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Relationships between sensory and physicochemical measurements in meat of rabbit from three different breeding systems using canonical correlation analysis

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Meat from rabbits reared either according to a standard (STAND) or a high quality norm (LABEL) or a low growth breeding (RUSSE) system were submitted to a sensory evaluation and to a large set of physicochemical measurements (weight of retail cuts, colour parameters, ultimate pH, femur flexure test, Warner-Bratzler shear test, water holding capacities and cooking losses). STAND rabbit meat exhibited the most juicy meat in back and in leg ($p < 0.01$). Leg tenderness significantly decreased ($p < 0.001$) in the rank order STAND > LABEL > RUSSE. Canonical correlation analysis showed strong correlations between physicochemical and sensory variables ($R^2 = 0.73$ and 0.68 between the two first pairs of canonical variates). Especially, sensory tenderness and WB shear test variables assessed on raw longissimus muscle (LL) were correlated. Fibrous attribute in back was correlated with cooking loss in LL. When analysed separately only RUSSE rabbits exhibited the same relations between variables as those calculated in whole dataset.

1. Introduction

Rabbit meat consumption is mainly an eating habit developed in Mediterranean countries of the EU and essentially concerns a middle-aged consumer population. Dalle-Zotte (2002) reported results of an Italian market research study on rabbit meat consumption habits. The first criterion of rabbit meat attractiveness for the traditional consumers was quality *sensu lato* followed by appearance, carcass weight and quality to price ratio. Rabbit meat is considered by the traditional consumer to have positive sensory properties: it is tender, lean and delicately flavoured although a main cause of refusal is its typical wild taste (Dalle-Zotte, 2002). Meat sensory properties are thus crucial for the consumer's choice. The determination of meat sensory quality can be made using a trained taste panel but is a slow and time-consuming process. Thus it is interesting to consider chemical, mechanical or optical measurements related to sensory qualities. For practical reasons these quality criteria should be easily measurable: mainly simple and rapid.

The relationships between sensory quality and physicochemical characteristics have been studied in various food products using multivariate analysis techniques. The most commonly used methodology is principal component analysis (PCA). In rabbit only one study has estimated the relationships between chemical and/or physical measurements and sensory evaluations using PCA (Hernandez, Pla, Oliver, & Blasco, 2000). They concluded that both fatty acids components and sensory variables play an important role in describing the variations observed in rabbit meat quality. But in this study none of the physical measurements appeared to be related to the sensory variables, implying that both were needed to describe rabbit meat quality. However, PCA is not the most suitable tool to focus on the relationships between two groups of variables; this is the question specifically addressed by the canonical correlation analysis (CCA). This is achieved by finding the largest correlation between a linear combination of the variables in the first set and a linear combination of the variables in the second set (Gittins,

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1985). In comparison, PCA calculates the linear combination with the largest variance within one set of variables. CCA is already used to highlight relationships between sensory evaluation and physicochemical measurements in food products (Dever, Cliff, & Hall, 1995; Karoui, Pillonel, Schaller, Bosset, & De Baerdemaeker, 2006).

The objective of this work was to examine the relationships between chemical and physical measurements of meat quality and the results of sensory evaluation on the same sample. For this purpose, we used three different breeding systems to produce high variability in meat quality: a standard production, a breeding system complying with "French" label norms and a very slow growth rate breeding system. All types of physicochemical measurements used in this study could be performed within a 24 h period thus allowing quality control and screening of many samples in a research or development situation. We hypothesized that simple physicochemical measurements can be used to describe sensory properties of rabbit meat.

2. Materials and methods

2.1. Animals

We produced three groups of rabbits which could provide a wide variation in meat sensory qualities combining the main breeding factors known to affect sensory properties of rabbit meat (Dalle-Zotte, 2002). At the experimental farm of ITAVI Rambouillet (France), three different rabbit breeding systems were settled on according to animal strains, housing and feeding (Combes et al., 2007). Rabbit from the STAND group (PS Hyplus 19 × PS Hyplus 39, commercial hybrids, Grimaud Frères, France) were reared according to the standard intensive breeding system in collective cages of 6 (17.5 rabbits/m^2) and received *ad libitum* a commercial pelleted feed (protein 17.0%, fat 3.3%, digestible energy 9.8 MJ/kg). Rabbits from the LABEL group (PS Hyplus 19 × PS Hyplus 99, commercial hybrids for the production of Label rabbits, Grimaud Frères France) were reared in pens of 36 animals at the same stocking density as rabbits from the STAND groups. The third group (RUSSE) consisted of a particular breed (pure Himalayan) with a very low growth rate. They were reared in hutches of 2 to 5 animals. The LABEL and RUSSE rabbits were given a commercial pelleted feed designed for Label production (protein 15.4%, fat 2.2%, digestible energy 9.3 MJ/kg) *ad libitum*. Rabbits from the three groups were slaughtered at the same weight (2315 ± 144 g) reached at 71 d, 92 d and 135 d for STAND, LABEL and RUSSE groups, respectively. Animals were slaughtered without prior fasting and transportation and in compliance with French national regulations. Thirty-two animals of each group were used in the experiment.

2.2. Physicochemical traits

The physicochemical traits measured in each animal have been previously described (Combes et al., 2007). After 24 h of chilling, the weighed carcass was divided according to the recommendations of the World Rabbit Scientific Association (Blasco, Ouhayoun, & Masoero, 1993). Proportions of perirenal fat (WPfC, %), fore- (WforeC, %), back- (WBackC, %) and hind-parts (WlegC, %) (weight/chilled carcass weight, ×100) were calculated. Meat to bone ratio was determined in leg (MBR) (Blasco et al., 1993). The femur weight was expressed as percentage of hind leg weight (WFLeg, %) or of chilled carcass weight (WFC, %). Ultimate pH was measured in muscle *longissimus lumborum* (LL, adjacent to the sixth lumbar vertebra) and in *biceps femoris* (BF), using a combined glass penetrating electrode (Ingold, Mettler Toledo, Greifensee, Switzerland). Color was assessed on the carcass surface over the LL and BF and on a freshly exposed cut surface of LL. A Minolta CR-300 chromameter (Minolta, Osaka, Japan) was set to the L^* (lightness), a^* (redness), and b^* (yellowness) CIE scale (*L_LL and *L_BF). Legs and back were vacuum packed and frozen. For each rabbit, one leg and one half-back were used for sensory analysis while the two other were used for physicochemical analysis.

After thawing, a sample of LL was weighed and cut into two parts to allow analysis as raw and cooked sample. Cooking loss was determined (CL_LL, %) in an LL sample vacuum packed and cooked in a water bath (85 °C) for 40 min (Combes, Lepetit, Darche, & Lebas, 2003b). Moisture content was determined in raw and cooked LL (MCr_LL and MCc_LL, %) and dry matter in the edible part of fore and hind leg (DM_Fore, DM_Leg, %) by drying at 103 °C overnight. Water holding capacity (WHC) was estimated by centrifuging raw or cooked LL portions for 10 min at 1500*g*, and determining the residual water by drying the sample at 103 °C overnight (Castellini, Dal Bosco, Bernardini, & Cyril, 1998). WHC was calculated with the following equation: WHC = (weight after centrifugation – weight after drying) and expressed either per gram of initial muscle weight (WHCm_rLL and WHCm_cLL for raw and cooked muscle, respectively) or per gram of moisture content in muscle (WHCw_rLL and WHCw_cLL for raw and cooked muscle, respectively). Expressible water loss of raw and cooked LL (WLm_rLL, WL_cLL) represented the total quantity of water per g/muscle minus the WHCm. We used TOBEC methodology (total body electrical conductivity, EM-SCAN SA-3044 5EM-SCAN Inc., Springfield, Illinois, USA) on mixed deboned leg meat (E_Leg), mixed fore part (E_Fore) or entire LL (E_LL) (Cauquil, Combes, Darche, & Lebas, 2001). TOBEC is a non-invasive technique that has been shown to accurately predict lean body mass or weight of total water in some mammals (Fortun-Lamothe, Lamboley-Gauzere, & Bannelier, 2002). The energy loss was detected as a phase change in the impedance of the coil and expressed as the *E*-value.

Raw or cooked LL muscle area was measured by image analysis (CSA_rLL and CSAcLL, mm^2). Warner-Bratzler (WB) shear test was performed as previously described (Gondret, Combes, Larzul, & De Rochambeau, 2002). The recorded parameters from the force displacement curve in raw LL were shear force applied at the first peak (F1_rLL, N) at second peak (F3_rLL, N) and at maximum whatever the peak (Fmax_rLL, N). The level of the minimum force applied between the two peaks was recorded (F2_rLL, N). Distances to those three points were also recorded (DF1_rLL, DF2_rLL and DF3_rLL, mm). In cooked LL, the force displacement curve exhibited only one peak, thus the recorded parameters were maximum shear force and the distance to this point (F1_cLL, N and DF1_cLL, mm). Total energy was calculated as the area under the force displacement curve (TE_rLL and TE_cLL, mJ) and stress was calculated (Stress_rLL and Stress_cLL, N/mm^2).

Femurs were submitted to a three-point flexure test. Length (Length_F, mm), and outside diameters at the point of loading, both perpendicular and parallel to the direction of the applied force (dlm_F and dap_F, mm), were measured using a dial calliper (+0.02 mm). The area moment of inertia (MI_F, mm^4), which is an estimation of bone distribution assuming that shape is similar to an elliptical plain tube was calculated according to the formula: MI=$\pi \times$ (dlm_F * dap_F^3)/64. Yield force (YF_F, N), distance to yield force (DYF_F, mm), energy to yield force (EYF_F, mJ), ultimate force (UF_F, N) distance to ultimate force (DUF_F, mm), energy to ultimate force (EUF_F, mJ) and stiffness (slope of the elastic part: Stif_F, N/mm) were collected from the load deformation curve. Bone strain (Strain_F) corresponding to the relative deformation of bone, stress defined as yield or ultimate force (StressYF and StressUF_F, N/mm^2) per unit of bone area, and modulus of elasticity (Mod_F, N/mm^2) as a measure of the degree of bone rigidity, were calculated according to formula reported by Patterson, Cook, Crenshaw, and Sunde (1986).

2.3. Sensory evaluation

A quantitative descriptive analysis was carried out using the same 96 rabbits (32 per group) by 8–12 trained tasters of rabbit meat in 11 sessions. The samples were assessed for tenderness, perception of meat fibres (fibrous), juiciness, sticky (abundance of sawdust-like particles coating the mouth) and flavour of rabbit meat. A 10-point scale was used for each sensory criterion, where 1 = very tough, little fibrous, dry, little coating and weak flavour, respectively. The sensory analysis was carried out on back and leg cooked in an oven (Thirode, Mitry-Mory, France) for 5 min up to a core temperature of 85 °C under dry heat (250 °C) and then followed for 20–30 min under humid heat (180 °C). LL was separated from loin immediately after cooking. LL and leg were then immediately cut into two pieces and three samples (one per group) were presented hot on a preheated plate to the panellists following a complete block design.

2.4. Data analysis

As a preliminary study, a principal component analysis (PCA) was performed on the sensory data set to provide a partial visualisation of the correlations between sensory variables in a reduced dimension plot using R 2.2.1 package (2005). Sensory data were then submitted to an analysis of variance with group as main effect. The normal distribution of the residues of the 63 physicochemical variables was checked, and it was decided to transform six variables using a natural logarithm function.

We performed a canonical correlation analysis (CCA). CCA is a multidimensional exploratory method that can highlight correlations between two groups of variables. The correlations are called the canonical correlations and the linear combinations are the canonical variates (Gittins, 1985). To perform CCA directly, the data set must contain more experimental units than the total amount of variables in both groups. But, even if the number of experimental units is great enough to enable computations, first dimensions in CCA may not be determined by the true underlying linear relationship between the two groups of variables but by an artificial subspace recovering. To overcome this limitation, a prior regularization step can be implemented. It consists in adding a term, the regularization parameter, on the diagonal of an ill-conditioned matrix to enable its inversion. In the context of CCA (Vinod, 1976), regularization can be applied on the two matrices corresponding to the orthogonal projections onto the respective column-space of the two sets of variables:

$$P_X = X(X'X + \lambda_1 Id)^{-1}X \quad \text{and} \quad P_Y = Y(Y'Y + \lambda_2 Id)^{-1}Y$$

where X and Y refer to the two matrices corresponding to physicochemical traits and sensory attributes, respectively. In the formula, X' denotes the transpose of X and Id the identity matrix. Optimal values for the regularization parameters λ_1 and λ_2, was set using a leave-one-out (Leurgans, Moyeed, & Silverman, 1993) cross-validation procedure. We used the R package CCA to perform the regularized extension of CCA (Gonzalez, Déjean, Martin, & Baccini, 2008). The results are presented as a variable plot that allows discerning the structure of correlation between the two sets of variables. Without loss of generality, initial variables can be assumed to be of unit variance and then their projections are inside a circle of radius 1 centred at the origin. Unit plot was also used to clarify the interpretation of the correlation between variables. The relationships between the two plots (variables and units) drawn on the matching axes can reveal associations between variables and units. In the present experiment regularized CCA was performed on the whole data set and for each group of rabbits separately. The regularization parameters were optimised for each data set as described above.

3. Results and discussion

Leg and back from 32 rabbits per groups were submitted to both sensory and physicochemical analysis. Sensory evaluation revealed significant differences in traits between groups (Table 1). Thus, the combination of genetic background, housing system and feeding intensity produced a limited variability in meat sensory quality. In the back, rabbits from STAND group were more juicy than LABEL ones as assessed by the panellists ($p < 0.05$). For this attribute, rabbit meat from the RUSSE group were not significantly different from the other two. In the leg significant differences were found in tenderness ($p < 0.001$) and juiciness ($p < 0.01$). Leg tenderness decreased in the rank order STAND > LABEL > RUSSE. Leg juiciness was highest in the STAND group and lowest in RUSSE group while LABEL meat was not significantly different from the other two. The effects of several breeding factors on sensory properties of rabbit meat have been previously studied, i.e. genetics (Aravind Reddy, Srinivasa Reddy, Gramakrishna Reddy, & Suresh Reddy, 1990; Her-

Table 1
Sensory attributes of meat of rabbits reared in three different breeding systems RMSE: root mean square error ($n = 96$)

	STAND	LABEL	RUSSE	RMSE	Groups effect
Back					
Fibrous	2.65	2.49	2.58	1.01	NS
Flavour	5.04	4.99	4.99	0.72	NS
Juiciness	3.33[a]	2.45[b]	2.79[ab]	1.04	<0.01
Sticky	1.48	1.48	1.60	0.64	NS
Tenderness	4.68	4.20	4.23	0.87	NS
Leg					
Fibrous	1.68	1.79	2.05	0.80	NS
Flavour	5.58	5.24	5.13	0.75	NS
Juiciness	3.68[a]	3.18[ab]	2.87[b]	1.00	<0.01
Sticky	0.96	0.85	0.88	0.38	NS
Tenderness	5.41[a]	4.78[b]	4.07[c]	0.80	<0.001

[a,b,c]Within a row, least squares means without a common superscript letter differ, $P < 0.05$.

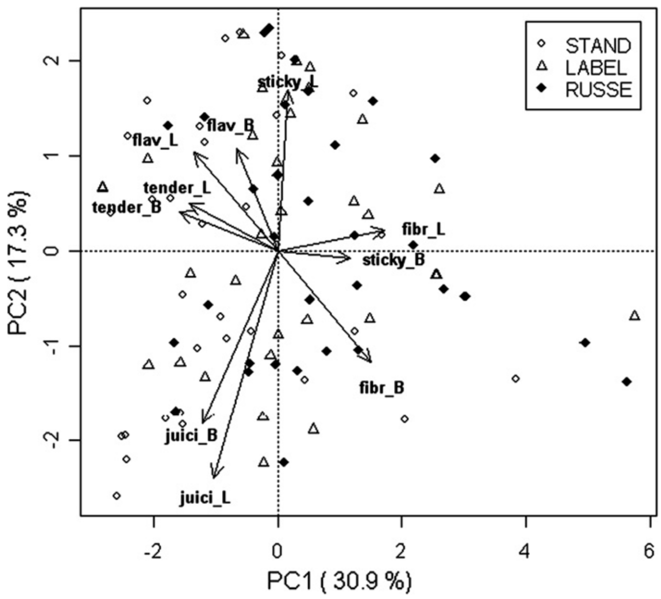

Fig. 1. Principal component analysis similarity map determined by principal components 1 (PC1) and 2 (PC2) of the 10 sensory attributes assessed in the three groups of rabbit (STAND (◇), LABEL (Δ), and RUSSE (♦); $n = 32$ per group). Abbreviations: fibr_B, fibr_L, flav_B, flav_L, juici_B, juici_L, stick_b, stick_L, tender_B and tender_L: fibrous, flavour, juiciness, sticky and tenderness in back and leg, respectively.

Table 2
The means and standard deviations (SD) of the physicochemical variables used in CCA

Variables	Mean	SD	Variables	Mean	SD
Carcass measurements					
WforeC (%)	31.61	1.94	MBR	6.55	0.94
WBackC (%)	52.99	1.93	DM_Fore (%)		
WLegC (%)	15.02	1.04	DM_Leg (%)	34.88	2.78
WPfC (%)	0.86	0.51		26.01	0.87
Meat quality indicators in muscles and carcass parts					
pH_LL	5.81	0.11	pH_BF	5.89	0.13
*LSurf_LL	52.88	3.84	*L_BF	53.62	3.05
*aSurf_LL	3.30	1.65	*a_BF	3.76	1.68
*bSurf_LL	−0.44	2.24	*b_BF	2.94	1.22
*LCSA_LL	54.26	2.79	E_Fore	309.95	14.29
*aCSA_LL	3.76	1.26	E_Leg	329.74	6.75
*bCSA_LL	3.04	0.97	E_LL	608.22	72.33
MC_rLL (%)	73.58	0.98	MC_cLL (%)	65.07	1.06
WHCw_rLL (%)	83.35	3.41	WHCw_cLL (%)	87.42	2.27
WHCm_rLL (%)	61.31	2.27	log(WHCm_cLL) (%)	4.04	0.03
log(WLm_rLL) (%)	2.49	0.20	WLm_cLL (%)	8.19	1.53
			CL_LL (%)	32.14	2.10
Warner-Bratzler shear measurements in muscles					
CSA_rLL (mm^2)	555.30	76.14	TE_rLL (mJ)	878.71	257.87
CSA_cLL (mm^2)	378.46	47.01	Fmax_rLL (N)	44.59	12.86
log(F1_rLL) (N)	3.66	0.23	Stress_rLL (N/mm^2)	0.07	0.02
log(DF1_rLL) (mm)	2.90	0.15	F1_cLL (N)	52.83	13.42
F2_rLL (N)	31.29	8.39	DF1_cLL (mm)	20.61	3.06
DF2_rLL (mm)	26.16	3.03	EF1_cLL (N)	480.10	172.39
log(F3_rLL) (N)	3.71	0.32	TE_cLL (mJ)	858.40	245.29
DF3_rLL (mm)	29.54	2.83	Stress_cLL (N/mm^2)	0.14	0.04
Bone shape and mechanical properties of the femur					
WFC (%)	0.82	0.13	StressYF_F (N/mm^2)	51.69	12.00
WFLeg (%)	5.46	0.89	UF_F (N)	341.09	66.23
Length_F (mm)	82.28	3.09	EUF_F (mJ)	314.95	107.03
dap_F (mm)	6.50	0.45	DUF_F (N)	1.42	0.32
dlm_F (mm)	7.92	0.53	StressUF_F (N/mm^2)	78.77	15.97
MI_F (mm^4)	109.17	28.11			
YF_F (N)	223.55	48.16	Stif_F (N/mm)	428.22	94.91
log(EYF_F) (mJ)	4.16	0.45	Mod_F (N/mm)	2364.66	849.59
DYF_F (mm)	0.58	0.18	Strain_F	0.0254	0.0081

WforeC, WBackC, WlegC, WPfC and WFC: fore, back, leg, perirenal fat, and femur weight to chilled carcass weight ratio; WFLeg: femur weight to leg weight ratio; MBR: Leg meat to bone ratio; DM_Fore, DM_Leg: dry matter of mixed fore part and deboned leg respectively; pH_BF, pH_LL: pH value in BF and LL; *L_BF, *a_BF, *b_BF, *LSurf_LL, *aSurf_LL, *bSurf_LL, *LCSA_LL, *aCSA_LL, *bCSA_LL: CIE L* a* b* in BF, LL surface and LL cross-section area; MC_rLL, MC_cLL: moisture content of raw or cooked LL; WHCw_rLL, WHCw_cLL: Water holding capacity in raw or cooked LL per total water content; WHCm_rLL, WHCv_cLL: Water holding capacity in raw and cooked LL per 100 g muscle; WLm_rLL, WL_cLL: Expressible water loss of raw and cooked LL; CL_LL: LL cooking loss; E_Fore, E_Leg, E_LL: TOBEC value measured in mixed fore part, leg part and in whole LL; CSA_rLL and CSA_cLL: raw and cooked LL cross-section area; F1_rLL, F2_rLL and F3_rLL: WB raw LL shear force value applied at the 1st peak, between 1st and 2nd peak and at the 2nd peak; Fmax_rLL: WB raw LL shear force value applied at the maximum; DF1_rLL, DF2_rLL and DF3_rLL: WB displacement at point F1, F2 and F3 in raw LL; TE_rLL: WB total energy necessary to shear raw LL; Stress_rLL: WB stress in raw LL; F1_cLL: WB cooked LL shear force value applied at the first peak; DF1_cLL: WB displacement at point F1 in cooked LL; EF1_cLL: WB energy at F1 in cooked LL; TE_cLL: WB total energy necessary to shear cooked LL; Stress_cLL: WB stress in cooked LL; Length_F: femur length; dap_F dlm_F: outside antero-posterior and latero-medial femur diameter; MI_F: femur moment of inertia; YF_F and UF_F: Femur yield and ultimate force; EYF_F, EUF_F: Femur energy at yield and ultimate force; DYF_F and DUF_F: Femur displacement at yield and ultimate force; StressYF_F, and StressUF_F and Femur yield and ultimate stress; Stif_F: Femur stiffness; Mod_F: Femur elastic modulus; Strain_F: femur strain.

Table 3
Correlation coefficients between the sensorial canonical variates and the physicochemical canonical variates for whole data set, and for the three groups (STAND, LABEL, RUSSE) considered separately

Dataset	1	2	3	4	5
Dimensions					
Whole	0.726	0.679	0.557	0.553	0.496
STAND	0.751	0.686	0.625	0.549	0.470
LABEL	0.850	0.769	0.740	0.664	0.610
RUSSE	0.875	0.778	0.750	0.650	0.612

nandez et al., 2005), feeding (Dal Bosco, Castellini, Bianchi, & Mugnai, 2004; Hernandez et al., 2000; Ouhayoun, Kopp, Bonnet, Demarne, & Delmas, 1987; Ramirez et al., 2004), age at slaughter (Gondret, Juin, Mourot, & Bonneau, 1998; Jehl & Juin, 1999),weight at slaughter (Roiron, Ouhayoun, & Delmas, 1992; Xiccato, Parigi-Bini, Dalle-Zotte, & Carazzolo, 1994), transportation (Xiccato et al., 1994) and Label (Combes, Jehl, Juin, Cauquil, & Lebas, 2002) or organic techniques (Combes et al., 2003a). Their respective influence on sensory traits in rabbit meat remains conflicting. This could be explained by several points. It can be related to differences in cooking procedure among the studies (Combes, Lepetit, Darche, & Lebas, 2003b; Dal Bosco, Castellini, & Bernardini, 2001). In addition rabbit carcasses are relatively small (1.3 kg) compared with other animals. It is thus difficult to obtain several similar samples for sensory analysis. Moreover, each study corresponded to a particular combination of breeding factors and was performed only once.

PCA was applied to the sensory data in order to investigate the relationships between the variables (Fig. 1). According to the principal component 1 (PC1), that accounted for 30.9% of the total variance, tenderness in leg and back were opposite to attributes sticky in the back and fibrous in the leg. Similarly, the attribute sticky in the leg was opposed to juiciness in the back and in leg according to the PC2. Tenderness, juiciness and flavour measured in back were respectively close to the same attributes measured in leg thus indi-

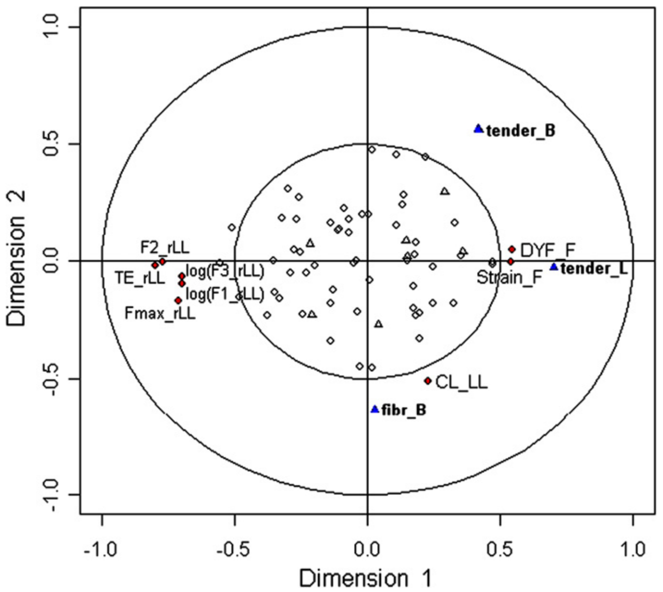

Fig. 2. Canonical correlation analysis similarity map determined by the canonical variates 1 and 2 for physicochemical measurements data (◇) and sensory attributes (Δ) of rabbit meat from three different breeding systems ($n = 96$). Abbreviations are given for variables with canonical coefficient higher than 0.5: tender_L, tender_B: tenderness in leg and back, respectively; fibr_B: fibrous in back; Strain_F: femur strain; DYF_F: femur displacement at yield force; F1_rLL, F2_rLL, F3_rLL: WB raw LL shear force value applied at the first peak between 1st and 2nd peak and at the 2nd peak, respectively; Fmax_rLL: WB raw LL shear force value applied at the maximum; TE_rLL: WB total energy necessary to shear raw LL; CL_LL: LL cooking loss.

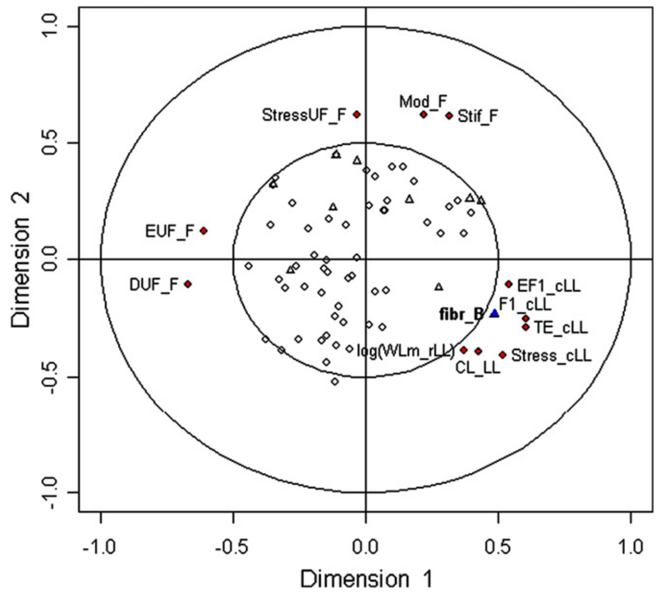

Fig. 4. Canonical correlation analysis similarity map determined by the canonical variates 1 and 2 for physicochemical measurements data (◇) and sensory attributes (Δ) of rabbit meat from the STAND group ($n = 32$). Abbreviations are given for variables with canonical coefficient higher than 0.5: fibr_B: fibrous in back; DUF_F, EUF_F and StressUF_F: Femur displacement, energy and stress at ultimate force, respectively; Mod_F: Femur elastic modulus; Stif_F: Femur stiffness; F1_cLL and EF1_cLL: WB energy and shear force value applied at the first peak in cooked LL; TE_cLL: WB total energy necessary to shear cooked LL; Stress_cLL: WB stress in cooked LL; WLm_rLL: Expressible water loss of raw LL; CL_LL: LL cooking loss.

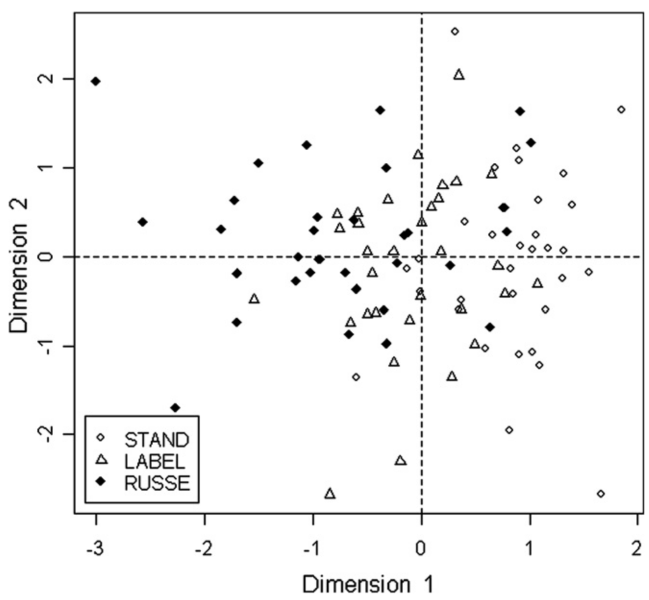

Fig. 3. Projection of the data of the three groups of rabbit (STAND (◇), LABEL (Δ), and RUSSE (♦)) on the plane determined by the canonical variates 1 and 2.

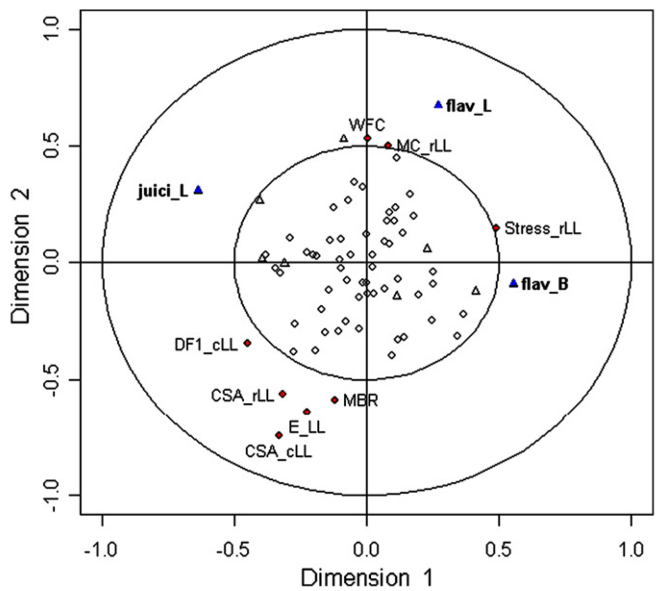

Fig. 5. Canonical correlation analysis similarity map determined by the canonical variates 1 and 2 for physicochemical measurements data (◇) and sensory attributes (Δ) of rabbit meat from the LABEL group ($n = 32$). Abbreviations are given for variables with canonical coefficient higher than 0.5: juicy_L: juiciness in leg; flav_L and flav_B: flavour in leg and back, respectively; CSA_rLL and CSA_cLL: raw and cooked LL cross-section area, respectively; E_LL: TOBEC value measured in whole LL; MBR: Leg meat to bone ratio; DF1_cLL: WB displacement at point F1 in cooked LL; Stress_rLL: WB stress in raw LL; MC_rLL: moisture content of raw LL; WFC: femur weight to chilled carcass weight ratio

cating that those three attributes described the same sensation in each retail cut. The angle between the sensory evaluation in leg and in back for sticky and fibrous attributes demonstrated oppositely that both attributes did not describe the same sensation.

On the same sample, 63 traits were measured or calculated, as weight of retail cuts, colour parameters, ultimate pH, femur flexure test, Warner-Bratzler shear test, moisture content, water holding capacities and cooking losses (Table 2). All types of physicochemical measurements used in this study were simple, easily measurable and could be performed within a 24 h period. Their ability to discriminate rabbit meat originating from the three breeding systems has already been published (Combes et al., 2007). In the present paper we attempted to evaluate the relationship between physicochemical traits and sensory characteristics. Typically, simple analytical measures are poorly correlated with sensory attributes (Hernandez et al., 2000). In our experiment, the highest Pearson correlation coefficients between the analytical and sensory variables were −0.58 for tenderness in leg and WB total energy to shear raw LL (data not shown). CCA made it possible to highlight higher correlations between canonicals. In the whole data set (including the three groups) the correlation coefficients between the sensory canonical variates and the physicochemical corresponding ones are given in Table 3. The correlations indicated that the subspace defined by the two first canonical variates (0.73 and 0.68) were the most informative to represent correlation between traits. Relationship between the 63 physiochemical variables and sensory traits are mapped in Fig. 2. Only three sensory attributes could be related to physicochemical traits: tenderness in back and leg and fibrous in back. The fibrous attribute in back was highly correlated to cooking loss measured in LL. Leg and back sensory tenderness were opposed to Warner-Bratlzer (WB) shear test parameters measured in raw back and positively related to bone strain and elasticity characteristics. Although the relationships between WB shear test measurements and sensory perception of tenderness were expected, these relations were more likely expected in cooked muscle (Peachey, Purchas, & Duizer, 2002) rather than in raw muscle for WB shear test measurement. In a previous study on rabbit meat, significant differences between groups of rabbits were observed in WB shear test parameters assessed on raw meat but not on cooked meat (Cauquil et al., 2001). It is well known that meat tenderness is related to myofibre and connective tissue structure of muscle and their interactions (Lepetit, Grajales, & Favier, 2000). The high heat-solubility of collagen in rabbit meat (Combes et al., 2003b) could explain the lower ability of cooked meat WB parameters to describe variability in sensory tenderness. Sensory tenderness was also related to femur mechanical parameters such as strain and elasticity characteristics. One explanation of this association could be that both variables were able to describe rabbit physiological maturity. In our experiment, the combination of genetic background, housing system and feeding intensity allowed production of rabbits slaughtered at the same weight (2.3 kg) but with a physiological maturity (defined as the ratio between slaughter weight to adult weight) of 51%, 63% and 85% for STAND, LABEL and RUSSE rabbits, respectively. This physiological maturity gradient is illustrated by the projection of the data on the plane define by the canonical variates 1 and 2 (Fig. 3). The first canonical variate opposed STAND and RUSSE rabbits, LABEL rabbits having an intermediate position. Moreover, WB total energy to shear raw LL and physiological maturity exhibited Pearson correlation coefficients of −0.57. Altogether these results confirmed that the canonical correlation structure between sensory data set and physicochemical data were related to physiological maturity of rabbits.

Considering the significant differences observed between groups for three out of 10 sensory attributes, we attempted to examine whether the relationships between physicochemical and sensory were similar for each group of rabbits. CCA analyses were performed considering the three groups separately. For each group, the correlation coefficient between the sensory canonical variates and the physicochemical corresponding ones are given in Table 3. The highest canonical correlation coefficients were observed for the RUSSE data set ($r = 0.87$) while the STAND data set exhibited the worst ($r = 0.75$). Relationships between the 63 physiochemical variables and sensory traits for each group are mapped in Figs. 4–6. The high value of the canonical correlation coefficients suggest close relation between physicochemical variables and sensory attributes. However from the three figures it can be observed that those relationships seemed to be group-specific. Interestingly, only RUSSE rabbits exhibited the same close similar relationships between WB variables and sensory tenderness (Fig. 6) as those observed in the whole data set (Fig. 2).

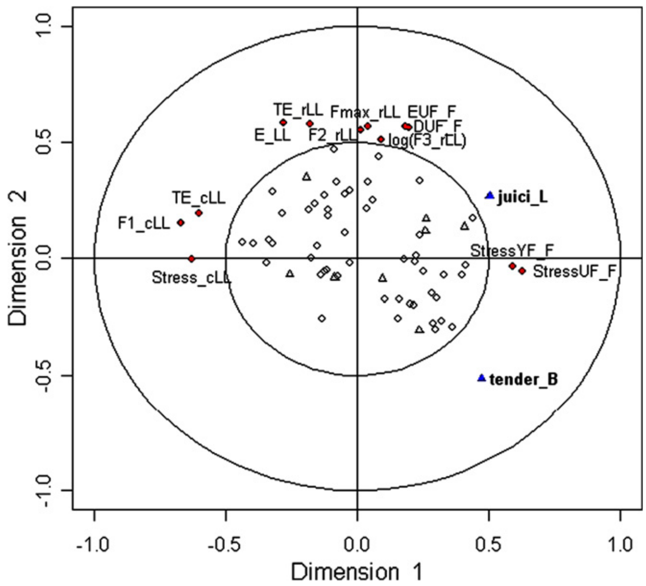

Fig. 6. Canonical correlation analysis similarity map determined by the canonical variates 1 and 2 for physicochemical measurements data (◇) and sensory attributes (Δ) of rabbit meat from the RUSSE group ($n = 32$); abbreviations are given for variables with canonical coefficient higher than 0.5: tender_B: tenderness in back; juicy_L: juiciness in leg; F1_cLL: WB shear force at F1 in cooked LL; TE_cLL: WB total energy necessary to shear cooked LL; Stress_cLL: WB stress in cooked LL; E_LL: TOBEC value measured in whole LL; F2_rLL and F3_rLL: WB raw LL shear force value applied between 1st and 2nd peak and at 2nd peak, respectively; Fmax_rLL: WB raw LL shear force value applied at the maximum; TE_rLL: WB total energy necessary to shear raw LL; DUF_F and EUF_F: Femur displacement and energy at ultimate force, respectively; StressYF_F and StressUF_F: Femur yield and ultimate stress, respectively.

4. Conclusion

The regularized extension of CCA was efficient in describing the relationships between numerous physicochemical variables and sensory attributes in rabbit meat. This study demonstrates that simple physicochemical variables such as WB shear test parameters and three points flexure test parameters were able to describe sensory attributes of rabbit meat. Nevertheless, these relationships could not be generalized within groups.

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