Magnetic Resonance Imaging and Relaxation Analysis to predict non-invasively and non-destructively salt-to-moisture ratios in dry-cured meat

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

P. Fantazzini[a], V. Bortolotti[b], C. Garavaglia[a], M. Gombia[b], S. Riccardi[a], P. Schembri[b], R. Virgili[c], C. Soresi Bordini[d]

[a] University of Bologna, Dept. of Physics, Viale Berti Pichat 6/2, 40127 Bologna, ITALY
[b] University of Bologna, Dept. DICMA, Viale Risorgimento 2, 40136 Bologna, ITALY
[c] SSICA Stazione Sperimentale per l'Industria delle Conserve Alimentari, V.le F Tanara, 31/A - 43100 Parma (ITALY)
[d] C.R.P.A. Centro Ricerche Produzioni Animali, Corso Garibaldi, 42, 42100 Reggio Emilia (ITALY)

ABSTRACT

The current systems are unable to control and predict the cured meat composition non-destructively and in a reasonable time for production needs. In this work T_1 and T_2 maps were obtained on internal sections of muscle Longissimus dorsi at increasing salting times. The maps allow one to visualize non-destructively and non-invasively the salting process. The method goes beyond the simple qualitative visualization, because for each section of the sample and in any region of the section, it is possible to obtain quantitative information on the progress of salting, and to predict salt-to-moisture ratios. Relaxation measurements were performed on cores sampled after imaging in order to better define the relaxation properties of the dry-cured meat.

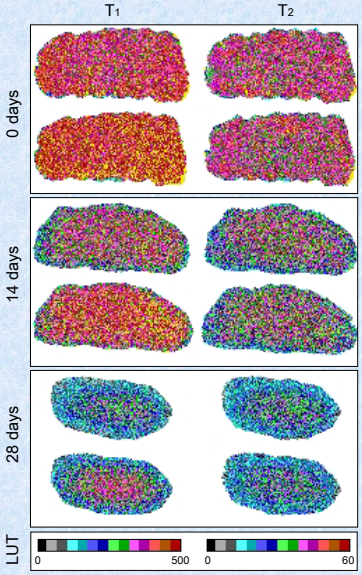

Figure 1

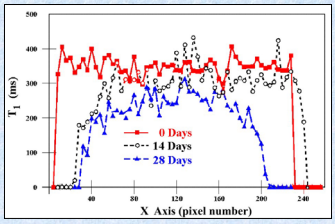

Figure 2

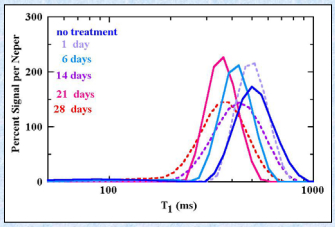

Figure 3a – central location

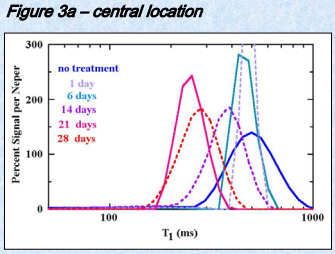

Figure 3b – peripheral location

INTRODUCTION

The principles governing processes occurring during curing, such as meat dehydration and salt diffusion within the product (1), are rather simple, but the final result of processing is subject to a variability which operators in this field are unable to predict and control. The first step of pork dry-curing is the salting phase, consisting of treatment of the pork surface with dry and/or wet salt. The proper management of the cold rooms, where raw cuts are cured, allows salt to diffuse inside muscle and allows pork to dehydrate. It is proved that this processing technique is affected by meat quality, muscle shape and size, trimming of cuts, unwanted changes of temperature and per cent relative humidity inside cold rooms. Moreover, with amounts of added salt being increasingly lowered to meet nutritional request for low-salt products, the improvement of curing control is a major goal for the meat industry.

In this work Magnetic Resonance Imaging and Relaxometry were used to study structural complexity of meat and to follow the changes during processing affecting final quality of the product. In particular, quantitative T_1 and T_2 maps of five sections, at a distance of 2 mm from one to another, and a voxel dimension of 0.55x0.55x5 mm^3 of fresh and salted muscle were obtained. Samples of pork *Longissimus dorsi* muscle, taken 24 hours post-mortem, were salted with percentages of NaCl in the 2.5 - 3.5% range and stored at 1-4°C under saturation moisture conditions for different times (0, 1, 6, 14, 21, 28 days) in order to obtain, in the product, a salt content increasing from 0 to 6%. At the pre-established times, the samples were divided into two parts, one for the determination of the percentage composition according to AOAC methods (2) and the other for MRI analysis.

T_1 and T_2 maps were obtained by images acquired by means of ARTOSCAN™ (Esaote SpA, Genova, Italia) operating at 8 MHz. Data acquired at increasing echo-time for T_2 maps (SE multislice sequence) and at increasing delay time for T_1 maps (SR multislice sequence) were processed with in-house software (3) in order to generate T_2, T_1, spin density corrected for the proper T_2 decay of each voxel, and the parameter S_N calculated by normalizing the signal intensity to the reference signal generated by a 100% porosity standard. The software generates T_1 and T_2 maps and histograms weighted by the signal in user-defined ROIs. STIR images with inversion time T_I = 85 ms were acquired in order to suppress the contribution to the image from the fat, according to previously obtained T_1 distribution of fat. After imaging, samples were cored for relaxation analysis by a relaxometer operating at 20 MHz.

Data analysis was carried out with the statistical package SPSS/PC, ver. 10.

RESULTS

The images reported in Fig. 1 correspond respectively to the T_1 and T_2 maps of two central sections at 0, 14, and 28 days, respectively. In all the sections of the samples undergoing salting, changes of NMR parameters are clearly seen when passing from the periphery to the centre of the sample, in accordance with the progressive and parallel increase in moisture from the periphery to the centre and the concomitant decrease in salt content. The gradient progresses with increasing salting time, as shown in Fig. 2. Detailed analyses of T_1 and T_2 distributions obtained by relaxometry confirmed the behaviour of NMR parameters obtained by imaging (see Figures 3a and 3b showing the decrease of T_1 with increasing salting time, in a central position (3a) and in the periphery (3b), respectively). Quantitative results of NMR parameters can be compared with the composition data, as shown in Table 1: it is shown the effect of salting day on MRI parameters, salt and moisture content. Data were compared by means of one-way analysis of variance (ANOVA, Bonferroni multiple test). The progressive reduction of T_1 and T_2 was detected both from imaging and relaxation measurements and are in agreement with moisture decrease and salt increase from muscle center to outer layers. Linear relationships ($P < 0.0001$) were found between muscle proximate composition and NMR data. Moisture of muscle cores was correlated (r=0.57; P=0.001) with the parameter S_N. Microbiological stability of cured meat products is based on the salt-to-moisture ratio, an index closely associated with meat water activity (a_w), a microbiological parameter whose value is selective for microbial growth. MRI and chemical measurements of *Longissimus dorsi* muscle were used to compute a model to fit the salt-to-moisture ratios of the tested samples. Multiple Regression Analysis (stepwise method) was carried out, and the variables included in the model (R^2 = 0.83 and $P < 0.000$) were T_1, S_N and the intra-muscular fat content (analytically measured) (see Fig. 4). By using a suitable combination of relaxation time maps and STIR images (image analysis of fat), a protocol based on MRI only can be developed to predict non invasively and non destructively salt-to-moisture ratios of cured pork.

	Salting day					
variable	1	6	14	21	28	
	Mean ± SEM*	Mean ± SEM*	Mean ± SEM*	Mean ± SEM*	Mean ± SEM*	P-value
S_N	82.0 ± 2.4	84.3 ± 3.8	74.4 ± 4.8	77.3 ± 1.2	72.2 ± 2.3	0.061
T_1	362^a± 7	$320^{a,b}$± 18	305^b± 10	270^b± 9	214^c± 10	<0.001
T_2	38.6^a± 0.7	37.4^a± 2.3	34.9^a± 1.5	28.1^b± 1.3	25.2^b± 1.7	<0.001
Moisture	73.2^a± 0.3	71.8^a± 0.8	71.0^a± 0.5	67.6^b± 0.6	62.1^c± 1.4	<0.001
Salt	0.97^a± 0.23	$2.4^{a,b}$± 0.5	$2.4^{a,b}$± 0.2	3.3^b± 0.2	5.1^c± 0.6	<0.001
*S/M***	1.3± 0.3	$3.3^{a,b}$± 0.7	$3.4^{a,b}$± 0.4	5.0^b± 0.4	8.2^c± 1.0	<0.001

*Standard error of the mean
**Salt-to-moisture ratio (per cent)
Different letters along the same row indicate significant difference (P <0.05)

Table 1

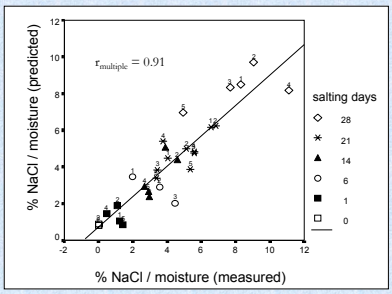

Figure 4

CONCLUSIONS

Application of MRI technique and development of a suitable analytical protocol allowed knowing quantitatively, non-invasively and non-destructively, salting process in pork Longissimus dorsi samples. T_1 and T_2 maps, together with STIR images, proved to be suitable tools to investigate, salt, water and fat content in regions of interest in inner layers of cured muscle.

REFERENCES

1 – J. Arnau, L. Guerrero, G. Casademont, P. Gou, *Physical and chemical changes in different zones of normal and PSE dry cured ham during processing*, Food Chem., 52, pp. 63-69, 1995.
2 – AOAC, "*Official Methods of Analisys"* (16th ed.) Association of Official Analytical Chemists, Arlington, Virginia (USA), 1995.
3– G. C. Borgia, V. Bortolotti, P. Fantazzini, *Changes of the local pore space structure quantified in heterogeneous porous media by 1H magnetic resonance relaxation tomography*, J. Appl. Phys., 90, p. 1155, 2001.

ACKNOWLEDGMENT

This research work was performed with the MIUR-MIPAF financial support to the project "Sistemi innovativi per la promozione e la riconoscibilità della qualità nella filiera produttiva dei prodotti carnei", with the support of the University of Bologna (Funds for selected research topics) and of the Stazione Sperimentale per l'Industria delle Conserve Alimentari di Parma.