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Sensory and rapid instrumental methods as a combined tool for quality control of cooked ham

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Abstract

In this preliminary investigation, different commercial categories of Italian cooked pork hams have been characterized using an integrated approach based on both sensory and fast instrumental measurements. For these purposes, Italian products belonging to different categories (cooked ham, "selected" cooked ham and "high quality" cooked ham) were evaluated by sensory descriptive analysis and by the application of rapid tools such as image analysis by an "electronic eye" and texture analyzer. The panel of trained assessors identified and evaluated 10 sensory descriptors able to define the quality of the products. Statistical analysis highlighted that sensory characteristics related to appearance and texture were the most significant in discriminating samples belonged to the highest (high quality cooked hams) and the lowest (cooked hams) quality of the product whereas the selected cooked hams, showed intermediate characteristics. In particular, high quality samples were characterized, above all, by the highest intensity of pink intensity, typical appearance and cohesiveness, and, at the same time, by the lowest intensity of juiciness; standard cooked ham samples showed the lowest intensity of all visual attributes and the highest value of juiciness, whereas the intermediate

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category (selected cooked ham) was not discriminated from the other. Also physical-rheological parameters measured by electronic eye and texture analyzer were effective in classifying samples. In particular, the PLS model built with data obtained from the electronic eye showed a satisfactory performance in terms of prediction of the pink intensity and presence of fat attributes evaluated during the sensory visual phase.
This study can be considered a first application of this combined approach that could represent a suitable and fast method to verify if the meat product purchased by consumer match its description in terms of compliance with the claimed quality.

Keywords: Food science

1. Introduction

Cooked pork ham as meat product made from entire pieces of muscle meat, belongs to the cured cooked meat category which after the curing process of the raw muscle meat, always undergoes heat treatment to achieve the desired palatability (Heinz and Hautzinger, 2007).

Cooked pork ham is a very common product that is consumed worldwide, and is the cured meat product most consumed in Italy (ASSICA, 2014), even if it is not included among Protected Geographical Indications (PGI) or Protected Denominations of Origin (PDO) products. However, the Italian market offers a wide variety of cooked hams that are classified in three different commercial categories: cooked ham, “selected” and “high quality” cooked ham (Ministerial Decree, G.U. n 231, 04.10.2005).

According to Italian regulations, the specifications established for each class of product define the raw materials, allow ingredients and aromas, adopted processing method and some physical and sensory characteristics (visual recognition of major thigh muscles of the pork leg, water content, etc.). However, the sensory properties that characterize the product and strongly influence consumers’ choice are not well defined in these specifications (Ministerial Decree, G.U. n 231, 04.10.2005).

The final quality of cooked ham depends on both the raw materials and the processing techniques. Especially yield is associated with raw meat pH and raw material with extreme pH (i.e. pale-soft and exudative and dark-firm-dry meat) are avoided (Aaslyng, 2002). In addition, other involved factors concern the type of meat cut, type and amount of ingredients, injected volume of brine, rate and extent of tumbling, cooking time, and temperature (Delahunty et al., 1997).

Visual appearance is a key factor in the consumer perception of the sensory quality of meat and meat products. In addition to the traditional color measurement (L*, a*, b* values in CIELAB colour space), various image processing techniques find widespread use as objective and non-destructive quality evaluation systems. The

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hyperspectral imaging (HSI) is a promising technology that allows to collect information about different physico-chemical properties (ElMasry et al., 2012; Iqbal et al., 2013; Iqbal et al., 2014). On the other hand, also the conventional image analysis represents an useful tool to the study of meat products' appearance characteristics (Sánchezet al., 2008; Fongaro et al., 2015), especially considering its cost effectiveness, consistency, speed and accuracy provided by its automated application (Brosnan and Sun, 2004)

Textural characteristics are also very important for the quality of cooked hams and depend on several factors that are related to biochemical constituents (water, fat, protein, connective tissue content etc.), raw meat pH, added non-meat ingredients, chemical reactions (entity of proteolysis and lipolysis prior to cooking) and processing variables such as the extent of heating (Aaslyng, 2002; Toldrá et al., 2010), cooling treatment used (Desmond et al., 2000), smoke flavourings used and storage time (Martinez et al., 2004).

Another highly appreciated characteristic in this product is represented by its flavor, which is mostly related to processing conditions, brining, and spices added (Toldrá et al., 2010).

Very few studies have investigated cooked ham and its physical and chemical properties in relation with the sensory profile to characterize the product, evaluate its quality, and test consumers' knowledge and acceptance (Delahunty et al., 1997; Válková et al., 2007; Tomović et al., 2013; Henrique et al., 2015).

Others studies have focused on the classification of cooked hams manufactured with pork legs produced in different countries and with different percentages of brine injection by a chemometric approach based on the physical and chemical parameters (Casiraghi et al., 2007; Moretti et al., 2009). However, the results from all these investigations are not always easily comparable because they take in account different raw materials and processing procedures (Tomović et al., 2013).

The aim of the present study was to analyze Italian cooked pork hams belonging to the main commercial categories for quality control by applying a combined approach of sensory (descriptive analysis) and fast instrumental (image and texture) analysis.

2. Materials and methods

2.1. Samples

The research was carried out on commercial brands of cooked pork ham belonging to different product categories: cooked ham (CH); "selected" cooked ham (SE), and "high quality" cooked ham (HQ). The main characteristics of these three classes are reported in Table 1.

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Table 1. Characteristics of different commercial categories of cooked ham (Ministerial Decree, G.U. n 231, 04.10.2005). Ingredients/additives that differ between CH, SE and HQ samples are shown in italic. [1]MDDP = moisture on deffated-deadditived product.

Category	Raw materials	Ingredients/Additives	MDDP[1]
COOKED HAM (**CH**)	Pork leg	Sodium chloride *Protein (milk and soy)* *Starches (native or modified)* *Polyphosphate* Sugar (dextrose, lactose, fructose, glucose syrup) Ascorbic acid Lactate Glutamate Nitrate and nitrite Wine Spices and aromas	≤81
SELECTED (**SE**)	Pork leg in which it is possible to identify at least 3 of the 4 major muscles	Sodium chloride *Protein (milk and soy)* *Starches (native or modified)* *Polyphosphate* Sugar (dextrose, lactose, fructose, glucose syrup) Ascorbic acid Lactate Glutamate Nitrate and nitrite Wine Spices and aromas	≤78.5
HIGH QUALITY (**HQ**)	Pork leg in which it is possible to identify at least 3 of the 4 major muscles	Sodium chloride Sugar (dextrose, lactose, fructose, glucose syrup) Ascorbic acid Lactate Glutamate Nitrate and nitrite Wine Spices and aromas	≤75.5

In particular, 15 samples (5 for each category) were selected from the Italian market in order to represent the variety of cooked pork hams available on the Italian market.

The set of samples included: balanced number of samples belonging to the different commercial category (CH, SE and HQ); samples belonging to the most common Italian brand of cooked pork ham and presence of samples characterized by different intensities of sensory attribute (a larger set of samples was evaluated during the training as described in the paragraph 2.2).

A sensory description of each product was generated and sensory differences between products were described and quantified by a panel of of highly trained assessors who have been preselected to have good sensory abilities and received general training as described in the following section. Moreover, textural and appearance properties (sensory profiling and instrumental) were measured on the whole set of samples.

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All cooked hams (pieces of about 5 kg) were stored at 4 °C, vacuum packed, protected from light, and physical analysis were carried out in several replicates, whereas for the sensory analysis, the final score was the average of the scores assigned by each judge to these samples in three different sessions.

2.2. Sensory characterization by descriptive analysis (DA)

Samples were tasted by a panel of 8 expert sensory assessors, balanced in terms of gender, varying in tasting experience, and previously trained in the assessment of cooked ham. All of them were regular consumers of cooked ham and interested in the study. Only assessors who demonstrated specific characteristics such us acuity, ability to communicate and/or to describe, knowledge of the involved product, interest, motivation and availability to attend both training and subsequent assessments, were selected. The recruitment, the preliminary screening and the training were done according to ISO 8586:2012 and ISO 13299:2010.

The performance of selected assessors should be monitored regularly to ensure that the criteria by which they were initially selected continue to be met.

During different sessions the DA panel generated a list of appearance, aroma, taste and texture attributes using the consensus training (Heymann et al., 2014). The training proceeded in 3 sessions: (i) definition of each descriptor of the sensory vocabulary and the training; in this step the panellists chose a list of 10 non-overlapping attributes that permit a descriptive analysis of the samples under study and, at the same time, represent an useful tool also for the quality control of the product; (ii) assessment of the intensity and the memorization of the scale; (iii) sensory evaluation and monitoring of performance of selected assessors in terms of repeatability, discriminatory capacity and reproducibility.

An agreement on the meaning of the attributes of the sensory lexicon, must be obtained. For this reason it is important clearly define attribute name, written definition, method of assessment and standards reference able to help judges in the memorization of the different intensity levels for each of the selected descriptors. After attributes generation, the product assessment protocol must be determined in order to standardize the procedure and avoid bias. This step includes the way in which the product needs to be assessed and methods to reset the senses back to a neutral state between samples. Then, a wide range of samples of a product should be evaluated by rating the intensity of each attribute on a scale. this training improves the judges ability in using the sensory scale and promote the use of the ends of the scale. The performance check is generally carried out by applying statistical treatments to confirm that the panel works in a consistent and reliable way. The conventional profiling method was applied (Meilgaard et al., 2007). The final list of descriptors included 3 relative to appearance: *typical appearance* (recognition of major muscle), *pink intensity* (intensity of colour), *presence of fat*

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(total amount of fat inside the slice); 3 perceived by orthonasal and retronasal routes: *overall aroma* (intensity of total aroma of the product), *spices and flavours* (intensity of spices and other flavours), *smoky* (aroma associated with smoked notes in meat products); 2 gustatory: *sweet* (basic taste), *salt* (basic taste); 2 relative to the texture: *cohesiveness* (resistance to the product separation, to be assessed during the first 3–4 bites), *juiciness* (amount of juice released from the product during mastication).

Rating of the attribute's intensities was done using a linear unstructured 100 mm scale anchored at their extremes (0: absence of sensation; 100: maximum of sensation intensity) and results were expressed as the mean of three replicates. Samples were coded with three-random numbers and were presented to the assessors in randomized blocks. Between samples, a break with water rinses and unsalted bread sticks was suggested to reduce the carry-over effects as much as possible. To make it easier to understand and evaluate visual attributes, a group of product images were provided to each judge as references. These images (anchors) were selected taking into account the previously results of the training session and were used to illustrate the maximum, the minimum or average intensity points on the scale of typical appearance, pink intensity and presence of fat. Moreover, in order to standardize the testing conditions as much as possible and avoid bias, panellists evaluated visual attributes by observing the same slice of product inside a plate, whereas evaluation of other attributes (smell, taste, and texture) was performed by providing assessors with a sample minced and placed in plastic cups.

2.3. Image analysis

The instrumental measurement of appearance was carried out by an "electronic eye" (visual analyzer VA400 IRIS, Alpha MOS, France), a high-resolution CCD (charge-coupled device) camera (resolution 2592 × 1944p) combined with powerful data processing software. This instrument was equipped with an adjustable photo-camera (16 M colours) in a dedicated measurement room with standardized, controlled and reproducible lighting conditions. The camera imaging was software-monitored, embedded in the cabin for a better protection adapted to quality control environment and equipped with several lenses of different focal length available to accurately assess very small to large products. Top and bottom lighting (2*2 fluorescent tubes) 6700°K colour temperature and IRC = 98 (near D65: daylight during a cloudy day at 12 AM). It has to be turned on 15 minutes at least before acquisition for lighting stabilization. Samples were placed on a removable white tray, diffusing a uniform light inside the device's 600 × 600 × 750-mm closable light chamber and the CCD camera takes a picture.

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The instrument is able to undergo automatic calibration with a certified colour checker, and image analysis (RGB scale or CIE L*a*b*) and statistical analysis were carried out using the advanced software available in the instrument (Alphasoft, version 14.0). The data processing software extracts color parameters from the picture and can then correlate these data with data from sensory panels.

2.4. TA-Hdi® texture analyzer

Textural characteristics of HQ, SE, and CH cooked hams were evaluated at 22 °C using a TA-Hdi® texture analyzer (StableMicro Systems, UK) equipped with a 245 N loading cell. Texture profile analysis (TPA), Allo-Kramer (AK) shear force, expressible moisture (EM), and gel strength were assessed in 10 replicates for each sample.

TPA, consisting in a double compression, was run on a 1 cm-high and 2 cm-wide cylindrical-shaped sample compressed up to 40% of its initial height. The test was performed using a 5 cm-diameter aluminium probe and a time of 20 sec was elapsed between two compression cycles. Force-time deformation curves were obtained and hardness (N), springiness, cohesiveness, chewiness (N), and gumminess (N) were calculated according to Bourne (1978).

Shear force test was performed using an A-K shear cell (10 blades) and a cross-head speed of 500 mm min^{-1} according to the procedure described by Bianchi et al. (2007). From each cooked ham, a $4 \times 2 \times 1$ cm sample was excised, weighed, and sheared perpendicularly to the direction of muscle fibers. Shear force was then calculated as N shear per g of sample.

Expressible moisture (%) was measured following the procedure proposed by Hoffman et al. (1982) with some modifications. A $4 \times 1 \times 0.3$ cm sample was cut, weighed, and placed between four filter papers (Whatman No. 1). The sample was compressed through a single compression cycle with a load of 12.15 N for 5 min and the amount of water released per gram of meat was calculated, conventionally expressed as percentage.

Lastly, gel strength ($N \times cm$) was assessed on a 1 cm-high and 2 cm-wide cylindrical-shaped sample using a 5 mm stainless steel spherical probe according to the procedure described by Petracci et al. (2009).

2.5. Statistical analysis

Instrumental data (AK-shear force, gel strength, expressible moisture, hardness, springiness, cohesiveness, chewiness, and gumminess) and the intensity of each sensory attribute (typical appearance, pink intensity, presence of fat, overall aroma, spices and flavours, smoky, sweet, salt, cohesiveness and juiciness) were analyzed with a one-way-ANOVA or Kruskal-Wallis (in case of significance of the Levene

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test) to test the effect of market category (HQ, SE, and CH). Sensory and physical data were explored by principal component analysis (PCA). Pearson's correlations between sensory and instrumental data were performed to check possible relations. Partial Least Square (PLS) regression was also applied to predict sensory attributes by instrumental variables. A cross-validation method was employed to validate PLS models. The precision and the predictive capabilities of the models were evaluated by the coefficients of determination (R^2) and root-mean square error estimated by cross-validation (RMSECV). All statistical analysis were performed by XLSTAT 7.5.2 version software (Addinsoft).

3. Results and discussion

3.1. Sensory analysis

Before sensory evaluation of samples, the reliability of the panel's performance and training efficiency was checked to ensure reproducibility and repeatability (data not shown). Sensory profiling results (Table 2) showed that, in general, all visual attribute intensities followed an upward trend passing from CH, SE, and HQ samples; on the other hand, regarding texture attributes, there was a decreasing trend for juiciness and a growing trend of cohesiveness intensity going from CH, SE, and HQ. On the contrary, olfactory and taste attributes did not appear to be able to differentiate the commercial class to which a product belonged.

These results are in agreement with previous studies present in literature which found appearance and texture sensory attributes as more significant in describing and differentiate hams than flavour descriptors (Nute et al., 1987), also when the sensory evaluation was carried out by consumers (Delahunty et al., 1997).

The importance of product appearance was also confirmed by a recent study in which the effect of different factors (visual appearance, price and pack label) in purchasing decision, were investigated (Resconi et al., 2016).

Fig. 1 shows the results obtained from PCA of sensory data: samples and sensory attributes with greater discriminating power were projected in a two-dimensional

Table 2. Sensory data of cooked hams (n = 5/group) measured by the panel of trained assessors using the DA method. CH, cooked ham; SE, "selected" cooked ham; HQ, "high quality" cooked ham. Mean values followed by different letters significantly differ between the categories ($p < 0.05$).

	Overall aroma	Spices and flavours	Smoky	Sweet	Salt	Typical appearance	Pink intensity	Presence of fat	Cohesiveness	Juiciness
CH	55^{b}	40^{ab}	10^{a}	46^{a}	49^{a}	37^{b}	33^{c}	40^{c}	39^{c}	49^{a}
SE	56^{b}	36^{b}	12^{b}	45^{a}	49^{a}	57^{a}	53^{b}	52^{b}	52^{b}	44^{b}
HQ	60^{a}	42^{a}	19^{b}	48^{a}	45^{a}	59^{a}	62^{a}	57^{a}	61^{a}	36^{c}

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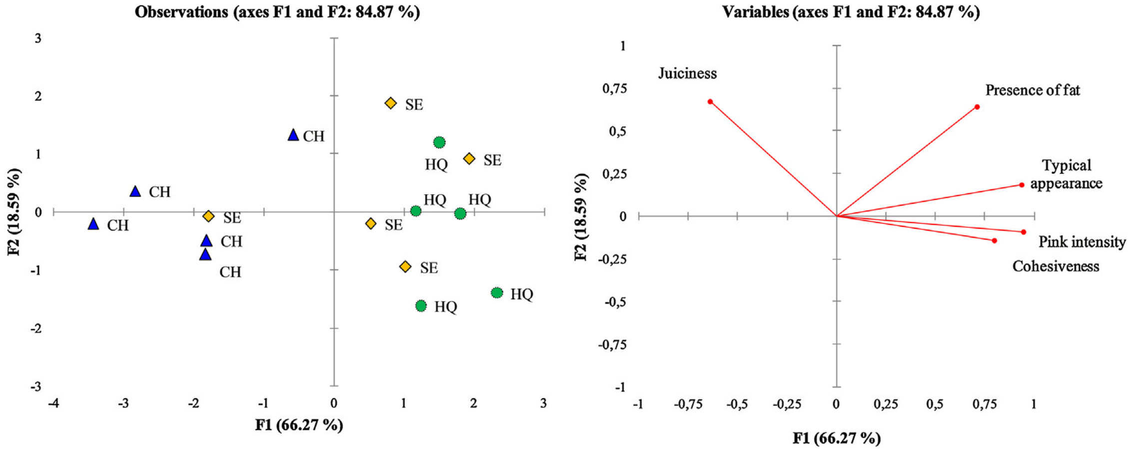

Fig. 1. Principal component analysis (PCA) of sensory data evaluated by descriptive analysis (DA) (loading plot on the right side). CH, cooked ham; SE, "selected" cooked ham; HQ, "high quality" cooked ham (score plot on the left side).

surface, described by orthogonal factors used as dimensions (F1 and F2) to highlight differences or similarities among analyzed samples. The first two components explained 84.87% of the total variance (66.27% for PC1 and 18.59% for PC2). In particular, almost all of HQ and SE samples were close and located between the first and the second quadrant; they were characterized, above all, by the highest intensity of pink intensity, typical appearance and cohesiveness, and, at the same time, by the lowest intensity of juiciness. In the third and fourth quadrants all CH samples and one SE sample, that showed the lowest intensity of all visual attributes and the highest value of juiciness, were positioned.

Similar results were observed also by Tomović et al. (2013) in a study performed on cooked hams processed with different carcass chilling methods (rapid and conventional) and time of deboning in which the colour panel score increased with decreasing juiciness.

Moreover, a recent study of Henrique et al. (2015) in which the Check-All-That-Apply (CATA) questionnaire was applied for the sensory characterization of cooked ham by consumers, showed that appearance attributes (characteristic ham aspect, intense pink colour, uniform aspect) and texture ones (juicy, tender) were positively correlated with the preference and the willingness to pay whereas a pale colour had a negative influence on liking.

In the present study the sensory traits mainly ascribed to the high quality product category are: pink intensity, typical appearance and cohesiveness. On the contrary, the highest intensity of juiciness mainly defined the standard quality of cooked hams; this result could be linked with the effect of the addition of phosphates as ingredient of brine, in increasing the amount of retained water and therefore on texture traits (Toldrá et al., 2010; Resconi et al., 2016).

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3.2. Image analysis

Cooked ham has a typical light pink colour as a consequence of nitrite addition. During the heating process, the colour of ham changes from red (pork meat) to pink; this physical characteristic depends primarily on the initial content of myoglobin present in the muscles used, and, consequently, is dependent upon the muscle type and age of the animal at slaughter (Toldrá et al., 2010).

To characterize the product's appearance, an "electronic eye" able to quickly assess this property using an acquired image subsequently processed by a specific software, was used. Data processing by the electronic eye allowed to obtain a colour spectra of a sample in RGB coordinates (Red, Green, Blue) that could be used to differentiate samples according to different hues and uniformity of colour. The application of the software available in the instrument (Alphasoft, version 14.0) allowed to group colour spectra in range of 16 bit for each coordinates RGB obtaining 4096 variables shown as histograms. In Fig. 2, some examples of colour spectra from samples belonging to each of the three commercial categories are shown. The proportion of each colour in the analyzed image, on a fixed scale of 4096 colours, is represented as a percentage. It is a color map of the object and the dashed line represents the minimum percentages of the colors displayed in the color spectra.

In particular, for CH, greater colour homogeneity described by the predominance (> frequency percentage) of a lower number of bars (colours) corresponding to different tonality of pink was seen; on the contrary, for categories "selected" (SE) and "high quality" (HQ), the trend was reversed and the number of bars increased passing from SE to HQ. These results are in contrast with Iqbal, Valous, Mendoza, Sun, Allen (2010), who found that inhomogeneous colour surfaces characterize the lowest quality class, when the images of three qualities of pre-sliced pork with different brine injection level were compared. However, these authors indicated that the lack of homogeneity is due to the presence of discoloured sections of pork muscles while, in this study, is mainly linked to the presence and the visual recognition of major thigh muscles of the pork leg.

To evaluate its ability in discriminating the different categories of cooked ham, data collected by electronic eye on the five samples of each commercial class were processed by PCA (Fig. 3). A selection of the most discriminant variables has been performed in order to improve the separation between samples. The first two components explained 80.68% of the total variance (62.00 for F1 and 18.68% for F2). Considering the locations of products on the surface (PCA score) is possible to note that HQ and SE samples were quite grouped in a cluster, whereas CH samples were clearly differentiated from HQ and SE but divided in two groups mainly as a function of F1. The different direction/location of vectors (PCA loadings), shows which variables (colours) were involved in the appearance variations among

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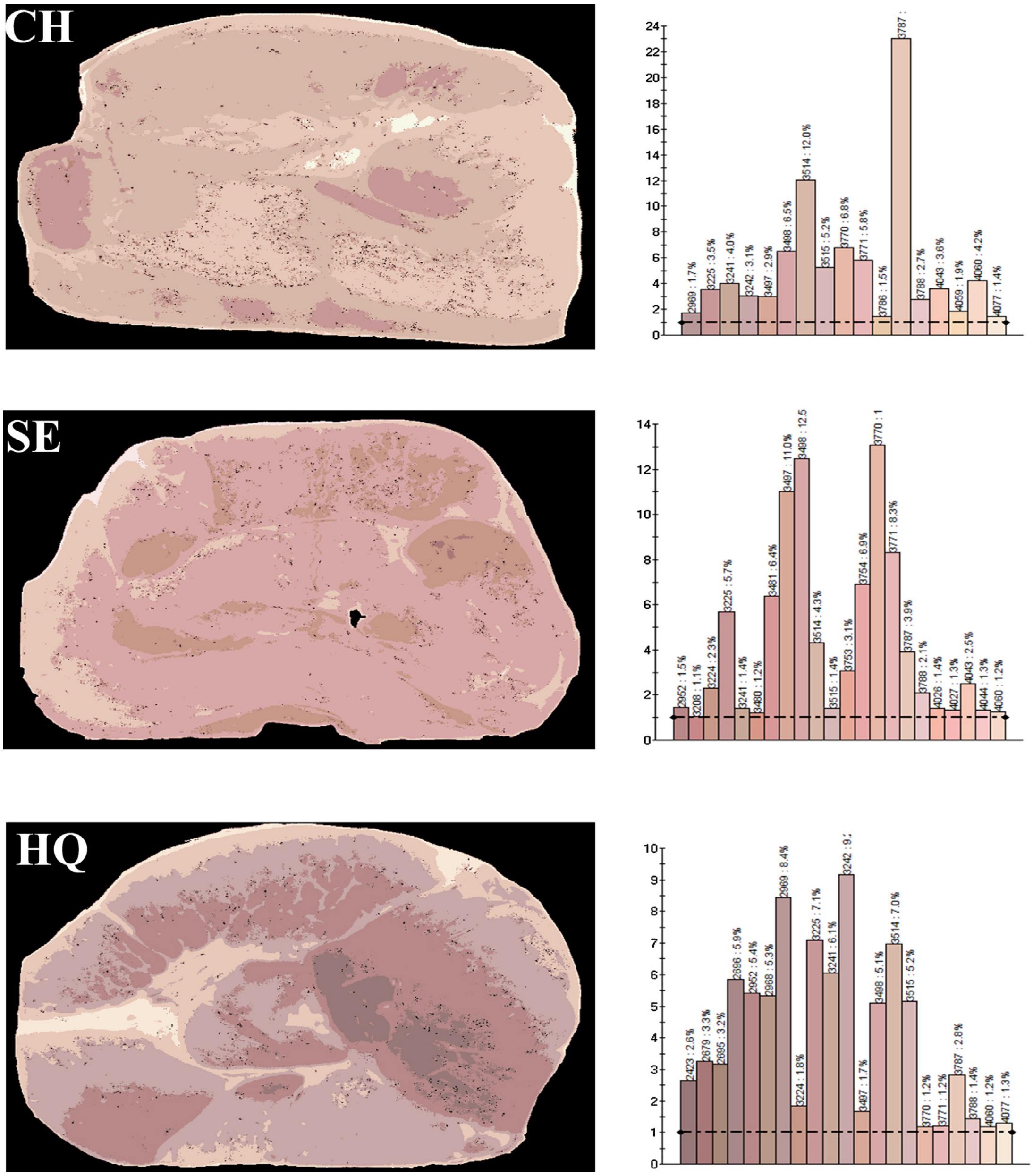

Fig. 2. Examples of color spectra obtained from the data processing by the electronic eye. CH, cooked ham; SE, "selected" cooked ham; HQ, "high quality" cooked ham.

samples. Variable "colours-2679" which describe the strongest pink intensity affected mainly the position of HQ samples, on the contrary, variable "colours-3514" which describe the weakest pink intensity, was opposite and characterized some CH samples.

These differences were probably linked to intrinsic variable of raw material such as the different water content that affected the concentration of meat pigments and therefore the ham colour (Moretti et al., 2009). The PCA score plot shows a good

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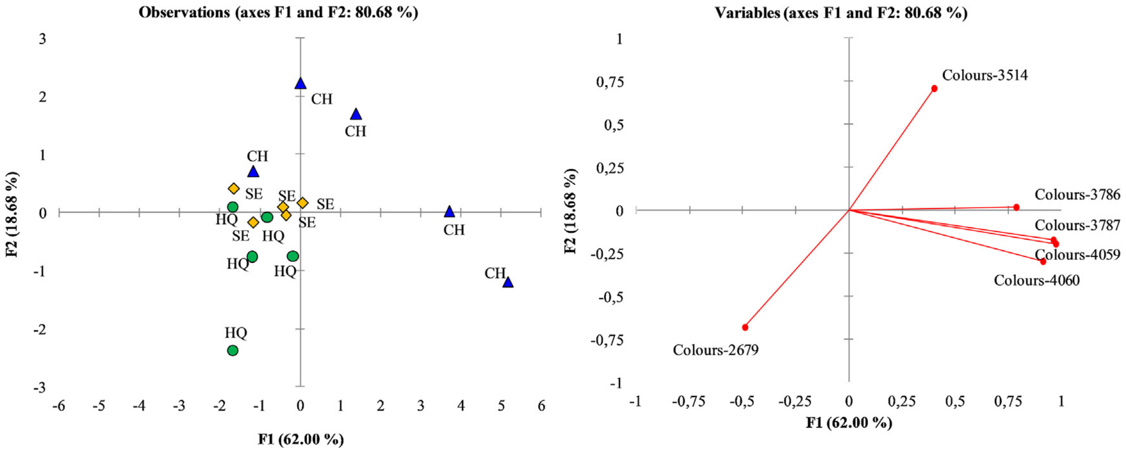

Fig. 3. Principal component analysis (PCA) built using data related to visual characteristics evaluated by electronic eye (loading plot on the right side). CH, cooked ham; SE, "selected" cooked ham; HQ, "high quality" cooked ham (score plot on the left side).

discrimination between samples: the lowest quality class (CH) was clearly differentiated from the highest one (HQ); however the intermediate category (SE) did not significantly differ from HQ and belong to the same cluster. This is in accordance with the study of Iqbal et al. (2010), who reported that it is easier to differentiate between the lowest and the highest qualities in function of their colour uniformity, homogeneity and fat content and therefore confirms the effectiveness of specific image descriptors of colour in checking the quality specifications.

3.3. TA-Hdi® texture analyzer

The data for gel strength, expressible moisture, sheaf force, and TPA parameters are summarized in Table 3. HQ ham had a lower expressible moisture compared with CH (12.9 vs. 18.6%; $p < 0.05$), while SE hams exhibited intermediate values (16.5%). In addition, HQ samples had higher shear force (28.15 vs. 18.23 and 19.72 N/g; $p < 0.05$) and springiness (1.62 vs. 1.29 and 1.31; $p < 0.05$) than CH and SE samples, which did not differ each other. On the other hand, gel strength, cohesiveness, hardness, gumminess, and chewiness were not substantially different between groups. Overall, these results showed that instrumental traits of HQ hams are different compared with both CH and SE, which seem to be more related, especially considering textural traits. These differences were likely due to the complex dissimilarities such as raw meat characteristics, ingredients, brine injection level, and processing among products of different market categories as noted in previous studies (Casiraghi et al., 2007; Válková et al., 2007; Moretti et al., 2009; Pancrazio et al., 2015). Lower expressible moisture in HQ hams was likely due to the lower total moisture imposed by national legislation. Moreover, HQ hams had also higher shear force and springiness because whole muscles were

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Table 3. Textural properties of cooked hams (n = 5/group) measured by TA-Hdi® texture analyzer and reported in Newton (N). CH, cooked ham; SE, "selected" cooked ham; HQ, "high quality" cooked ham. Mean values followed by different letters significantly differ between the categories ($p < 0.05$). sem = standard error of mean.

Parameter	Categories			sem	*p-value*
	CH	SE	HQ		
Number of samples	5	5	5		
Gel strength (N × cm)	12.68	12.45	13.01	0.81	0.965
Expressible moisture (%)	18.6[a]	16.5[ab]	12.9[b]	0.99	0.049
Shear force (N/g)	18.23[b]	19.72[b]	28.15[a]	1.89	0.045
Texture Profile Analysis (TPA)					
Cohesiveness	1.68	1.62	1.88	0.05	0.113
Hardness (N)	50.47	78.97	79.07	7.94	0.252
Gumminess (N)	131.94	125.01	93.12	12.10	0.417
Springiness	1.29[b]	1.31[b]	1.62[a]	0.06	0.033
Chewiness (N)	169.68	161.68	149.35	16.99	0.862

used and, a lower brine injection level was also found by Casiraghi et al. (2007). This agrees with the results of Válková et al. (2007) who found that shear force and springiness were negatively and positively correlated, respectively, with moisture content. Casiraghi et al. (2007) did not find any differences in product cohesiveness when hams with increasing brine injection level were compared.

The results of PCA analysis of instrumental texture parameters are shown in Fig. 4. Two principal components were extracted that accounted for 74.88% of the variance in the 8 variables. The first PC was mainly defined by the instrumental traits of gumminess, chewiness and hardness and gel strength, while the second PC was characterised by three instrumental parameters (AK-shear force, springiness, and cohesiveness). Expressible moisture appeared to equally contribute to both PCs. A good discrimination between HQ and the other classes of products (CH and SE) was observed. Positive PC2 values were associated with HQ samples, one SE ham and one CH thus confirming that AK-shear force, springiness, cohesiveness were mainly involved in product category discrimination. Otherwise, hardness, gumminess, chewiness, and gel strength seem to independently vary within each market category.

3.4. The relationship between sensory and instrumental data

The data obtained from both sensory and instrumental approaches were also statistically assessed to determine possible correlations; the sensory attribute of pink

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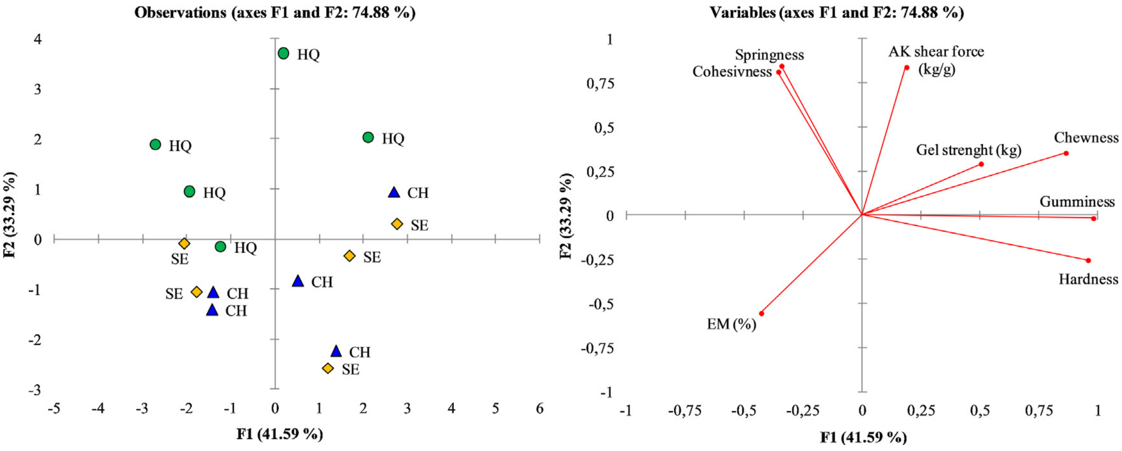

Fig. 4. Principal component analysis (PCA) built using data related to textural characteristics evaluated by texture analyzer (loading plot on the right side). CH, cooked ham; SE, "selected" cooked ham; HQ, "high quality" cooked ham (score plot on the left side).

intensity was correlated with physical parameters (electronic eye and texture analyzer) with Pearson's correlation coefficient ranging between 0.57 and 0.72 ($p < 0.05$).

In particular the pink intensity attribute showed a positive correlation with AK shear force (0.62), springiness (0.57) and with the variable "Colours-2679" (0.72) that, in this study, were related with products belonging to the high quality category. A negative correlation was found, instead, with the variable "Colors-3514" (-0.66).

On the other hand, no significant correlation was discovered between the attribute presence of fat and instrumental measurements (appearance and texture), in agreement with previous studies (Válková et al., 2007). Considering the texture sensory attributes, only juiciness showed some negative correlations with instrumental parameters of AK shear force (-0.79), cohesiveness (-0.54) and springiness (-0.63) ($p < 0.05$). In contrast, (Resconi et al., 2015), reported a positive correlation between juiciness and springiness, both enhanced with the increase in polyphosphates while, in the present work, only juiciness characterized the product category with the higher phosphate content (CH).

Among texture instrumental parameters, positive correlations was found between: gumminess and hardness (0.95) as already observed by Válková et al. (2007), springness and cohesiveness (0.76), chewiness and hardness (0.75) and also between chewiness and gumminess (0.89) ($p < 0.05$), these two latter correlations were also confirmed by Resconi et al., 2015; which found a reduction in hardness and gumminess as a function of the increase of the phosphate content.

In addition, some correlations were obtained also among sensory attributes: pink intensity showed significant positive correlations with typical appearance (0.84)

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Table 4. Coefficients of determination (R^2) and root mean square errors calculated in cross validation (RMSECV) estimated for specific sensory characteristics by PLS models built using texture and visual instrumental data.

	Sensory attribute (*y*)	R^2	RMSECV
Texture analyzer	Cohesiveness	0.24	9.87
	Juiciness	0.48	37.99
Electronic eye	Pink intensity	0.95	3.24
	Presence of fat	0.88	5.84

and cohesiveness (0.72) and a negative one with juiciness (-0.64) ($p < 0.05$); the latter result was in accordance with Tomović et al. (2013) who reported a similar correlation coefficient (-0.51, $p < 0.05$) confirming that these attributes were significant in the evaluation of the sensory profile of cooked ham obtained from different raw materials and technological process parameters applied.

The instrumental dataset and the sensory attributes related to them was also subjected to PLS regression with the aim to estimate a prediction model for sensory characteristics. For visual and texture sensory attributes (cohesiveness, juiciness, pink intensity and presence of fat), models using data coming from electronic eye and texture analyzer were developed. All PLS results were showed in Table 4. The best results were obtained from models developed using electronic eye data that allowed an effective prediction of pink intensity ($R^2 = 0.95$, RMSECV = 3.24) and presence of fat ($R^2 = 0.88$, RMSECV = 5.84) as showed by Fig. 5. For colour prediction, the developed model was better than that obtained by Iqbal et al. (2013) in cooked, pre-sliced turkey hams though by another image system (NIR hyperspectral imaging).

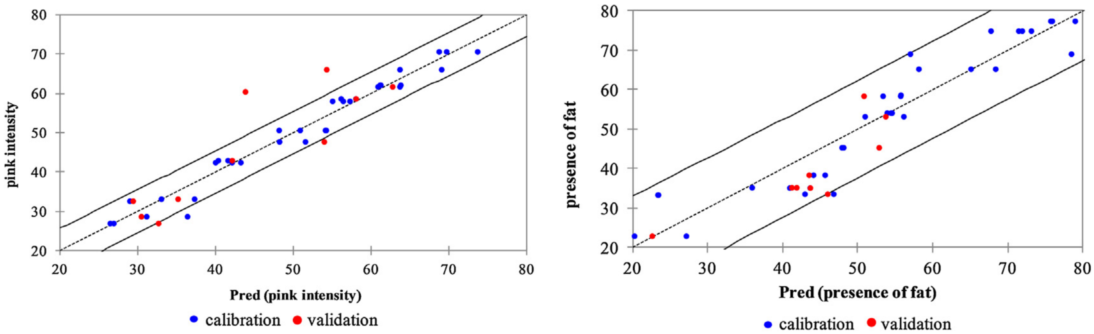

Fig. 5. Predicted vs. measured plot from PLS model developed for "pink intensity" and "presence of fat" sensory attributes by means of instrumental data from electronic eye. Calibration and validation data are shown as black and white dots, respectively.

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4. Conclusions

In this investigation, the application of physical-rheological and sensory techniques were able to provide useful information for quality control of Italian cooked ham samples. Sensory analysis resulted effective in defining the profile and the quality of the product. Among sensory attributes, those relating to appearance (pink intensity, typical appearance, and presence of fat) and texture (cohesiveness and juiciness) were the most effective in describing the class of ham providing a significant discrimination especially between the lowest quality market category (CH) and the other two higher quality categories (HQ and SE).

Data obtained by electronic eye were in agreement with sensory ones; on the other hand, considering physical-rheological parameters, AK-shear force, expressible moisture, springiness, and cohesiveness were able to clearly discriminate only the premium class (“high quality”) from each others.

The electronic eye applied in this study allowed to develop a PLS models with a promising value of prediction of visual attribute of presence of fat and pink intensity (R^2 = 0.88, RMSECV = 5.84 and R^2 = 0.95, RMSECV = 3.24, respectively).

Based on these preliminary results, the use of physical-rheological parameters could be proposed to complement sensory analysis, for example in the definition of reference standards and for rapid quality control of different categories and classes of the same product. This study permitted to hypothesize a preliminary model for a fast and effective screenings to be conducted by a “one-day” experimental plan suitable for the quality control also of other categories of meat products. This analytical approach could be particularly interesting for food providers, buyers and retailers that intend to protect and promote these products to better addressing consumer needs and enhancing their competitiveness on the market. However, further efforts aimed to differentiate and certify a higher quality product and to improve consumer's knowledge and to direct them towards a more informed choice, are needed. Work in progress includes a consumer study on cooked pork hams to investigate the correspondence between attributes generated by the panel and consumer lexicon used in quality-related communications.

Declarations

Author contribution statement

Sara Barbieri, Francesca Soglia: Performed the experiments; Wrote the paper.

Rosa Palagano, Federica Tesini: Analyzed and interpreted the data.

Alessandra Bendini, Massimiliano Petracci: Conceived and designed the experiments.

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Claudio Cavani, Tullia Gallina Toschi: Contributed reagents, materials, analysis tools or data.

Competing interest statement

The authors declare no conflict of interest.

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Additional information

No additional information is available for this paper.

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