements, making them suitable for rapid implementation in industrial meat applications[11] Most studies reveal the NIR-spectra potential to provide real-time QC based on: predict the chemical composition of meat [16,17]; predict the technological parameters and sensory attributes [18,19]; predict carcass fat and meat quality [16]; classify and identify specific meat and meat products [20].

NIR is a technique which can distinguishing PGI from non-PGI meat products. However, NIR needed discriminating methods to predicting sensory attributes of meat. This is mainly due to factors like the inherent heterogeneity of meat and complexity of NIR-spectra, which demands an understanding of chemometric tools to establish any correlative relation between the generated spectra and the peculiarities of the studied samples [21] In this sense, pre-treatment techniques such as multiplicative scatter correction (MSC), standard normal variate (SNV), smoothing (SMT), baseline removal, and first (1^{st}d) and second (2^{nd}d) derivatives are used to reduce and correct possible interferences related to scattering, baseline shift, path-length variation, and overlapping spectral bands. Additionally, multivariate statistical techniques such as principal component analysis (PCA), partial least squares (PLS), sample projections algorithm (SPA), uninformative variable elimination (UVE), genetic algorithms (GA), K-nearest neighbors algorithm (KNN), multiple linear regression

(MLR), principal component regression (PCR), partial least square regression (PLSR), support vector machine (SVM) and artificial neural network (ANN) are applied to simplify modelling purposes and used for quantitative and qualitative purposes [10,22]. Despite the NIRs technique has potential in QC, sensory evaluations play a crucial role in assessing the quality and acceptability of products. By incorporating this evaluation, companies can understand consumer preferences, optimize product development, and ensure customer satisfaction. It also aids in identifying product defects, evaluating changes in formulation or processing, and maintaining consistency in product quality. Overall, sensory evaluation helps in making informed decisions, enhancing product appeal, and achieving success in the market. However, there are inherent subjective issues and increased variability associated with sensory evaluations due to their reliance on humans' resources. Human perception and interpretation of sensory attributes, introduces subjectivity and variability into the process. Although this sensory assessment is carried out by a panel of trained tasters, it is crucial to carefully select and train sensory marks, establish clear evaluation protocols, and awareness of potential sources of variability are necessary to improve the reliability of sensory evaluations [23].

In this framework, the purpose of this piece of research is to evaluate the potential of NIR as a rapid predictor of physiochemical attributes in dry-cured loin samples. By collecting the NIR spectra of dry-cured Bísaro loin and using different spectral mathematical pre-treatments and chemometric modeling, the aim is to combine this data with sensory evaluation information. This approach can lead to a new analytical method addressed to sensory characterization of the dry-cured product, allowing product classification, and helping to developing specific market products.

2. Materials and Methods

2.1. Animals and samples manufactured

This study is a part of a project (BISOLIVE) between a research center (Carcass and Meat Quality Laboratory at the School of Agriculture of the Polytechnic Institute of Bragança (LTQCC-IPB), Portugal) and a meat manufacturing industry (Bísaro industry – Salsicharia Tradicional, Lda, ®, Portugal) to enhance the value of livestock.

Forty castrated Bísaro breed animals were randomly selected from an industrial pork manufacturing (Bísaro Salsicharia Tradicional, Lda, ®, Portugal) and reared on the farms of Covas and Castro Vicente (Portugal) as part of an extensive production system for 90 days until they reached an average body weight of 100 ± 4.5 kg (fattening phase). Animals were stunned, slaughtered and exsanguinated at a local slaughterhouse (Municipal Slaughterhouse of Bragança, Portugal). The procedure was described by Álvarez-Rodríguez and Teixeira [24] and followed the welfare regulations EU Council Regulation (EC) No. 1099/2009 [25]. At 24h postmortem the carcasses were carefully halved, and the left side was weighed and recorded. They were carried to the LTQCC-IPB for carcass evaluation and meat analysis. Forty parts of *Longissimus thoracis et lumborum* (LTL) muscle samples were obtained between the 7th and 12th rib of animals. After being collected, the animals` muscles were refrigerated in a chamber between 2 and 5 °C. The traditional drying process in the region was carried out at the Bísaro industry – Salsicharia Tradicional, Lda, ®, Portugal. All the dry-cured loins were manufactured on the same day using same series of steps applied in the typical production of the final product. The first step was dry salting and seasoning phase with the following ingredients: 1.5 % of salt, 0.5 % of paprika, 0.5 % of garlic, and 0.1 % of oregano. The mixing process took place in a rotating drum for 30 minutes. After this step, the pieces were placed in a refrigeration chamber between 2 and 4 °C for 4 days. The next phase was stuffing into collagen casings and drying. The most important step of the drying process involves temperature and relative humidity as key control points. Both change as the drying time progresses: on the firsts 15 days, the cuts were subjected to a temperature between 4 and 8 °C with a relative humidity between 80 and 90 %; during the second 15 days, the product was subjected to a temperature between 8 and 12 °C and relative humidity between 70 and 80 %; and during the last 30 days, the product was subjected to a temperature between 12 and 18 °C and a relative humidity between 60 and 70 %. Thus, by increasing

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the temperature and decreasing the relative humidity, total drying time is reached, 60 days, as reported by Leite et al. [26].

2.2. Sensory analysis

To evaluate the dry-cured loins quality, a trained taste panel of nine members who had been previously recruited, selected and trained for descriptive analysis according to NP (NP-ISO-8586-1, 2001) was employed [27]. Training consisted in two phases: the 1st, involved individual evaluations of dry-cured loin samples from different pork animals; the 2nd, focused to adapt the panel elements to scales and sensory descriptors (muscle color, flavor persistency, flavor intensity, bitterness, acidity, sweetness, saltiness, chewiness, juiciness, hardness, scatol odor, androsterone odor, cured odor, rancid odor, odor intensity, fat distribution, muscle/fat, and fat color). A structured scoring scale was used in which 1 indicated the absence and 9 the high intensity of the attribute. The whole process (approximately 8 sessions lasting 1-2 h each) was conducted in a specific tasting room in the Sensory Analysis Laboratory at the Polytechnic Institute of Bragança. The choice, definition and consensus of the evaluation methodology of the descriptors were established during 4 sessions. Standard guidelines (ISO-8589, 2007) [28] were followed, maintaining the room temperature at approximately 20 °C and relative humidity at around 50 %. The room was illuminated with white light and each booth had a white light equally. From each dry-cured loin, 1.5 mm thick slices were cutting with industrial meat slicer machine. All samples were randomly coded with three-digit numbers and offered in disposable plastic dishes to each taster. Mineral water and unsalted toasted bread were used to clean the palate and remove residual flavors. In order to minimize fatigue, a total of four sessions were conducted. Each session included two samples of dry-cured loin for each taster, resulting in ten different samples per session. Tasters were instructed to carefully observe, smell, and taste the samples, paying attention to various sensory aspects. They were then asked to provide judgments on the appearance (color intensity and brightness), odor (intensity and identification), oral texture (hardness, juiciness, and chewiness), and flavor (basic taste, flavor intensity, identification, and persistence). A structured scale of 9 point with the extremes representing either the minimum (low intense sensation) or the maximum (high intense sensation) it was used for the quantitative attributes considering a quantitative descriptive analysis. Odor androsterone and scatol identification ranged from 1 (none) to 9 (higher), general color from 1 (light) to 9 (dark), fat color from 1 (white) to 9 (yellow), hardness from 1 (tender) to 9 (hard), juiciness from 1 (dry) to 9 (moist), chewability from 1 (easy) to 9 (difficult). The tasters also identified basic taste and flavor persistence from a list of possibilities. The methodology used was that described by the standard guidelines (ISO-6658, 2005) [29].

2.3. Sample Set and NIRS Analysis

A total of 40 samples of dry-cured Bísaro loin were taken for analysis. The samples were minced and placed in petri dishes with a diameter of approximately 9 cm. For spectral analysis, an FT-NIR Master™ N500 (BÜCHI, Labortechnik AG, Postfach) was utilized. The instrument operates within a spectral range of 4000 to 10,000 $^{cm-1}$, with a resolution of 4 $^{cm-1}$ and a 360° rotation system. The NIRCal BÜCHI software, version 5.5, was employed to save the spectral data into an Excel™ file. Three spectra were measured for each sample, and these spectra were used to develop the calibration equations.

2.4. Data Analysis

The raw spectra were smoothed with a cubic smoothing spline (smoothing parameter 0.01) to remove instrumental noise. Furthermore, as reflectance spectra may carry some variability caused by scattering effects [30], the spectra were pretreated with four different methods to remove this undesirable effect: multiplicative scatter correction (MSC), standard normal variate (SNV), first derivative (1std), and second derivative (2ndd). The first and second derivatives were determined using the central finite-difference method.

The samples' spectra were partitioned in calibration (67 %) and prediction (33 %) subsets applying the SPXY algorithm. The SPXY modifies the classic Kennard-Stone algorithm to select samples according to their differences in X (instrumental responses) and Y (predicted parameter) spaces [31].

The regression models to predict the sensory attributes of the dry-cured loins were obtained using support vector regression (SVR) [32]. Different kinds of SVR were tested (Table 1), and the parameters of the models were defined through a hybrid algorithm based on particle swarm optimization (PSO) combined with pattern search [33]. The objective function of PSO was to minimize the root mean square error (RMSECV) obtained by 5-fold cross-validation. Several models using all possible combinations in Table 1 (pre-treatment, normalization, SVR type, and kernel) and the PSO-optimized parameters were tested for each sensory attribute.

The partial least square (PLS) models [34] were also tested to check if a linear model could predict the sensory attributes using the NIR spectra and to compare the performance with SVR models.

All data analysis was carried out in MATLAB R2022b using homemade routines developed by the authors and functions available in the software. The LIBSVM 3.3 [35] for MATLAB was employed for SVR.

Table 1. Tested parameters for SVR models to predict sensory attributes of the dry-cured Bísaro loins.

Pre-treatment	Normalization*	SVR type**	Kernel**	PSO parameters**
MSC	Mean center	ε-SVR	Linear	C
SNV	Autoscale	ν-SVR	Polynomial	ε (for ε-SVR)
1^{st}d	Pareto		Radial Base	ν (ν-SVR)
2^{nd}d	Poison		Sigmoid	γ (except for linear kernel)
	MinMax [-1+1]			Intercept (for polynomial and sigmoid kernel)
				Degree (2 to 5 for polynomial kernel)

** Chang and Lin [35]; * Van den Berg et al. [36]; SVR –support vector regression; 1^{st}d- first derivative; 2^{nd}d - second derivative; SNV - standard normal variate; MSC - multiplicative scatter correction; PSO-particle swarm optimization.

3. Results and discussion

3.1. Sensory data

The descriptive values of dry-cured loins determined are summarized in Table 2. Mean values together with the minimum, maximum and standard deviation for the 40 samples analyzed shown that the range of variation was wide enough to guarantee an adequate margin for calibration purposes.

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Table 2. Sensory attributes of the forty dry-cured Bísaro loins with min, max and mean represented (n=40).

Attributes	Min	Max	Mean (±sd)
Odor	5.13	6.78	5.92(±0.38)
Andros	1.11	2.38	1.50(±0.28)
Scatol	1.00	1.78	1.24(±0.19)
Color	2.88	6.11	4.05(±0.73)
Fat color	1.56	4.89	3.11(±0.85)
Hardness	2.44	6.56	3.90(±1.23)
Juiciness	3.44	6.11	5.10(±0.64)
Chewiness	2.13	5.44	3.62(±0.85)
Flavor intensity	5.11	6.44	5.89(±0.33)
Flavor persistence	4.56	6.33	5.67(±0.42)

sd– standard deviation; Andros- odor androsterone; Min- minimum; Max- maximum.

The sensory attributes evaluated are concern to texture characteristics, appearance parameters and taste parameters, including basic characteristics of both.

Regarding texture parameters, hardness is defined as the force required to compress food between molars to achieve deformation [37]. In this way, it's possible to correlate hardness to the proteins in the connective tissue component as well as the myofibrillar component of the meat. Chewiness determines the number of chews required for the meat to be ready for swallowing and juiciness dependent on the protein structures/compositions of the muscle fibers and connective tissues and so on correlated to the sensation of moisture observed in the initial chewing movements of meat [38,39]. It was possible to verify that the intramuscular composition and fat deposition existing in the dry-cured Bísaro loin samples resulted in the rapid release of fluid contained in them and justify the variation found in the texture parameters. All of them showed relatively large range (6.56-2.44; 5.44-2.13; 6.11-3.44 for hardness, chewiness and juiciness, respectively) with an average value of 3.90, 3.62, and 5.10, respectively, a standard deviation of 1.23, 0.85 and 0.64, respectively. The margins reported by Revilla et al. [40] are proximately close to those obtained in dry-cured beef "Cecina". Also, Ruivo [41] constates that higher body weights have repercussions such as an increasing subcutaneous and intermuscular fat content, an increase in myoglobin ratio, and a decrease in water loss from the muscles, which are in accordance with our results of chemicals, which are not presented here.

Regarding appearance, mean values for fat color and color were lower (3.11 and 4.05, respectively) to those described by Revilla et al. [40] and within those obtained by Seong et al. [42], with 4.75 value given by the panelists for the loins ripened for 60 days in their study. The color of meat is closely associated with freshness, myoglobin content and technological quality traits such as pH or water-holding capacity, which in pork meat significant variations in color and tenderness. These indicators play a crucial role in visual attraction and sensory acceptability, and directly related to financial losses for the industry if they do not meet consumer demands [10,12]. Also, in the process of producing, substances such as drying conditions, ripening time, condiments, salt, nitrites, and nitrates are added, which directly influence the final color ratios [4,41].

Other attributes evaluated like androsterone and skatole were included in flavor parameters in this work. Studies demonstrate that, due to the high levels of intrinsic factors such as age, sex and weight at slaughter, the meat from entire males presents undesirable odors, even when clarity a limit of 150 days of age and 100 kg of slaughter weight [43]. Our samples complied the weights close to 100 kg and so it was expected that these hormones would not have a high expression in their analysis. Which in accordance to [44] who found pigs intended for fresh consumption to be preferably slaughtered between 60 and 120 kg, while those primarily destined for processing are slaughtered between 140 and 180 kg.

Also, Squires and Bonneau [45] mention that the fat from entire males contains a higher amount of polyunsaturated fatty acids, resulting in meat with lower oxidation resistance, which leads to

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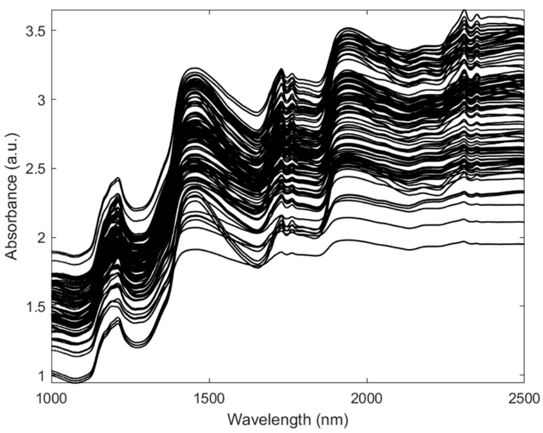
lower quality products and processing difficulties. Autochthonous breeds such as Bísaro are not suited for high yields of lean meat production, but for processed products, as they have highly marbled meat that confers excellent flavor due to the variety of feed they typically consume [3]. Moreover, it is highly rich in fat-soluble vitamins, including vitamins A and E combined with selenium content, which makes this pork meat less susceptible to oxidative rancidity compared to meat from other animals [5]. Regarding the presence of fat, the feeding process can influence the duration of the drying process, specifically affecting the intensity and persistence of flavor [46]. Longer periods for drying positive affects the biochemical and microbiological development of flavor. Flavor generation by drying is part of the process and a natural way of producing aroma in meat products. This has become a consumer need in contrast to the direct addition of flavorings to flavorless meat products [47]. In this way, it was expected high range values on flavor intensity and flavor persistence (6.44-5.11; 6.33-4.56, respectively), in accordance with the findings of (4.60 flavor intensity) on study of Seong et al. [42] for 60 days of ripening time on sensory characteristics of dry-cured loins. Obtaining meat with the desired characteristics is a challenging objective to achieve [48].

Odor is also important attribute inter with flavor, because the ripening degree (proteolysis and lipolysis changes) reflects the ripening odor compounds that become a significant part of meat flavor [49,50]. Therefore, the range values of odor could be partially due to the biochemical changes during the ripening period, very high compared with Seong et al. [42] work.

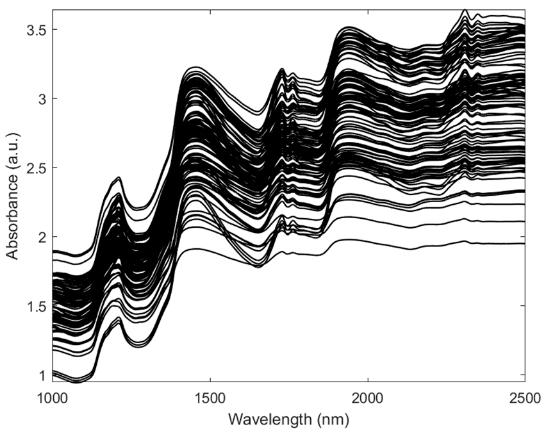
As pork and its derivatives can suffer variations as stated above, quality levels and prices would be directly influenced. Therefore, it is crucial to define the distinctive attributes that characterize these products. Sensory evaluation plays a significant role in this regard, as attributes such as odor, taste, color, texture and even the presence of visual fat are representative of the product. Thus, NIR is a key tool that must be applied to streamline and substantiate the entire process [10].

3.2. NIR analysis

The dry-cured loins' spectra obtained after each pre-treatment are presented in Figure 1. The NIR spectra of samples present typical broader peaks related to major constituents of protein, lipid, and water [16,51,52]. The major peaks were assigned in Figure 1(c); C-H bonds correspond to 1200 nm, 1710-1760 nm, and 2300-2350 nm (first overtone, second overtone, and combination band, respectively). The N-H and O-H bonds correspond to the 1450 and 1900 nm regions (second and first overtones, respectively).



(a)



(b)

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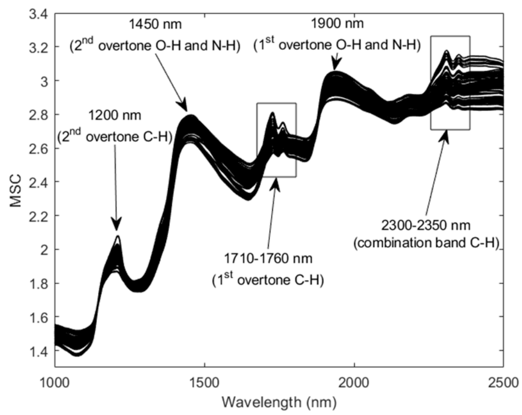
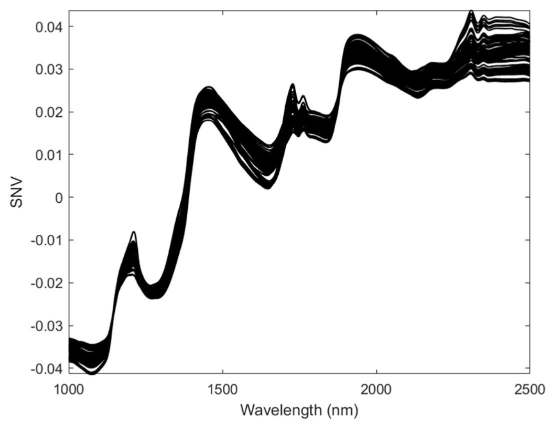
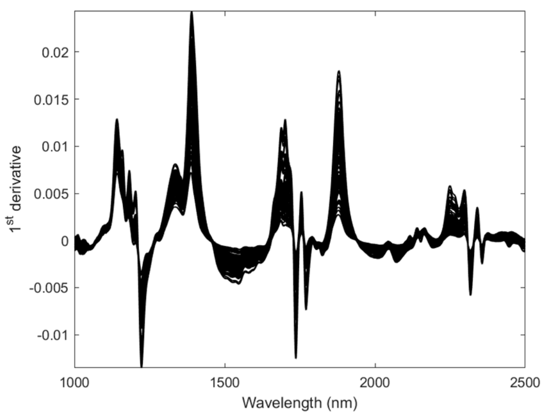


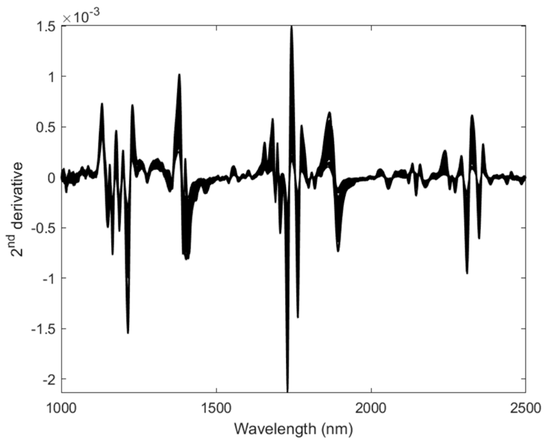
(c)



(d)



(e)



(f)

Figure 1. NIR spectra: raw spectra (a), smoothed spectra (b), MSC (c), SNV (d), first derivative (e), and second derivative (f).

The SVR models were calibrated for all sensory attributes using the possible parameters combination in Table 1. The best results were achieved by applying MSC pre-treatment, MinMax normalization, ε-SVR, and the radial base kernel. Table 3 presents the best optimized ε-SVR for each sensory attribute.

Table 3. Parameters and figures of merit of the best ε-SVR models obtained for each sensory attribute.

				Calibration		Prediction		
Attribute	C	ε	γ	RMSE	R^2	RMSE	R^2	RSD(%)
Odor	23.43	0.0161	0.0227	0.0155	0.9995	0.0549	0.9888	0.98
Andros	18.11	0.0010	0.0258	0.0011	1.0000	0.0400	0.9892	2.87
Scatol	87.79	0.0051	0.0221	0.0051	0.9998	0.0548	0.9616	4.47
Color	39.03	0.0074	0.0151	0.0072	0.9998	0.0507	0.9853	1.85
Fat color	100.0	0.0010	0.0446	0.0010	1.0000	0.0685	0.9878	2.26
Hardness	100.0	0.0010	0.0257	0.0011	1.0000	0.0403	0.9955	1.03
Juiciness	34.28	0.0522	0.0155	0.0499	0.9966	0.1031	0.9705	2.65
Chewiness	40.46	0.0395	0.0090	0.0374	0.9966	0.0674	0.9800	1.81
Flavor intensity	53.00	0.0252	0.0135	0.0240	0.9974	0.0554	0.9876	0.98
Flavor persistence	51.00	0.0010	0.0124	0.0011	1.0000	0.0417	0.9907	0.80

* All models used MSC pre-treatment, MinMax normalization, and radial base kernel; MSC- multiplicative scatter correction; Andros- odor androsterone; C/ γ /ε PSO- particle swarm

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optimization parameters; RSD- percentual relative standard deviation; RMSE- root mean square error; R^2- coefficient of determination.

For the ε-SVR with the radial base kernel, the parameters C, ε, and γ were optimized (Table 3) using the PSO algorithm to minimize the RMSECV for 5-fold cross-validation. The values of these parameters control the complexity of the regression model and, consequently, the prediction capabilities for new data sets. Low values of ε bring the models closer to the calibration data. However, this excessive adjustment may result in a loss of generalization to predict new data. The parameter γ is related to smoothness and C to the complexity of the regression model. The regression model is spikier and more complex for high values of γ and C [53,54]. Good SVR models were obtained for all sensory attributes with R^2 close to the value 1 (0.9616 - 0.9955) and low values of RMSE (0.0400 – 0.1031) for the prediction set. Furthermore, the relative standard deviation (RSD) for the prediction set was less than 5 % for all sensory attributes, and the confidence interval (95 %) contains the ideal point (unit slope and zero intercept) [55] for all the models in Table 3. Figure 2 confirms the good prediction achieved by the ε-SVR models to the sensory attributes. These values are better than those found in Hernández-Ramos et al. [56] work, which has scores variations of R^2=0.51 for the pig aroma parameter, R^2=0.67 for the hardness parameter, R^2=0.78 for the fat color attribute and R^2=0.82 to flavor intensity.

The results for PLS models for the sensory attributes are shown in Table S1 (Supplementary Material). The R^2 values reported in the current study for juiciness (R^2=0.62) disagree with Ripoll et al. [57], Prieto et al. [58] and Wang et al. [39] works which reported less accurate predictions of juiciness (R^2=0.53; 0.21; 0.17, respectively); and also disagreement but less accurate (R^2=0.41) than reported by Prieto et al. [58], who achieved a higher value (R^2=0.59) for the flavor intensity parameter.

In addition, for the chewiness parameter, the Wang et al. [39] study only reached a model with an R^2=0.09 value, while in the present study, a R^2 value of 0.58 was obtained. Also, in the work of Rødbotte et al. [59], obtaining any predictive model for sensory juiciness scores was impossible even after applying mathematical pre-treatment to the spectral data (multiplicative scatter correction). All of the authors mentioned above stress that predicting textural parameter scores is a complex subject, and attributes are difficult to accurately predict consistently.

All PLS models had poor prediction capabilities, and the Durbin-Watson statistical test (DW) had non-significant probabilities (pDW > 0.05), indicating a lack of correlation between PLS residuals and lack of non-linearities in the multivariate signal [55]. However, applying a non-linear SVR model greatly improved the prediction capability of the meat sensory attributes using the NIR spectra.

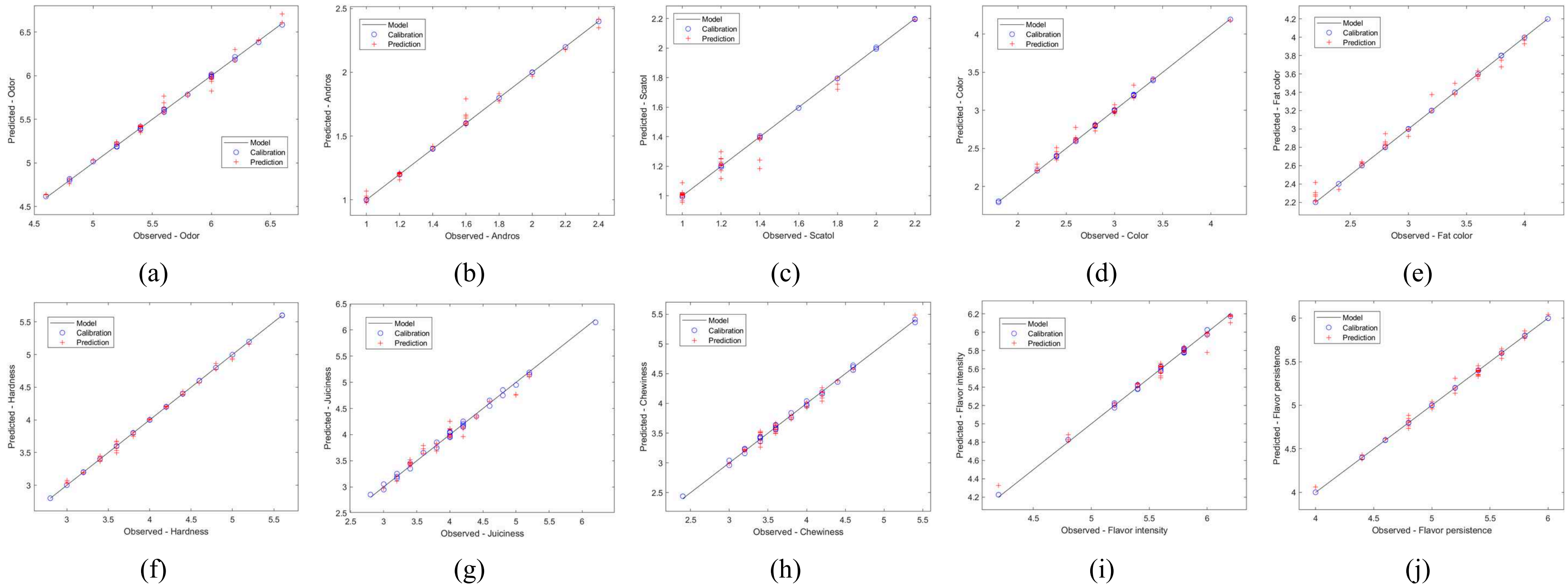

Figure 2. Predicted values for the best ε-SVR models and the observed values for each sensory attribute.

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4. Conclusion

This study involved the assessment of various sensory attributes (like odor, androsterone, scatol, color, fat color, hardness, juiciness, chewiness, flavor intensity, and flavor persistence) of dry-cured loins using NIR spectra and advanced chemometric techniques. The NIR spectra exhibited characteristic peaks related to major components such as protein, lipid, and water. The use of SVR models, specifically with a radial base kernel, produced highly accurate predictions for all sensory attributes, with R-squared values close to 1 and low root mean square error (RMSE) values. The models demonstrated good generalization to predict new data, as indicated by low relative standard deviation. Overall, the study demonstrated that non-linear SVR models, particularly when applied to NIR spectra, significantly improved the prediction of sensory attributes in dry-cured loins. This highlights the potential of advanced analytical techniques to enhance the accuracy of sensory evaluation in food quality assessment.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

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Institutional Review Board Statement: All animals were cared for and slaughtered in compliance with the welfare regulations and respecting EU Council Regulation (EC)No. 1099/2009.

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Data Availability Statement: Data is contained within the article.

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Conflicts of Interest: The authors declare that there are no conflicts of interest.

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