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The use of multivariate analysis for evaluating relationships among fat depots in heavy pigs of different genotypes

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Abstract

The aim of the present work was to study distribution and reciprocal relationships of fat depots in heavy pigs of several genetic types. On 161 barrows and gilts belonging to four genetic types (Large White and relative crosses with Italian Landrace, Belgian Landrace and Duroc), slaughtered from 125 to 180 kg l.w., thickness, colour (C.I.E, L^* , a^* , b^*) and weight of backfat and of kidney fat were determined. Subcutaneous and intermuscular fat of ham were weighed. On *biceps femoris*, *semimembranosus* and *semitendinosus* muscles ether extract content was determined. Allometric analysis showed that body growth did not particularly increase the intramuscular fat content of the ham. Principal component analysis indicated that PC1 (0.43% of variation) represented the overall fatness, associated all the depots in a similar manner, and was linked to body weight and sex. PC2 (0.22% of variation), linked to genotypes and body weight, expressed the opposition between intramuscular fat deposition and subcutaneous and internal fat accumulation. Using measurements easily recorded on the side (backfat thickness and colour, percent kidney fat), only the estimate of subcutaneous fat, among ham depots, showed good accuracy ($R^2=0.65$). © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Fat depot; Heavy pig; Ham fat; Multivariate analysis

1. Introduction

Concerning fat distribution in pig carcass, many studies have shown a fairly uniform and consistent picture of the evolution of individual depots during growth (subcutaneous fat in various body sites, kidney fat, intermuscular and intramuscular fat) in relation to factors such as genetic type, sex, and feeding level (Davies & Pryor, 1977; Geri, Franci, Zappa, & Campodoni, 1984; Kempster & Evans, 1979; Walstra, 1980; Wood, Whelehan, Ellis, Smith, & Laird, 1983).

The reciprocal relationships between fat depots have also been the subject of several investigations, but the results, especially as regards correlations between subcutaneous and inter/intramuscular fat, appear contradictory even in the most recent works (Cameron, 1990; Cameron, Nute, Brown, Enser, & Wood, 1999; Hovenier,

Kanis, van Asseldonk, & Westerink, 1992; Kolstad, Jopson, & Vangen, 1996; Sonesson, de Greef, & Meuwissen, 1998; Villé et al., 1997). Even though backfat thickness has always been the selective criterion for reducing fatness in pigs, and it is routinely used in commercial carcass evaluations to estimate general fatness (or its complement lean meat; Cook, Chadwick, & Kempster, 1989; Diestre, Gispert, & Oliver, 1989; Russo et al., 1989), yet the effectiveness of such estimates are certainly due to the fact that backfat thickness values measure the subcutaneous fat depot, which in pigs is more than two-thirds of the entire body fat (Wood et al., 1983). Disagreement still remains, however, regarding the interrelations between individual fat depots. Jones, Richmond, Price, and Berg (1980) took the view that the partition of fat between depots in pigs may be changed as the result of selection for leaner carcasses, while Wood et al. (1983) did not find such a relocation of body fat from subcutaneous to other sites.

In view of the different commercial importance of the various fat depots, and in view of the effect of

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intramuscular fat on the organoleptic characteristics of the meat (Wood, Jones, Francombe, & Whelehan, 1986), a better understanding of relationships between pig fat depots is necessary. This need is particularly acute in Italian pig production, which uses heavy pigs, normally not studied in foreign reports, and which is particularly geared to ham production, the tissue components of which are but rarely studied even though here the fat is fundamental for the quality of the seasoned product.

The interrelations between various measurements, especially those relating to meat quality, are often studied by multivariate analysis (Næs, Baardseth, Helgesen, & Isaksson, 1996). Amongst these techniques, the use of principal component analysis (PCA) for evaluating pig meat quality (De Vries, van der Wal, Long, Eikelenboom, & Merks, 1994; Karlsson, 1992) has made possible a closer examination of underlying factors and relationships between the original variables, but there have been no corresponding studies on the individual fat depots.

The aim of the present work was to study, using multivariate analysis, the distribution and relations between some fat depots in the carcass, especially in the ham, of heavy pigs from the most common genotypes in Italy.

2. Materials and methods

A total of 161 pigs, castrated males and females, of four genetic types obtained from 38 Large White sows mated with 4 Large White (LW), 4 Italian Landrace (IL), 4 Belgian Landrace (BL) and 4 Duroc (D) boars were used in the study. Number of animals, age, live weight and carcass weight for each genetic type are shown in Table 1. Further details on the experimental design and on the results concerning comparison among the genetic types are given in previous works (Franci, Pugliese, Acciaioli,

Poli, & Geri, 1994a; Franci, Pugliese, Bozzi, Parisi, Acciaioli, & Geri, 1994b; Franci et al., 1995). According to the original plan, equal numbers of pigs in medium (130 kg) and heavy (160 kg) weight classes were to have been slaughtered but the actual weights at slaughter varied around the planned weight, as shown in Fig. 1.

One hour after slaughter, along the line of separation of the half-carcasses, thickness of outer and inner layer of backfat, at the first and last thoracic vertebra and at *gluteus medius* muscle, was measured and colour parameters (C.I.E., L^* , a^* , b^*) on the inner layer of backfat at last thoracic vertebra were determined. Right sides were dissected into the main commercial cuts. Among the commercial cuts, in this study only backfat and kidney fat were considered as indicators of carcass fatness, the former for the subcutaneous depot, the latter for the internal depot. Trimmed right ham was dissected and subcutaneous fat including skin (HSFat), intermuscular fat (HIFat), bone and individual muscles were weighted. On *biceps femoris*, *semimembranosus* and *semitendinosus* muscles, ether extract content was determined (AOAC, 1980) and hence the total fat in each muscle was calculated. The sum of fat of the three muscles was considered intramuscular fat of the ham (HMFat).

Relative growth of the fat depots weight on carcass weight was studied using the allometric equation (Huxley, 1932), linearised by logarithmic transformation of the data, applying the following model:

$$\text{Log } Y_{ijk} = \text{Log } a + G_i + S_j + b^* \text{Log } \text{CARCASS}_{ijk} + E_{ijk}$$

where Y is the weight of the depot of k th animal, $\text{log } a$ the intercept, G the effect of the i th genetic type, S the effect of the j th sex, b the regression coefficient on carcass weight (allometric coefficient), and E the random error.

Table 1
Weights, age and weight gain of the experimental subjects

	Genetic type				Overall
	LW	IL×LW	BL×LW	D×LW	
No. of animals	39	42	41	39	161
Barrows–gilts	21–18	20–22	20–21	18–21	79–82
<i>Slaughter age (days)</i>					
Mean±S.D.	307±37	300±28	298±42	296±44	300±38
Minimum–maximum	238–406	253–359	245–403	233–385	233–406
<i>Live weight (kg)</i>					
Mean±S.D.	149.1±17.1	149.6±15.7	147.4±16	147.7±15.7	148.5±16
Minimum–maximum	124–183	126–179	125–180	126–175	124–183
<i>Carcass weight (kg)</i>					
Mean±S.D.	118.6±14.6	117.3±14.7	118.1±14.5	117.8±13.3	118±14.2
Minimum–maximum	94–146	92–142	93–144	98–139	92–146
<i>Weight gain (g/day; 100 day - slaughter)</i>					
Mean±S.D.	609±76	612±63	624±68	605±70	613±69
Minimum–maximum	453–770	472–775	456–771	466–760	453–775

Relations between variables were studied with PCA using the PROC FACTOR of SAS (1996). Equations to estimate the proportions of various fat depots of the ham, using measurements easily taken on the carcass, were performed with multiple regression analysis, applying the stepwise method to choose the independent variables to be maintained in the model ($P < 0.1$).

3. Results and discussion

3.1. Allometric growth

As shown in Table 1 the range of slaughter weights reflects the commercial categories of Italian pig production, which is based on animals of medium–heavy weight. The relation between weight of individual fat depots and carcass weight was studied with the allometric equation (Table 2). Preliminary analyses with more complex models excluded a possible effect of age at slaughter. Also, the second degree regression coefficient on carcass weight in the logarithmic equation and the interaction between carcass weight and genetic type were not significant. The analysis of the allometric coefficients showed that, as expected, all the fat depots grew faster than the carcass. The R^2 values, generally modest, and the rather high standard error of some coefficients, especially for HMFat, indicated that a large

part of the variation was not explained by the model. Irrespective of the statistical significance, backfat and kidney fat increased their relative weight more than ham fat depots, among which intermuscular fat was the latest. Intramuscular fat, in particular, exhibited the lowest allometric coefficient (statistically not different from unity) indicating that in this developmental range the increase of body weight did not notably increase the fat content in ham muscles, confirming the results of Geri et al. (1984). These researchers also found that trunk fat was later developing than ham fat depots, but unlike the findings of the present study, they found in ham a faster growth rate of subcutaneous than intramuscular and intermuscular fat, in that order. In more extensive developmental ranges, Kempster and Evans (1979) and Walstra (1980) found later growth of perirenal fat than of subcutaneous and intermuscular fat, in that order.

Generally barrows had a greater proportion of all fat depots than gilts, as expected, while the comparison between genotypes showed more limited differences, due to higher percentage of backfat and kidney fat in carcasses of IL×LW. No significant differences for ham fat emerged although Duroc crosses had almost 10% more intermuscular fat than the other genetic types and, as LW pigs, the highest level of intramuscular fat. Reports comparing these breeds, both pure and crossbred, are contradictory for backfat which resulted in higher percentage (Blanchard, Warkup, Ellis, Willis, & Avery,

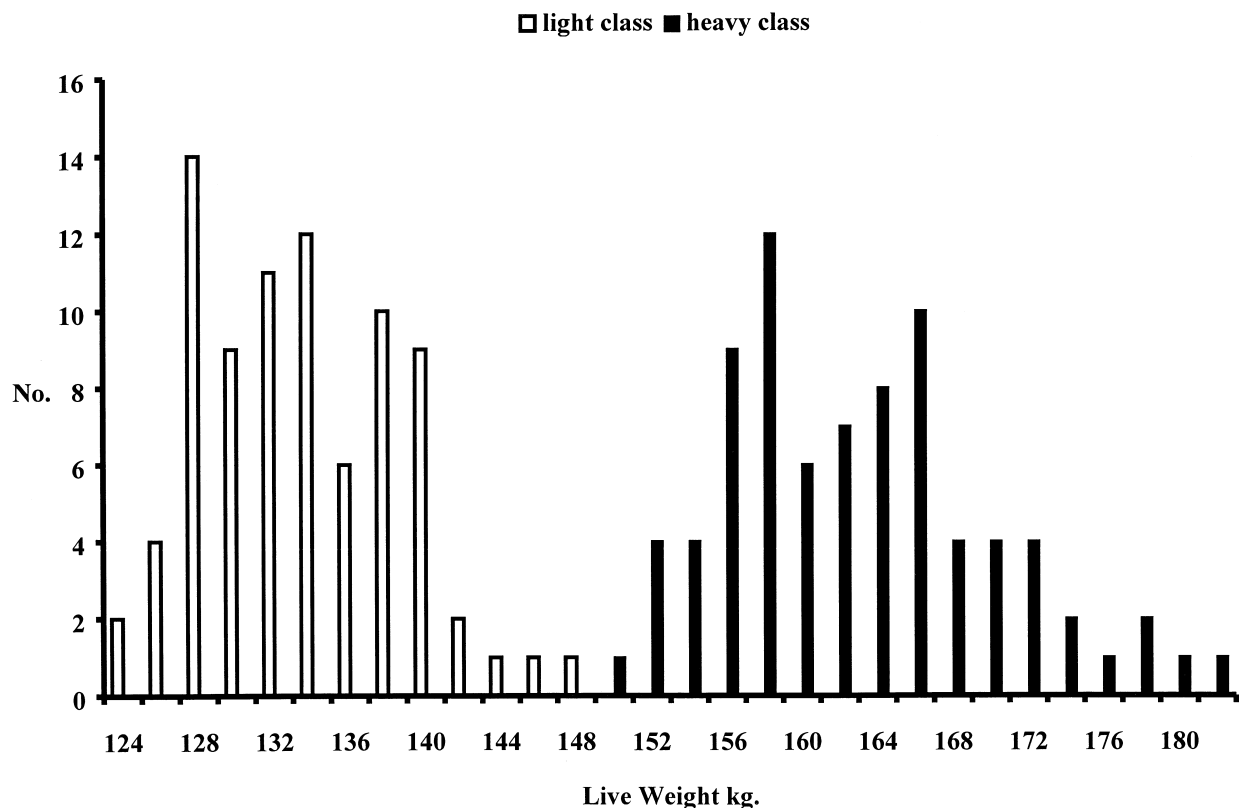


Fig. 1. Distribution of slaughter weights of the experimental subjects.

1999; Edwards, Wood, Moncrieff, & Porter, 1992; Hovenier et al., 1992), at equal level (Kolstad et al., 1996; Simpson, Webb, & Dick, 1987) or in lower percentage (Cameron, 1990; Lo, McLaren, McKeith, Fernando, & Novakofski, 1992; McGluoghlin, Allen, Tarrant, Joseph, Lynch, & Hanrahan, 1988) in Duroc than in Landrace and Large White. Results concerning other depots are more consistent, with higher levels of internal fat in Landrace than in Duroc, Large White and Belgian Landrace (Bout, Girard, Runavot, & Sellier, 1989; Kolstad et al., 1996), and with the highest levels of intermuscular and/or intramuscular fat in Duroc and Duroc-sired pigs (Blanchard et al., 1999; Cameron, 1990; Edwards et al., 1992; Hovenier et al., 1992; Kolstad et al., 1996; Lo et al., 1992; McGluoghlin et al., 1988; Simpson et al., 1987; Warriss, Brown, Franklin, & Kestin, 1990). However, these reports refer to the light pig and use the *longissimus dorsi* as sample muscle, and this may in part explain the less than perfect correspondence with the present findings, among which, in particular, it is surprising the same value of intramuscular fat for LW and Duroc-sired pigs. However, it must be noted that intramuscular fat content showed high individual variation, only partially explained by the model effects.

3.2. Analysis of principal components

Table 3 shows the parameters of multivariate analysis for the percentage of the fat depots. It should be noted that percent backfat and percent kidney fat are expressed on the carcass, percent HSFat and percent HIFat on the ham, and percent intramuscular fat on the respective muscle. The first three PCs explained a large proportion of the variation (75%), indicating a strong association among the traits. Factor1 can represent the general fatness of the carcass and associated all the depots with similar degree of intensity. Almost all variables showed

the greatest loading with Factor1. Factor2, which explained more than 20% of variance, expressed the opposition between the accumulation of subcutaneous (backfat and HSFat) and internal fat on the one hand, and the deposition of fat within the muscle on the other. Furthermore, HIFat showed a loading coefficient modest but in line with intramuscular fat. Finally Factor3, which also explained a quite considerable amount of variation (about 10%), basically expressed, after the associations from the first two factors, the opposition between intermuscular fat of the ham and the fat of some representative muscles (*semitendinosus*, *semimembranosus*).

Fig. 2 graphically shows the values of the first two factors for individual pigs, identified by the combination of weight class (medium, heavy) and sex. As regards Factor1, positive values were mainly obtained by heavy castrated males, which therefore were characterised by greater overall fatness, while for Factor2 higher values, indicating a greater proportion of intramuscular than subcutaneous and internal fat, were shown mainly by the lighter pigs, irrespective of sex, in agreement with the pattern of allometric development described above. The graph on the combination of weight class and genotype (Fig. 3) did not show clear distinctions between genetic types for Factor1 but revealed a greater frequency of LW and D×LW pigs with high values of Factor2.

Covariance analysis (Table 4) for Factors1-3, as calculated by PCA, corroborates what is displayed in Figs. 2 and 3. The significant effect of carcass weight and sex on Factor1, and the relative estimates, indicate that overall fatness was greater in the heavier carcasses and in castrated males. The effect of carcass weight and genetic type on Factor2, on the other hand, revealed that in the lighter carcasses and in LW and D×LW pigs there was a preferential partition of fat towards the muscles rather than towards the subcutaneous and internal sites. This confirmed the results of Table 2, which, concerning the individual depots, allowed only an approx-

Table 2
Allometric coefficient and estimated least squares means of some fat cuts and depots weight (g) on carcass weight

	All. coeff.—S.E.	l.s. mean ^a		Genetic type ^b				R ²
		Gender						
		Barrows	gilts	LW	IL×LW	BL×LW	D×LW	
<i>Fat cut of side</i>								
Backfat	1.597 ± 0.142	3280a ^d	2812b	2900b	3265a	3046	2949b	0.491
Kidney fat	1.611 ± 0.193	862a	665b	789b	901a	653c	707bc	0.448
<i>Of trimmed ham</i>								
Subcutaneous fat	1.341 ± 0.082	2223a	2093b	2127	2208	2207	2089	0.641
Intermuscular fat	1.473 ± 0.138	388a	361b	362	376	365	395	0.44
Muscular fat ^c	1.256 ± 0.215	97	89	101	88	86	98	0.223

^a Estimated at the geometric mean of carcass weight (117.116 kg).

^b Respectively Large White; Italian Landrace × Large White; Belgian Landrace × Large White; Duroc × Large White.

^c As sum of intramuscular fat of *Biceps femoris*, *Semimembranosus* and *Semitendinosus*

^d a, b, c, Means within criterion with different letters are different at $P < 0.05$.

imate explanation of genotypic differences. Factor3 was not affected by the factors studied.

Multivariate analysis allows the relationships existing between the various fat depots to be shown in a situation where their development is variously conditioned by genetic and environmental factors, as here, and made it easier to understand the often contradictory results reported in previous works that investigated the correlations between subcutaneous, intermuscular and intramuscular fat in the pig. Kolstad et al. (1996) found high positive correlations between subcutaneous and

inter/intramuscular fat in pigs fed at maintenance in line with the findings of Cameron (1990) on pigs fed ad libitum. Positive but modest genetic and phenotypic correlations between the same depots (0.37 and 0.30, respectively) were reported by Hovenier et al. (1992). Sonesson et al. (1998) also found low phenotypic (0.13) and genetic (0.31) correlations between backfat thickness and marbling score of LD muscle. Villé et al. (1997), on the other hand, did not find any significant correlations between intramuscular fat and backfat thickness. Lastly, for Cameron et al. (1999) responses in intramuscular fat content and carcass fat had the same sign in pig lines selected for rate or efficiency of lean growth, but higher muscular fat content was found in the leanest carcasses in the selection line for daily food intake. The present study confirms that intramuscular fat, which has been associated with the eating quality of meat (Bejerholm & Barton-Gade, 1986; Wood et al., 1986), seems only partly linked to overall fatness, and this, as Hovenier et al. (1992), Villé et al. (1997) and Warriss et al. (1990) stated, made possible the combined selection for low backfat and high intramuscular fat content. Moreover, the findings of the present study showed that this relative independence was mainly due to breed differences.

In subsequent PC analysis, some backfat measurements, feasible on the half carcass (thickness and colour parameters), were subjected to multivariate analysis with percentages of fat depots (Table 5). Factor1, which

Table 3
Eigenvalue and eigenvectors in the factors analysis for the major fat cuts and depots percentages

	Factor1	Factor2	Factor3
Eigenvalue	3.011	1.553	0.691
Proportion	0.43	0.222	0.099
Cumulative	0.43	0.652	0.751
<i>Eigenvector</i>			
Backfat ^a	0.647	-0.575	0.187
Kidneyfat ^a	0.688	-0.426	0.034
Subcutaneous fat of ham ^b	0.781	-0.446	0.096
Intermuscular fat of ham ^b	0.665	0.149	-0.682
<i>Biceps femoris</i> fat ^c	0.666	0.433	-0.129
<i>Semimembranosus</i> fat ^c	0.531	0.585	0.292
<i>Semitendinosus</i> fat ^c	0.585	0.539	0.282

^a Percentage on side.

^b Percentage on trimmed ham.

^c Percentage of ether extract on the muscle.

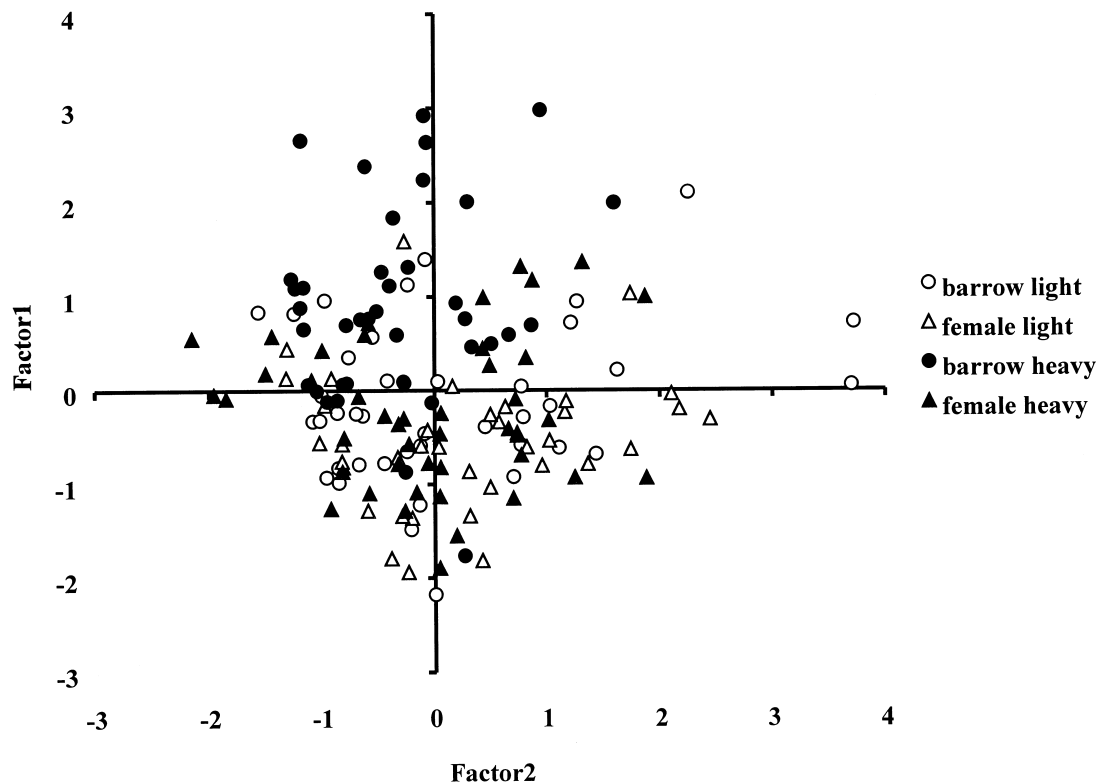


Fig. 2. Values of the first two Factors according weight class and sex of pigs.

explained 37% of the variation, again represented an indicator of overall fatness in which the greatest weight is attributed to subcutaneous fat (thickness and percentage of backfat and HSFat). Among the thickness measures, the most caudal and those of outer layer showed the highest loading coefficient. Colour parameters furnished an important but negative contribution indicating that the fatness of carcass was detected by less light and less coloured subcutaneous fat. Inter/intramuscular fat depots had lower loading coefficients for this first factor and achieved their greatest contribution with Factor2, which still explained 13% of variation. Factor2, in particular, combined muscular fat depots and *b* parameter of colour and seemed to indicate that, at the same overall fatness, the partition that favours intra/intermuscular fat in the ham is linked to more highly coloured sub-

cutaneous fat, especially as regards the yellow component. In Factor2 there is also the opposition, reinforced in Factor3, between the thickness of the two different layers at the same location, showing that backfat growth is possible by one of the two layers developing more strongly than the other. This confirms the relative independence of backfat development at various locations as reported by Geri, Zappa and Franci (1986) and Wood et al. (1983).

3.3. Estimate of ham fat content

The use of equations to estimate the composition of pig carcasses has become widespread at the operational level. However, the papers that have recommended their use (Cameron, 1990; Cook et al., 1989; Diestre et al.,

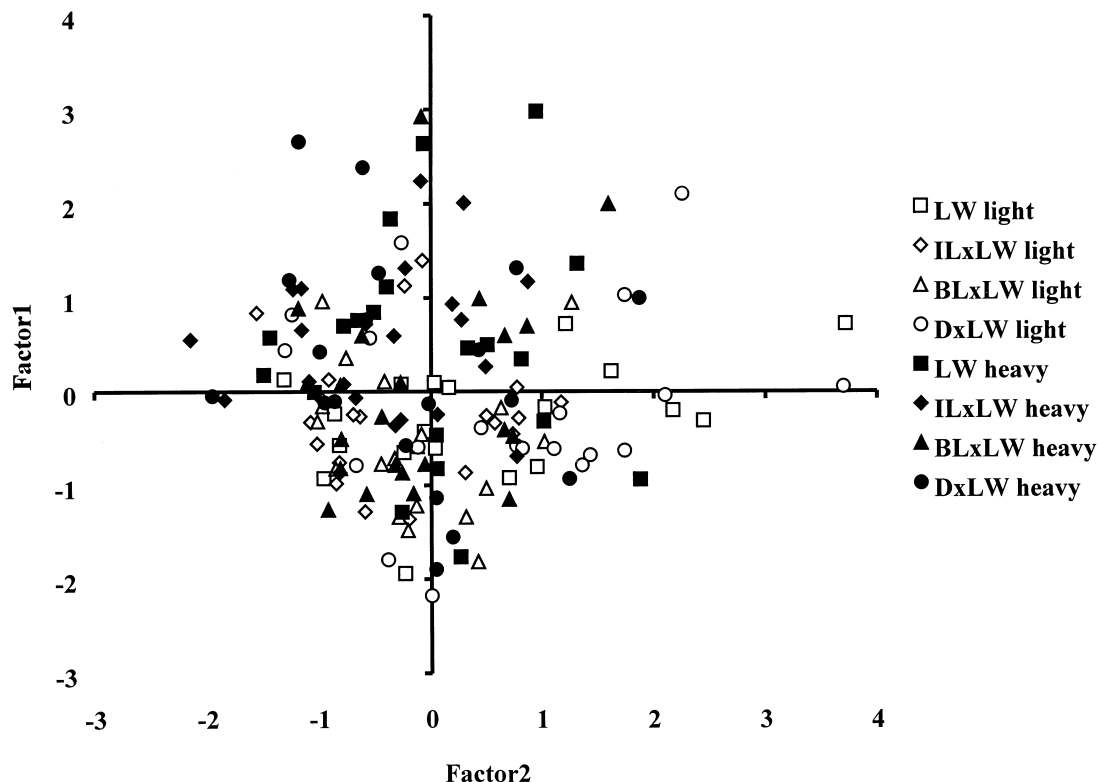
Table 4
Effect of gender, genotype and carcass weight on the first three factors^a

	Gender		<i>P</i> ^c	Genetic type ^b				<i>P</i>	Carcass weight		r.s.d.
	Barrow	Gilt		LW	IL×LW	BL×LW	D×LW		<i>b</i> ±S.D.	<i>P</i>	
Factor1	0.396	−0.381	**	0.032	0.186	−0.262	0.074	0.1	0.023±0.005	**	0.863
Factor2	−0.097	0.11	n.s.	0.26 a	−0.36 b	−0.129	0.255 a	**	−0.012±0.005	**	0.96
Factor3	0.036	−0.036	n.s.	0.212	0.052	−0.023	−0.24	n.s.	−0.009±0.005	n.s.	0.994

^a From Table 3.

^b Respectively Large White; Italian Landrace × Large White; Belgian Landrace × Large White; Duroc × Large White. Means with different letters are significantly different ($P < 0.05$).

^c ** $P < 0.01$; ns, not significant.



1989; Russo et al., 1989) have been limited to estimates of overall fatness or overall lean content. In the present work equations are proposed to estimate fat content in ham, which in Italian pig production is the most valuable product (Table 6). As independent variables thickness and colour parameters of backfat and percentage of kidney fat were considered since this last was easily separable during carcass dressing. For backfat thickness it was preferred to use the measurements of outer and inner layers separately because the equations thus obtained produced higher R^2 values than equations that used their combined measurement.

R^2 values indicate that in the ham, only the estimate of the amount of subcutaneous fat had good accuracy, while intramuscular fat content, especially in *semimembranosus* and *semitendinosus*, could not be predicted.

The most frequently recurring independent variables were Kfat% and the thickness of both layers at the last rib, which thus seems to be the most predictive backfat measure, confirming other works that used the thickness of backfat at mid-loin to estimate the carcass fatness (Cook et al., 1989; Diestre et al., 1989; Russo et al., 1989). For HSFat% estimate, however, thickness at *gluteus medius* assumed particular importance, probably because this location is near (or basically belongs) to subcutaneous fat of ham, but the colour component L , statistically the second most predictive independent variable, was also of interest in view of their easy recording on the side. Finally, the marginal predictive role of carcass weight, which is in accordance with the findings of Cameron (1990), should also be noted.

Table 5

Eigenvalue and eigenvectors in the factors analysis for backfat thickness and colour parameters and fat cuts and depots percentages

	Factor1	Factor2	Factor3
Eigenvalue	5.872	2.112	1.272
Proportion	0.367	0.132	0.08
Cumulative	0.367	0.499	0.579
<i>Eigenvector</i>			
<i>Backfat thickness</i>			
First thoracic outer layer	0.597	0.211	0.51
First thoracic inner layer	0.473	-0.299	-0.308
Last thoracic outer layer	0.699	0.21	0.474
Last thoracic inner layer	0.66	-0.114	-0.144
<i>Gluteus medius</i> outer layer	0.818	-0.038	0.201
<i>Gluteus medius</i> inner layer	0.681	-0.231	-0.145
<i>Backfat colour</i>			
L^*	-0.542	0.215	-0.125
a^*	-0.449	0.252	0.453
b^*	-0.558	0.466	0.221
Backfat ^a	0.814	-0.252	0.044
Kidneyfat ^a	0.68	-0.06	-0.091
Subcutaneous fat of ham ^b	0.838	-0.038	0.076
Intermuscular fat of ham ^b	0.48	0.507	0.118
<i>Biceps femoris</i> fat ^c	0.436	0.628	-0.161
<i>Semimembranosus</i> fat ^c	0.282	0.638	-0.365
<i>Semitendinosus</i> fat ^c	0.316	0.642	-0.389

^a Percentage on side.

^b Percentage on trimmed ham.

^c Percentage of ether extract on the muscle.

4. Conclusions

The allometric study showed that growth patterns of fat depots in pigs, already known from studies on earlier development periods, remained substantially valid also for the weight range of primary interest in Italian pig production (125–180 kg l.w.) Furthermore, in this range, body growth did not particularly increase the intramuscular fat of the ham, but, if anything, the intermuscular depot.

The use of multivariate analysis allowed a better understanding of the reciprocal relations between the various fat depots, especially of the ham, in a variable situation determined by factors such as genetic type, sex and body growth. There seemed to exist an overall fatness that affected all individual depots in a similar manner, particularly linked to body weight and sex. The partition and the relative weight of individual depots, however, favoured intramuscular fat at the expense of subcutaneous and internal fat in some genotypes (specifically LW and Duroc-sired pigs) and in the lighter pigs. In the development of backfat, on the other hand, a certain opposition between the contributions of outer and inner layer seemed evident.

Table 6

Estimate equations of fat depots percentage of trimmed ham using some measures taken on half carcass

Equation ^a	R^2	r.s.d.	C(p) ^b
HSFat% = 24.71 + 0.248*GMOL - 0.214*L + 1.517*KFat% + 0.195*GMIL + 0.218*FTOL - 0.037*CARC	0.653	1.836	3.65
HIFat% = 0.671 + 0.116*LTOL + 0.430*KFat% + 0.114*b	0.256	0.646	2.68
BfFat% = -0.039 + 0.177*LTOL + 0.052*LTIL - 0.068*GMOL + 0.288*KFat%	0.172	0.923	4.97
SmFat% = 1.444 + 0.115*LTOL - 0.0135*CARC + 0.036*LTIL	0.071	1.002	1.28
StFat% = -0.241 + 0.823*KFat% + 0.094*LTIL + 0.469*b	0.099	1.77	1.47

^a The independent variables are listed according to decreasing value of partial statistic F; HSFat% = Subcutaneous fat of ham; HIFat% = Intermuscular fat of ham; BfFat%, SmFat%, StFat% = Ether extract of *Biceps femoris*, *Semimembranosus*, *Semitendinosus*; CARC = Carcass weight (kg); KFat% = percentage of kidney fat; FTOL, LTOL, LTIL, GMOL, GMIL = Backfat thickness (mm) of outer layer (OL) or inner layer (IL) at first (FT), last (LT) thoracic vertebra or at *gluteus medius* (GM); L, b = colour parameters of backfat.

^b Mallow's C_p statistic.

In this situation of variability, which can occur in practice in slaughter houses, predicting fat content in the ham from measurements easily recorded on the side (backfat thickness and colour, percent kidney fat) did not seem feasible, except for the estimate of the subcutaneous depot which achieved a fairly high reliability.

References

- AOAC (1980). *Official methods of analysis* (13th ed.). Washington D.C: Association of Official Analytical Chemist.
- Bejerholm, C., & Barton-Gade, P. (1986). Effect of intramuscular fat level on eating quality of pig meat. In *Proceedings of the 32nd European Meeting of Meat Research Workers*, Gent, Belgium, 389–391.
- Blanchard, P. J., Warkup, C. C., Ellis, M., Willis, M. B., & Avery, P. (1999). The influence of the proportion of Duroc genes on growth, carcass and pork eating quality characteristics. *Animal Science*, 68, 495–501.
- Bout, J., Girard, J. P., Runavot, J. P., & Sellier, P. (1989). Genetic variation in chemical composition of fat depots in pigs. In *40th Meeting EAAP*, Dublin, 7 pp, GP 3.12
- Cameron, N. D. (1990). Comparison of Duroc and British Landrace pigs and the estimation of genetic and phenotypic parameters for growth and carcass traits. *Animal Production*, 50, 141–153.
- Cameron, N. D., Nute, G. R., Brown, S. N., Enser, M., & Wood, J. D. (1999). Meat quality of Large White pig genotypes selected for components of efficient lean growth rate. *Animal Science*, 68, 115–127.
- Cook, G. L., Chadwick, J. P., & Kempster, A. J. (1989). An assessment of carcass probes for use in Great Britain for the EC pig carcass grading scheme. *Animal Production*, 48, 427–434.
- Davies, A. S., & Pryor, W. J. (1977). Growth changes and distribution of dissectable and intramuscular fat in pigs. *Journal of Agricultural Science (Cambridge)*, 89, 257–266.
- De Vries, A. G., van der Wal, P. G., Long, T., Eikelenboom, G., & Merks, J. W. M. (1994). Genetic parameters of pork quality and production traits in Yorkshire populations. *Livestock Production Science*, 40, 277–289.
- Diestre, A., Gispert, M., & Oliver, M. A. (1989). The evaluation of automatic probes in Spain for the new scheme for pig carcass grading according to the EC regulations. *Animal Production*, 48, 443–448.
- Edwards, S. A., Wood, J. D., Moncrieff, C. B., & Porter, S. J. (1992). Comparison of the Duroc and Large White as terminal sire breeds and their effect on pigmeat quality. *Animal Production*, 54, 289–297.
- Franci, O., Bozzi, R., Pugliese, C., Poli, B. M., Parisi, G., Balo, F., & Geri, G. (1995). Confronto fra progenie di verri Large White, Landrace Italiana, Landrace Belga, Duroc, Cinta Senese e scrofe Large White a 130 e 160 kg di peso vivo. 3. Caratteristiche fisico-chimiche del magro e del grasso della coscia. *Zootecnica e Nutrizione Animale*, 21, 237–247.
- Franci, O., Pugliese, C., Acciaioli, A., Poli, B. M., & Geri, G. (1994a). Confronto fra progenie di verri Large White, Landrace Italiana, Landrace Belga, Duroc, Cinta Senese e scrofe Large White a 130 e 160 kg di peso vivo. 1. Rilievi in vita e alla macellazione. *Zootecnica e Nutrizione Animale*, 20, 129–142.
- Franci, O., Pugliese, C., Bozzi, R., Parisi, G., Acciaioli, A., & Geri, G. (1994b). Confronto fra progenie di verri Large White, Landrace Italiana, Landrace Belga, Duroc, Cinta Senese e scrofe Large White a 130 e 160 kg di peso vivo. 2. Composizione della carcassa e caratteristiche del coscio. *Zootecnica e Nutrizione Animale*, 21, 177–186.
- Geri, G., Franci, O., Zappa, A., & Campodoni, G. (1984). Accrescimento relativo e distribuzione del grasso in suini maschi castrati e femmine da 20 a 200 chilogrammi di peso vivo. *Zootecnica e Nutrizione Animale*, 10, 365–380.
- Geri, G., Zappa, A., & Franci, O. (1986). Influenza dello sviluppo corporeo e della localizzazione sulla cellularità del tessuto adiposo nei suini. *Zootecnica e Nutrizione Animale*, 12, 9–24.
- Hovenier, R., Kanis, E., van Asseldonk, Th., & Westerink, N. G. (1992). Genetic parameters of pig meat quality traits in a halotane negative population. *Livestock Production Science*, 32, 309–327.
- Huxley, J. S. (1932). *Problems of relative growth*. London: Methuen and Co. Ltd.
- Jones, S. D., Richmond, R. J., Price, M. A., & Berg, R. B. (1980). Effects of breed and sex on the patterns of fat deposition and distribution in swine. *Canadian Journal of Animal Science*, 60, 223–230.
- Karlsson, A. (1992). The use of principal component analysis (PCA) for evaluating results from pig meat quality measurements. *Meat Science*, 31, 423–433.
- Kempster, A. J., & Evans, D. G. (1979). The effects of genotype, sex and feeding regime on pig carcass development. 2. Tissues weight distribution and fat partition between depots. *Journal of Agricultural Science (Cambridge)*, 93, 349–358.
- Kolstad, K., Jopson, N. B., & Vangen, O. (1996). Breed and sex differences in fat distribution and mobilization in growing pigs fed at maintenance. *Livestock Production Science*, 47, 33–41.
- Lo, L. L., McLaren, D. G., McKeith, F. K., Fernando, R. L., & Novakofski, J. (1992). Genetic analyses of growth, real-time ultrasound, carcass, and pork quality traits in Duroc and Landrace pigs: I. Breed effects. *Journal of Animal Science*, 70, 2373–2386.
- McGluoghlin, P., Allen, P., Tarrant, P. V., Joseph, R. L., Lynch, P. B., & Hanrahan, T. J. (1988). Growth and carcass quality of crossbred pigs sired by Duroc, Landrace and Large White boars. *Livestock Production Science*, 18, 275–288.
- Næs, T., Baardseth, P., Helgensen, H., & Isaksson, T. (1996). Multivariate techniques in the analysis of meat quality. *Meat Science*, 43, S135–S149.
- Russo, V., Lo Fiego, D. P., Badiani, A., Bigi, D., Fabbri, R., Bosi, P., Barchi, D., & Benatti, L. (1989). Metodi di classificazione delle carcasce suine in Italia. *Rivista di Suinicoltura*, 30(4), 109–114.
- SAS (1996). *SAS/STAT software, release 6.12*. Cary, NC: SAS Institute Inc.
- Simpson, S. P., Webb, A. J., & Dick, S. (1987). Evaluation of Large White and Duroc boars as terminal sires under two different feeding regimes. *Animal Production*, 45, 111–116.
- Sonesson, A. K., de Greef, K. H., & Meuwissen, T. H. E. (1998). Genetic parameters and trends of meat quality, carcass composition and performance traits in two selected lines of large white pigs. *Livestock Production Science*, 57, 23–32.
- Villé, H., Rombouts, G., Van Hecke, P., Perremans, S., Maes, G., Spincemaille, G., & Geers, R. (1997). An evaluation of ultrasound and nuclear magnetic resonance spectroscopy to measure in vivo intramuscular fat content of longissimus muscle of pigs. *Journal of Animal Science*, 75, 2942–2949.
- Walstra, P. (1980). *Growth and carcass composition from birth to maturity in relation to feeding level and sex in dutch landrace pigs*. Wageningen: H. Veenman & Zonen B.V.
- Warriss, P. D., Brown, S. N., Franklin, J. G., & Kestin, S. C. (1990). The thickness and quality of backfat in various pig breeds and their relationship to intramuscular fat and the setting of joints from the carcasses. *Meat Science*, 28, 21–29.
- Wood, J. D., Jones, R. C. D., Francombe, M. A., & Whelehan, O. P. (1986). The effects of fat thickness and sex on pig meat quality with special reference to the problems associated with overleaness. 2 Laboratory and trained taste panel results. *Animal Production*, 43, 535–544.
- Wood, J. D., Whelehan, O. P., Ellis, M., Smith, W. C., & Laird, R. (1983). Effects of selection for low backfat thickness in pigs on the sites of tissue deposition in the body. *Animal Production*, 36, 389–397.