DETERMINATION OF DRY-CURED HAM COMPOSITION USING X-RAY ABSORPTIOMETRY AND ULTRASOUND TECHNOLOGIES

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Abstract – The characterization and classification of dry-cured ham according to salt and fat contents is of interest to industries and consumers. Non-destructive technologies, such as X-ray absorptiometry and ultrasound, could be useful for this purpose. In this work, the feasibility of using X-rays and ultrasound to predict the salt and fat contents in dry-cured ham as well as their ability for ham classification according to salt content were evaluated. Predictive models for fat and salt contents were based on the measurement of X-ray attenuation at different incident energies and the ultrasound velocity at 2 and 15 ºC. The X-ray absorptiometry showed a better fat and salt prediction than the ultrasound. Overall, hams can be correctly classified with a probability of 80% using X-ray absorptiometry.

Key Words – Non-destructive technologies, Nutritional characterization, Predictive models

I. INTRODUCTION

The characterization and classification of food products according to their composition is of interest to consumers in order to provide them with nutritionally characterized products, which they may choose according to their needs and/or preferences. Moreover, labeling information such as 'reduced salt content' or 'reduced fat content' should be confirmed in order to ensure compliance with European regulations [1]. In the case of heterogeneous products, such as dry-cured ham, this characterization is of special interest since variation of salt content within batch and batch-to-batch is high. Non-destructive technologies such as X-ray absorptiometry and ultrasound (US) could be useful for this purpose. X-rays has previously been used to determine carcass and meat composition [2, 3]. US has also been previously used to characterize dry-cured ham fat from Iberian pigs [4]. Nevertheless, no studies applying these technologies to salt or fat content determination in dry-cured ham were found in literature. The aim of the present study was to evaluate the feasibility of X-rays and ultrasound to predict salt and fat contents in boned dry-cured ham. In addition, the usefulness of the developed models for classifying the product in different groups according to salt content was determined.

II. MATERIALS AND METHODS

1. Samples

Twenty hams from crosses consisting of Large White and Landrace breeds were obtained from different commercial slaughterhouses. The hams were salted with an excess of salt for 0.6, 0.7, 0.8, 1.1, 1.2, 1.3, 1.4 and 1.5 days/kg of raw ham in order to obtain a wide variation of salt contents. Once the drying and curing processes were finalized, all the hams were boned, formatted in blocks of constant thickness and divided into six portions (n=120) for further analysis. The samples were then divided into two sets for the model development and validation (Table 1).

2. X-ray absorptiometry

2.1 Equipment and scanning conditions

A commercially available X-ray inspector model X20V G90 (Multiscan technologies, S.L, Cocentaina, Spain) was used to scan the dry-cured ham portions. In this system, X-rays are emitted from below the samples and the transmitted X-rays are measured at the upper part of the device whereas a conveyor belt moves the sample through it. The system uses low-energy X-rays to obtain images (matrices of attenuation values, 4000 x 1280 pixels) of the scanned object in the horizontal plane at a constant speed. Three different voltages and intensities, specifically 90 kV and 4 mA, 70 kV and 8 mA and 50 kV and 15 mA, were used to scan the hams in exactly the same position in order to be able to compare the obtained matrices of values.

2.2 Data treatment

Matrices of attenuation values were imported from the X-ray inspector device. The global X-ray attenuation value (A) of the sample for each of the used energies was obtained by the following equation:

$$A = -\sum Ln\left(\frac{I\,(i;j)}{I_0\,(i;j)}\right)$$

where I is the intensity of the transmitted radiation through each pixel of the matrix $(i;j)$; I_o is the energy of the incident radiation to each pixel of the matrix $(i;j)$; i ranges from 1 to 4000 and j ranges from 1 to 1280. The global X-ray attenuation value (A) of each ham and for each incident energy (50, 70 and 90 kV) was referred to sample weight (A_{90}/weight, A_{70}/weight and A_{50}/weight).

3. Ultrasound

The experimental set-up for the ultrasonic measurements consisted of a couple of narrow-band ultrasonic transducers (1 MHz, 0.75'' crystal diameter, A314S-SU model, Panametrics, Waltham, MA, USA), a pulser-receiver (Panametrics, Model 5058PR, Walthom, USA) and a digital oscilloscope (Tektronix, TDS5034, Digital phosphor oscilloscope. Tektronix inc. Bearverton, Oregon. USA). A custom digital height gage was linked to the computer by a RS232 interface, in order to measure the sample thickness (± 0.01 mm). The ultrasonic velocity in the sample was computed from the time of flight, average of 3 signal acquisitions, and the sample thickness. The ultrasonic measurements were performed on each of the six portions from which each ham had been divided. The number of experimental measurements carried out on each portion depended on their size and ranged between 15 and 20. The ultrasonic velocity was measured at two different temperatures (2 and 15 ºC) in a temperature-controlled chamber.

4. Chemical analysis

Water content was analyzed by drying at 103 ºC ± 2ºC until reaching a constant weight. Chloride content was determined according to ISO 1841-2 using a potentiometric titrator 785 DMP Titrino (Metrohm AG, Herisau, Switzerland) and expressed as salt content. The total fat content was estimated by near infrared spectroscopy using a FoodScanTM Lab (Foss Analytical, Dinamarca). All the analyses were performed in triplicate.

5. Statistical analysis

A_{90}/weight, A_{70}/weight and A_{50}/weight and ultrasonic velocity (V_{us}) at 15 ºC and variation of ultrasonic velocity between 2 and 15 ºC (ΔV_{us}) were used as dependent variables to develop predictive models. REG procedure from XLSTAT package (Addinsoft, Paris, France) was used to predict the salt and fat contents of the samples. The models were identified using a Stepwise method. Levels of significance to enter and keep the dependent variables in the model were p=0.05 and p=0.1, respectively. Predictive models were evaluated using not only variables from each technology separately but also using the combination of US and X-Ray variables. The prediction capacity of such models is given by the coefficient of determination (R^2) and the Root Mean Square Error (RMSE).

III. RESULTS AND DISCUSSION

1. Relationship of X-ray absorptiometry and ultrasound variables with salt and fat contents

X-ray attenuation values obtained at the three different energies were found to be correlated to the salt and fat contents of the dry-cured ham portions (Figures 1A and B). An increase of attenuation with the decrease of fat or the increase of salt content was observed, the effect being more pronounced at 50 kV. The ham composition also largely affected the US measurements. The increase of salt content involved a higher US velocity at both temperatures tested (2 and 15 ºC) (Figure 1C) due to the increase of the solid content. Regarding the fat content, and considering that the fat melted at 15 ºC, it was observed that the US velocity measured at 2 ºC was higher than at 15 ºC except for hams with low fat content. Thus, the

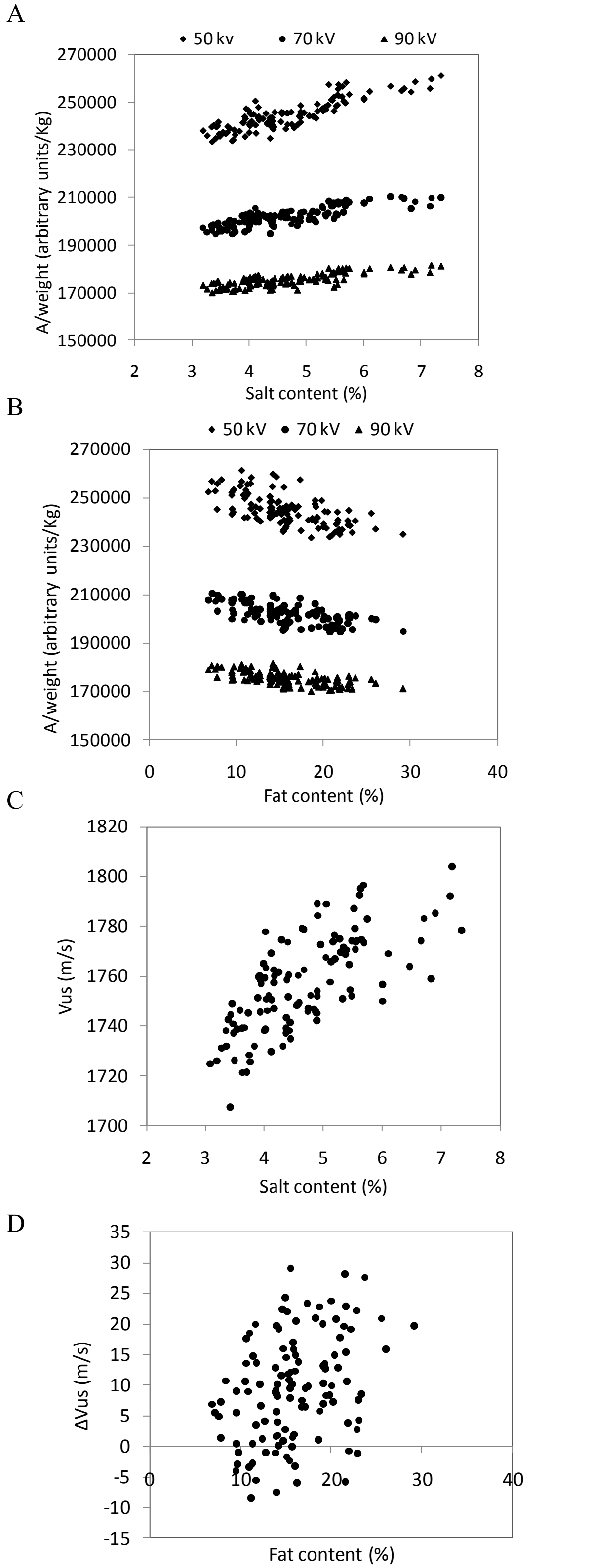

Figure 1. Influence of salt and fat contents on X-ray attenuation (A and B), ultrasound velocity at 15ºC (C) and increment of ultrasound velocity from 15 to 2 ºC (D).

difference between the US velocity measured at 2 and 15 ºC (Δv_{us}) increased when the fat content was higher (Figure 1D). Nevertheless, a large dispersion was found in the experimental data which points to the fact that not only the fat but also other components (proteins, salt, water, etc...) affect the Δv_{us}.

2. Predictive models

The parameters of the models developed to predict the salt and fat contents in the dry-cured ham portions using X-rays and US are presented in Table 1. X-rays can accurately estimate salt content (RMSE=0.51%) using the information obtained at 50 kV. Fat content can be estimated with less precision (RMSE=3.49%) using the combination of the information obtained at 50 and 90 kV. Due to the fact that the portions were taken from formatted dry-cured hams the thickness was constant and therefore did not produce a variation on the attenuation of X-rays. The differences obtained were mainly due to the sample composition.

Simple regression models were also obtained to estimate both the salt content, as a function of the US velocity at 15 ºC, and the fat content, as a function of Δv_{us} (Table 1). Including only a variable in the model resulted in a less accurate prediction of salt (RMSE=5.00%) than those from X-ray measurements. Regarding the fat, the Δv_{us} did not provide a good estimation, which indicates that Δv_{us} is affected by other food constituents. Thereby, further studies will be carried out to obtain more reliable models for a joint estimation of the main constituents of

Table 1. Parameters of salt and fat predictive models using X-ray and ultrasound technologies.

	Salt		Fat	
	X-rays	US	X-rays	US
Calibration				
n	80	80	80	80
R^2	0.75	0.52	0.51	0.1
RMSE (%)	0.47	3.16	3.24	12.02
Model variables	A_{50}/weight	V_{us}	A_{50}/weight A_{90}/weight	ΔV_{us}
Validation				
n	40	40	40	40
R^2	0.76	0.52	0.37	0.17
RMSE (%)	0.51	5.00	3.49	18.15

ham, such as fat, salt, water and protein, from the US measurements. The combination of variables from both X-rays and US technologies did not significantly decrease the error of prediction.

3. Usefulness for nutritional characterization of dry-cured ham portions

Ham portions from validation data set had a wide salt content variation (Figure 2). The average salt content of the portions was 4.7% with a standard deviation of 1.0%. The portions were assigned to three different groups depending on their measured salt content. Hams with a salt content of ≤ 3.7% were considered to have a low level of salt, hams with a salt content of > 5.7% were considered to have a high level of salt and the others to have a moderate level of salt.

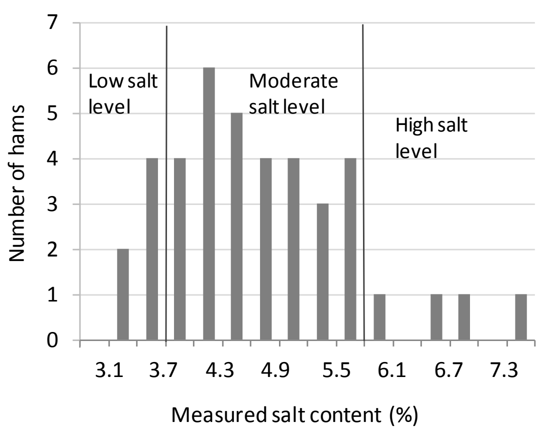

Figure 2. Distribution of validation set according to its measured salt content.

The feasibility of X-ray absorptiometry to industrially classify dry-cured ham portions in different groups according to salt content is presented in Table 2. Overall, hams can be correctly classified with a probability of 80%. Discrepancies were found between low and moderate levels and between moderate and high levels but not between low and high salt levels. Thus, this technology could be considered useful to characterize, categorize and properly label products according to salt content. Only one of five hams was classified as having a low salt level when in fact it had a moderate salt level. Thus, nutritional claims such as "reduced salt content" could be ensured if set restrictive values were used to define the groups. The need for only one X-ray incident energy for the prediction of salt content could facilitate the implementation of this technology online in dry-cured ham industry.

Table 2. Classification of hams from validation set in different groups according to the salt content using X-rays.

		Predicted salt level			
		low	Moderate	High	total
Real salt level	Low	4	2	0	6
	Moderate	1	24	5	30
	High	0	0	4	4
	Total	5	26	9	40

IV. CONCLUSION

Measurements by X-ray and US technologies could be used to determine salt and fat contents of dry-cured ham portions. The selection of products with a reduced salt content is feasible using X-rays if set restrictive values are implemented when defining the groups.

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