RELATIONSHIP BETWEEN ELECTRICAL IMPEDANCE SPECTROSCOPY AND SENSORY QUALITY OF BEEF

Oliván, M.[1], García, P.[1], Martínez, M.J.[1], Mocha, M.[1], Osoro, K.[1], Elvira, J.[2], Oliver, M.A [3]
[1] S.E.R.I.D.A. Apdo 13, 33300-Villaviciosa, Asturias, Spain
[2] NTE, S.A.Can Malé, s/n. 08186 Lliçà d'Amunt, Catalunya, Spain
[3] IRTA, Centre de Tecnologia de la Carn, Granja Camps i Armet, 17121-Monells, Girona, Spain

Background

Prediction of the sensory quality of beef from on-line carcass measurements would be of great value for the beef industry. During the last years different optical probes have been developed for the on-line evaluation of meat. Fluorescence and reflectance measurements have been used to detect connective and adipose tissue in beef (Swatland & Findlay, 1997; Swatland, 2000) and spectrophotometric measurements have been correlated with important attributes of meat quality, such as water-holding capacity or intramuscular fat (Swatland, 1995). The electrical impedance spectroscopy (EIS) has been applied with success as a predictor of the intramuscular fat content in beef and pork (Madsen et al., 1999; Marchello et al., 1999), and can be used to select green hams on the basis of the pH and fatness (Oliver et al., 2001) and even to predict sensory quality attributes of dry cured hams (Guerrero et al., 2004).

Objectives

The objective of this study was to evaluate an EIS (Electrical Impedance Spectroscopy) on-line probe, based on electrical impedance measurements, as predictor of the sensory quality of beef.

Materials and methods

This study was carried out on a set of 30 carcasses of yearling bulls (500 kg live weight) of two local breeds from northern Spain: Asturiana de los Valles (AV) and Asturiana de la Montaña (AM). These carcasses were selected from 5 different biological types derived from different combinations of breed (AV and AM), physiological state (bull and steer) and presence of muscular hypertrophy (*mh*/*mh*, *mh*/+, +/+), in order to obtain a sample set that included a wide range of carcass and meat traits.
At 24 h *post-mortem* carcasses were quartered between the 5th and 6th ribs and several measurements were performed on the *Longissimus* muscle of the left carcass: pH (pH24) was recorded on the loin of the 5th rib and electrical measurements were performed with an EIS on-line probe, supplied by the company NTE (Riu et al., 2001), inserted perpendicularly to muscle between the 4th and 5th lumbar vertebrae (*Longissimus lumborum*, LL) and between the 10th and 11th ribs (*Longissimus thoracis*, LT). The probe has two needles (length 50 mm) separated by 8 mm. Each needle is composed of 2 electrodes having the device a total of 4 electrodes. A temperature sensor was included in the probe to record the inner temperature of the sample. This device measures two parameters: R_∞ and R_0, that record the resistence at the higher (112 kHz) and the lower (5 kHz) frequencies, respectively, expressed in ohms (Ω). A third parameter, called K-value, is calculated, corresponding to the ratio R_∞ over R_0.
The loin comprised between the 6th and the 11th ribs was extracted and transported to the laboratory. The 6th rib joint was kept on a poliexpan tray covered with plastic permeable to O_2 at 4 ºC during 7 days, for subsequent determination of moisture (ISO 1442), intramuscular fat (IMF, ISO 1443) and water holding capacity measured as expressible juice of raw meat (EJ) according to a modification of the method of Grau and Hamm described by Sierra (1973). The rest of the loin was sliced, vacuum packed and kept at 4ºC for 7 days ageing, being later frozen at -18 ºC. The instrumental toughness (kg/cm^2) was evaluated on cooked meat in an Instron 1011 equipment with a Warner-Bratzler shearing device. Sensory analysis was performed by an eight member trained panel on steaks cooked to an internal temperature of 70º C. On a 100 mm scale, panellist assessed a profile composed of hardiness, juiciness and chewiness.
Analysis of variance was performed to study the effect of biological type on the physico-chemical, electrical and sensory traits. Differences between means were calculated with the LSD test. Multiple linear regressions were assessed between variables by the stepwise method. Principal component analysis was made to describe the relationships between meat quality and electrical parameters and discriminant analysis was applied to

study the ability of electrical measurements to classify the meat samples according to the water holding capacity (WHC), measured as expressible juice (EJ): high (H, EJ>21%) or low (L, EJ<21%). All the statistical analyses were performed using the SPSS programme 11.5.1 (2002).

Results and discussion

There was a significant effect of biological type on EJ ($p<0.001$) and IMF ($p<0.05$) of meat (Table 1). Meat of AV bulls with muscular hypertrophy (*mh*/*mh* or *mh*/+) showed higher juice losses and lower intramuscular fat than any other meat type, and there was a general tendency of EJ to increase as the intramuscular fat content of meat decreased.
Biological type affected also significantly to R_∞ ($p<0.05$) and K ($p<0.001$) when measured on the LT (10th-11th ribs). Values of R_0 were higher as the IMF of meat increased and K values decreased as the juice losses increased. There were not significant differences between meat types on toughness or hardiness, but there was a tendency of meat with lower fat content and higher juice losses (AV bulls) of showing lower juiciness and higher chewiness than meat of AV steers or AM bulls.
The principal component analysis (Fig. 1) showed that the electrical variable K (ratio R_∞:R_0) was positively related with juice losses (EJ) and moisture, as it is a parameter proportional to the ratio of extracellular water to total water in meat (Lozano et al. 1995). However, R_∞ and R_0 were positively related with the IMF content of meat, because the resistance of the muscle at high frequencies depends directly on the geometry of the conductive medium under measurement, hence it reflects the amount and/or size of fat cells. Furthermore, because fat is an insulator, the greater the fat content the higher the impedance reading. The first principal component explained 33% of the total variance and contrasted meat of high juice losses (EJ), high K value and high chewiness, hardiness and toughness with meat of high IMF content and juiciness.
Multiple regression analysis of electrical variables confirmed that R_0-LT and R_0-LL were negatively related with EJ and contributed significantly to predict this variable ($r= -0.66$, r.s.d.= 2.39, $p<0.001$). These results agree with those presented by Swatland (1982), Whitman et al. (1996) and Gobantes et al. (2000) who showed that low frequency electrical conductivity (R_0) is related to water holding capacity of meat. When including in the stepwise regression analysis physico-chemical and electrical variables, the best prediction of EJ was obtained from the IMF, R_0-LT and R_∞-LT, that explained 67% of the variance ($r=0.82$, r.s.d.= 1.82, $p<0.001$). This confirms that the intramuscular fat content of meat has a great influence on the water holding capacity, as described by Oliván et al. (2003), who compared meat quality of different breeds (AV and AM) and/or genotypes (*mh*/*mh*, *mh*/+, +/+) and found that the higher the intramuscular fat content the lower are juice losses of raw meat. Therefore, electrical variables that estimate the amount of fat cells in the tissue (R_0-LT and R_∞-LT) may be used as predictors of the expressible juice losses of meat.
The electrical variable that contributed significantly to predict the IMF content of meat was R_0-LL ($r= 0.39$, r.s.d.= 0.96, $p<0.05$). However, when including all quality traits in the stepwise regression analysis, none of the electrical variables was selected but moisture and juiciness were significantly related with IMF as they explained together 81% of the variance of data ($r=0.90$, r.s.d.= 0.46, $p<0.001$).
Discriminant analysis was used in order to test the ability of on-line measurements (pH and electrical variables) to classify meat samples according to the amount of expressible juice (EJ): high (EJ>21%) or low (EJ<21%) (Table 2). When using pH24 and the electrical variables measured on the LL (4th-5th lumbar vertebrae), 60.0% of samples were well classified. However, pH24 and electrical measurements performed on the LT (10th-11th ribs) allowed to classify 73.3% of the meat samples correctly in high (H) or low (L) juice losses. When the chemical composition of meat (moisture + IMF) was also included, the proportion of well classified samples increased to 90.0 %, being 100% in the group of high EJ (H). This is not the first time that electrical impedance measurements allow the classification of meat by quality traits. Guerrero et al. (2004) showed that EIS measures detected correctly 69% of green hams with problems of pastiness, due to its relationship with PSE meat.

Conclusions

The results of the present study indicate that the electrical measurements performed with the EIS on-line probe on the carcass of yearling bulls at 24 h *post-mortem* are useful predictors of the sensory and technological quality of meat at 7 days *post-mortem* and could be used for on-line beef quality grading.

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Table 1. Effect of biological type on physico-chemical, electrical and sensory traits.

	Biological type					
Breed	**AV**				**AM**	
Muscular hypertrophy	**mh/mh**	**mh/+**		**+/+**	**+/+**	**Significance**
Physiological state	**Bull**	**Bull**	**Steer**	**Bull**	**Bull**	
N	4	7	5	7	7	
pH24	5.4	5.5	5.4	5.5	5.5	NS
EJ (%)	25.64 c	23.76 cd	17.47 a	21.93 bd	19.56 ab	***
Moisture (%)	73.89	73.28	73.26	73.06	73.06	NS
IMF (%)	2.02 a	3.12 ab	3.54 ab	3.34 ab	4.07 b	*
Toughness (kg/cm^2)	2.62	2.17	2.04	2.29	2.29	NS
Hardiness	3.53	2.74	2.16	2.80	2.80	NS
Juiciness	2.98	3.64	4.01	3.89	4.27	+
Chewiness	4.15	3.53	3.20	3.43	3.49	+
EIS on LL (4th-5th lumbar vertebrae):						
R_∞-LL (Ω)	12.0	10.5	12.3	12.1	12.5	NS
R_0-LL (Ω)	49.6	57.5	76.9	70.0	65.9	NS
K-LL	0.27	0.19	0.16	0.17	0.22	NS
EIS on LT (10th-11th ribs):						
R_∞-LT (Ω)	8.9	10.4	12.3	11.1	12.9	NS
R_0-LT (Ω)	20.5a	33.3ab	58.1b	43.7ab	51.1ab	*
K-LT	0.45b	0.32ab	0.23a	0.26a	0.26a	***

NS: no significant; +: $p<0.1$;*: $p<0.05$; **: $p<0.01$; ***: $p<0.001$
For each variable, data followed by different letters are significantly different ($p<0.05$).

Table 2. Classification of meat samples according to low (L) or high (H) expressible juice by discriminant analysis based on pH24, electrical variables and chemical composition.

		pH24 + impedances on LL			pH24 + impedances on LT			pH24 + impedances on LT + moisture + IMF		
		L	**H**	**Total**	**L**	**H**	**Total**	**L**	**H**	**Total**
L	**n**	8	5	13	10	3	13	13	0	13
	%	61.5	38.5	100.0	76.9	23.1	100.0	100.0	0.0	100.0
H	**n**	7	10	17	5	12	17	3	14	17
	%	41.2	58.8	100.0	29.4	70.6	100.0	17.6	82.4	100.0

H: high EJ (>21%), L: low EJ (<21%).

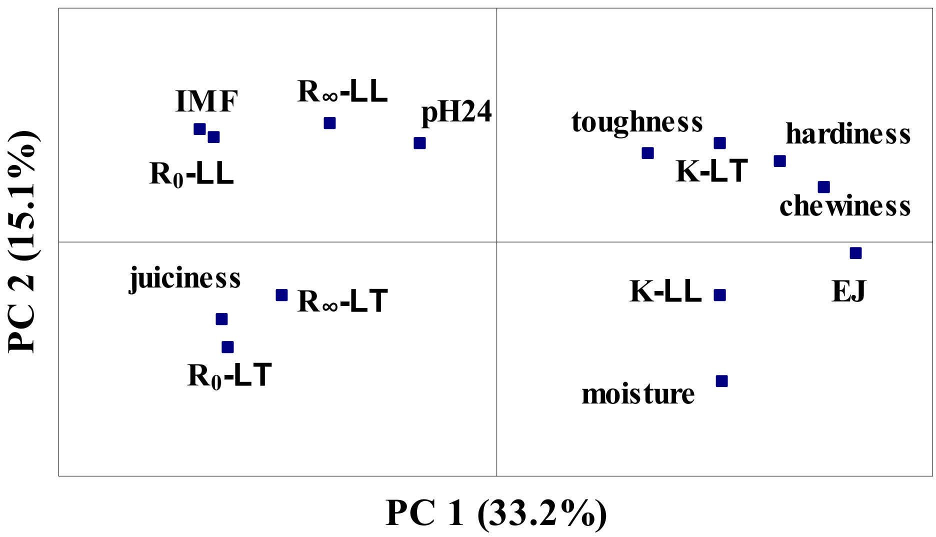

Figure 1. Principal component analysis of physico-chemical, electrical and sensory traits.