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GENETIC ASPECTS OF MEAT QUALITY IN PIGS [1]

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SUMMARY

Danish investigations have shown that environmental conditions like season of year, temperature during transport, and carcass weight have, on an average of a larger sample of individuals, only a slight effect at least on the variance of meat colour in the muscle.

Investigations within many breeds of pigs, including those given in tables 7, 8, and 10, give estimates of additive gene effects of $h^2 = 0.3$ to $h^2 = 0.4$ for values of muscle colour and 45 mn pH values.

The genetic correlation between sexes in meat colour and in two other characters is given.

The phenotypic and genetic variability of characteristics related to meat quality are given together with objective carcass measurements, and the phenotypic and genetic relationship between these are discussed.

The possibility of being able to master, through a selection program, the problem of meat quality and the problem of stress adaptability related to this, is discussed.

INTRODUCTION

Problems on meat quality have been reported as early as in 1883, and in connection with a pork exhibition in Berlin HERTER and WILSDORF (1914) dealt with problems like meat with a pale, moist surface creating processing problems. These authors also dealt with breed differences in muscle colour. Already in the early days of the Danish bacon production the meat colour was taken into consideration, as the first director of the Danish pig progeny testing stations reported of complaints from Great Britain, indicating that occasionnally the Danish bacon had a poor, pale colour (BECK, 1931). A regulation was made requiring that all test carcasses should be scored for colour in m. *L. dorsi*. This subjective colour grading covered an arbitrary five class scale given on the surface of the cross section of the m. *L. dorsi* behind the shoulder and another one in front of the ham.

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In their description of acute heart problems associated with sudden death in pigs, FREDE (1926) and HUPKA (1939) used the designation « muscular degeneration » for the most pronounced cases of muscles with discolouration. LUDVIGSEN (1953, 1954) described muscular discolouration in the *Danish Landrace* in connection with processing and canning problems and claimed that this discolouration involved both nutritional and genetic factors.

WISMER-PEDERSEN (1959) found a phenotypic correlation of $r_P = -0.71$ between the pH measurement in the m. *L. dorsi* behind the last rib 45 minutes after killing and the water-holding capacity of this muscle. He also found a correlation of $r_P = -0.86$ between the same pH value and the corresponding concentration of lactic acid. CLAUSEN and NÖRTOFT THOMSEN (1960) associated a high acid content of the meat with pale colour characteristics and reported a correlation of $r_P = +0.6$ between these traits.

WISMER-PEDERSEN and BRISKEY (1961) were able to produce pale, moist meat by delaying the temperature fall in the carcass after killing. They concluded that the fast process of chilling the carcass *post mortem* caused a partial reduction in pale colour characteristics of porcine muscle. HALLUNG (1962) confirmed these results.

Because of the relationship shown by LUDVIGSEN (1953, 1954, 1955) between the colour changes in the skeletal muscles and the concentration of lactic acid in the same muscle, CLAUSEN and NÖRTOFT (1956) introduced an arbitrary colour scale of 10 classes to be given on the cross section of the m. *L. dorsi* cut at the tip of the last rib. This score was introduced in January 1954 and is still used on all test pigs slaughtered. During the period 1954-1965 certain environmental and genetic causation factors have been investigated.

As earlier mentioned, WISMER-PEDERSEN (1959) found a phenotypic correlation of $r_P = -0.71$ between the pH value in the m. *L. dorsi* behind the last rib 45 minutes *post mortem* and the water holding capacity in the same muscle. Furthermore he found $r_P = -0.86$ between this 45 minutes pH value and the corresponding concentration of lactic acid ; consequently the 45 minutes pH value was measured on all Danish test pigs from 1958 to 1962, but due to missing data only the material from the test year 1958-59 could be analyzed.

Table 1 shows the relationship between the Danish colour score and the 45 minutes pH, both taken at the tip of the last rib.

ENVIRONMENTAL FACTORS AFFECTING THE MEAT COLOUR

LUDVIGSEN (1954) and WISMER-PEDERSEN and RIEMANN (1960) discussed the importance of preventing the pigs from fighting and biting during transport to the bacon factory in order to reduce the incidence of pale, moist muscles. In 1959 the Danish Meat Research Institute developed a halter to be placed on the pigs before delivery at the bacon factory (WICHMAN-JÖRGENSEN 1959, 1961). This halter was tested on pigs from the three progeny testing stations from January to July 1960, and caused a general improvement in the mean of the muscle colour score of the test pigs. (« Sjælland » : $P \leqslant 0.20$, « Fyn « : $P \leqslant 0.001$, and « Jylland » $P \leqslant 0.20$).

Using halter, the phenotypic variance within the same day of delivery was also decreased, but most in the uncastrated animals, the gilts (table 2).

TABLE I

The pH measurement in the m. L. dorsi *at the tip of the last rib 45 minutes after killing at the different classes for meat colour in the cross section of the m.* L. dorsi, *this cut also made at the tip of the last rib*

pH du muscle long dorsal à la dernière côte 45 minutes après l'abattage pour les différentes classes de note de couleur

Specification of the description of the muscle cross section surface (1)	Score for meat colour	pH-measurement	Distribution of meat colour scores (%)	
			1960-61	1965-66
Number of test pigs			*4 618*	*5 257*
Gray, same colour as boiled meat. Very moist surface, rough and stringy structure	0.5	5.45	0.3	0.2
Very pale, pinkish, moist surface, rough structure.	1.0	5.48	3.9	2.7
Pale pink, slightly moist surface, somewhat rough structure	1.5	5.56	15.9	14.5
Slightly paler than desirable, almost dry surface and almost normal structure	2.0	5.80	22.4	22.1
Ideal red colour, dry surface, normal structure	2.5	6.19	41.8	52.0
Same specification	3.0	6.25	13.9	7.9
Slightly darker than desirable, dry surface	3.5	6.28	1.5	0.6
Same specification	4.0	6.28	0.3	0
Very dark, dry surface	4.5	0	0	0
Same specification	5.0	0	0	0

(1) NÖRTOFT-THOMSEN and PEDERSEN (1961).

	Colour class	Per cent	
Pronounced too light meat colour	0.5-1.5	20	17
A little too light meat colour	2.0	22	22
Satisfactory meat colour	2.5-4.0	58	61

TABLE 2

Phenotypic variance of meat colour score within the same day of delivery with and without halter. 4 weeks, January-June 1960

Variance phénotypique de la note de couleur, intra-jour de transport à l'abattoir avec ou sans contention des animaux

Test station	« Sjælland »		« Fyn »		« Jylland »		3 stations, average	
Distance of delivery	2 km		14 km		8 km		8 km	
Using halter	—	+	—	+	—	+	—	+
							Number :	
Variance within same day of deliv.:							*514*	*523*
Castrates	0.42	0.39	0.31	0.25	0.31	0.33	0.35	0.33
Decline in variance when using halter (%)	7.6		19.6		— 3.9		*6.6*	
Gilts	0.41	0.36	0.32	0.22	0.37	0.32	0.37	0.31
Decline in variance when using halter (%)	11.9		31.4		14.8		15.8	

It is clearly shown that the procedure of using halter decreases the variance between pigs delivered on the same lorry, and that the gilts are the most sensible sex, their variance in meat colour score being app. 10 per cent larger than that of the castrates. A remarkable effect of the distance (km to bacon factory) on the intra week variance in meat colour is demonstrated.

To repeat this examination of the effect of transport stress on both the colour score and the 45 minutes pH value, an experiment was carried out with 54 test groups (each test group consisted of two castrates and two gilts) to be delivered from the newly established fourth test station to the bacon factory, driving distance being 0.5 km. One gilt and one castrate from each of the 54 test groups were killed in their individual pens and transported dead to the bacon factory, whereas the other gilt and castrate litter mates were transported alive to the factory (NÖRTOFT THOMSEN, 1961). The results are shown in table 3.

TABLE 3

Effect of transport on meat colour
and 45 mn pH in m. L. dorsi *behind the last rib*

(One litter mate in each of the two treatments and in each sex)

Effet du transport sur la couleur de la viande et le pH à 45 mn
du muscle long dorsal derrière la dernière côte

(Dans chaque portée un mâle et une femelle ont été attribués à chaque traitement)

	Pigs killed at the factory		Pigs killed in pen	
	54 castrates	54 gilts	54 castrates	54 gilts
Meat colour score, mean........	2.19	2.06	2.27	2.25
Meat colour standard deviation..	0.518	0.550	0.502	0.502
45 mn pH value, mean	5.90	5.83	5.99	5.95
45 mn, standard deviation	0.467	0.483	0.438	*0.370*

The muscle colour mean was improved in both the castrates and the gilts killed in the pen. The standard deviation within litter and sex decreased in both sexes, but most in the gilts. However, only the standard deviation of the 45 minutes pH value in the muscle differed significantly in the gilts killed in the pen from that of the gilts killed at the factory ($P \leqslant 0.048$, table 3).

To investigate the effect of transportation on the meat quality in order to standardize the treatment during transport of not only the test pigs, but also ordinary bacon pigs from commercial producers, the Danish Meat Research Institute has set into operation an experiment in 1971 (WICHMANN-JÖRGENSEN, 1971).

The effect of season on both the meat colour score and 45 mn pH in the m. *L. dorsi* is investigated examining their variances. The effect of the 3 months-season is approximately 5 per cent of the phenotypic variance. In table 4 is given the relative variance of the month and the day of delivery and of the individual test pig for each of six station-sex subgroups within the test year 1958-59.

It is clearly shown that 85 to 100 per cent of the phenotypic variance is deu

TABLE 4

Relative importance of month and day of delivery as causes of variance in meat colour score and 45 mn pH in m. L. dorsi
3 testing stations. 1958-59

Importance relative du mois et du jour de livraison à l'abattoir dans la variance de la note de couleur et du pH à 45 mn du muscle long dorsal
3 stations. 1958-59

Sex	« Sjælland »		« Fyn »		« Jylland »	
	Castrates	Gilts	Castrates	Gilts	Castrates	Gilts
Number of test pigs	*584*	*624*	*586*	*624*	*545*	*580*
Meat colour score						
Month, at same station	— 0.1	— 0.3	6.1	4.1	— 4.2	— 0.3
Week day of delivery	3.7	— 0.7	2.8	— 1.2	8.6	3.6
Test pig killed on the same day as contemporaries ...	96.4	101.0	91.1	97.1	95.6	96.7
45 mn pH						
Month, at same station	— 0.2	2.9	9.2	5.1	— 1.3	2.8
Week day of delivery	13.8	— 0.4	4.0	5.0	8.6	7.4
Test pig killed on the same day as contemporaries ...	86.5	97.5	86.8	89.9	92.7	89.9

TABLE 5

Relation between meat colour and pH in the m. L. dorsi *on the one side and the chilled carcass weight on the other side*

Relation entre la couleur de la viande et le pH du muscle long dorsal d'une part et le poids de la carcasse froide d'autre part

		« Sjælland »		« Fyn »		« Jylland »		« Vestjylland »	
Points for meat colour, 1962-63 (4 990 pigs finished the test)									
Regression per 1 kg chilled carcass weight	♂♂.....	— .034 ± .01		— .049 ± .01		— .028 ± .01		— .017 ± .01	
	♀♀.....	— .033 ± .01		— .063 ± .01		— .040 ± .01		— .017 ± .01	
Reduction of the total variance when correcting to the mean chilled carcass weight									
8 year-station-sex sub-groups of app. 600 pigs each		%	Mean (kg)	%	Mean (kg)	%	Mean (kg)	%	Mean (kg)
Castrates		1.7	65.0	2.5	65.3	1.0	65.2	0.4	65.3
Gilts		2.1	65.4	4.8	65.6	1.7	65.3	0.3	64.4
pH-measurement, 1961-62 (4 998 pigs finished the test)									
Regression of the pH-measurement in the m. *L. dorsi* on the chilled carcass weight :									
H^+ power exponents per 1 kg	♂♂..	— .040 ± .008		— .026 ± .008		— .017 ± .008		— .014 ± .009	
	♀♀..	— .015 ± .009		— .035 ± .007		— .010 ± .008		— .023 ± .009	

to the difference between the individual reaction among pigs delivered to the bacon factory on the same lorry on the same day.

The influence of outside temperature on the muscle colour score was estimated as the linear regression of the mean muscle colour score on the temperature, measured outside the test stations at noon in C° for all test stations and sexes over four years. The mean temperature of year fluctuated from 7.2 C° to 11.0 C°, and the regression estimates fluctuated from + 0.000 02 to — 0.02. 24 out of 28 regression coefficients showed a negative influence of the outdoor temperature, the delivery distance of 14 km showing the strongest influence.

Effect of chilled carcass weight on muscle colour and 45 mn pH in m. L. dorsi

Table 5 shows the repeatability of the consistently negative effects of chilled carcass weight on both muscle colour and pH though these effects are only slight, being of the order between 0.3 per cent and 4.8 per cent of the phenotypic variance.

Similarity in relationship to other characters for the 45 mn pH value and for the meat colour both in the m. L. dorsi *at the tip of the last rib*

In the previous tables 2, 3, 4, and 5 it is shown that these two characters have reacted quite similarly against the causative effects mentioned. The reactions of these two characters with a third one are also very similar which is shown in table 6. The correlation of the residual sector is a measure of the covariation within litters after the elimination of the additive gene effect. The effects of the inter- (epistatic) and intra- (dominant) allelic gene action are included in this correlation.

Meat colour and pH in the muscle are negatively correlated with fast gain and positively with feed consumption rate. At constant gain the covariation between feed consumption and these two characters is not changed. Length of the pig and all fat measurements are positively correlated with colour and pH in the muscle whereas meat content is negatively correlated. None of these correlations are strong.

The intra-station phenotypic correlation between the two characters was estimated at + 0.68 and + 0.71 for castrates and gilts, respectively. However, it is of more importance that in the same material of 1 715 castrates and 1 811 gilts, the genetic correlation was estimated at $r_G = + 0.86$ (480 d. f. for sires).

HERITABILITY ESTIMATES FOR POINTS FOR MEAT COLOUR AND 45 MN PH, BOTH IN THE *M. L. DORSI* AT THE TIP OF THE LAST RIB

The partitioning of the phenotypic variance of the meat colour score and two other important carcass characteristics are based on the data from 1956 to 1965 (table 8). This should include a sufficient number of test year — test station — sex subgroups, one year of test comprising material from four test stations, and therefore eight subgroups including app. 90 degrees of freedom for sires.

The hierarchical structure of these estimates from 1958 to 1965 is : two test pigs of the same sex per test group, five test pigs of the same sex per sire half-sib family, and 12 test pigs of the same sex per breeding centre (élite herd).

Within the élite herds relationships of 17.5 p. 100 were found between dams mated to the same sire, and 2.6 p. 100 between sires standing at the same breeding centre.

TABLE 6

Phenotypic correlations with points for meat colour and the pH-measurement
The 3 Pig Progeny Testing Stations, year of test 1958-59
Correction is undertaken for effect from cold carcass weight, seasons of year and test stations

Corrélations phénotypiques avec la couleur de la viande et le pH.
Données des 3 stations de contrôle de la descendance, année 1958-59,
corrigées pour le poids de carcasse et les effets de la saison et de la station

	Castrates	Gilts
$r_{phenotype}$, d.f.	1 711	1 807
$r_{residue}$, d.f.	805	903

		Points for meat colour in the cross section of the musc. *long. dorsi*		pH-measurement in the musc. *long. dorsi* at the same place	
		$r_{phenotype}$	$r_{residue}$	$r_{phenotype}$	residue
Ave. daily gain in grams from 20 to 90 kg live weight	Castrates	— 0.03	+ 0.10	— 0.08	— 0.10
	Gilts	— 0.01	— 0.12	— 0.04	— 0.26
Feed consumption (Scand. FU) per kg live weight gain from 20 to 90 kg live weight	Castrates	+ 0.06	— 0.02	+ 0.12	+ 0.13
	Gilts	+ 0.05	+ 0.26	+ 0.09	+ 0.30
Feed consumption rate at constant gain	Castrates	+ 0.07	— 0.02	+ 0.11	+ 0.11
	Gilts	+ 0.07	+ 0.23	+ 0.10	+ 0.18
Body length in cm	Castrates	+ 0.16	+ 0.19	+ 0.16	+ 0.27
	Gilts	+ 0.19	+ 0.12	+ 0.15	+ 0.25
Points (0-15) for size and shape of hams	Castrates	— 0.19	— 0.13	— 0.29	— 0.12
	Gilts	— 0.28	— 0.05	— 0.27	— 0.03
Area of the musc. *long. dorsi* on the cross section of the cut bacon side, cm²	Castrates	— 0.14	— 0.06	— 0.17	— 0.16
	Gilts	— 0.14	— 0.11	— 0.14	— 0.10
Are of fat on the cross section of the cut bacon side, cm²	Castrates	+ 0.09	— 0.15	+ 0.19	+ 0.11
	Gilts	+ 0.14	+ 0.07	+ 0.18	— 0.04
Mid-back measurement, cm	Castrates	+ 0.02	— 0.36	+ 0.05	— 0.29
	Gilts	+ 0.05	— 0.27	+ 0.07	— 0.40
Side fat measurement on the cross section of the cut bacon side, cm²	Castrates	+ 0.07	— 0.30	+ 0.18	+ 0.02
	Gilts	+ 0.10	— 0.02	+ 0.16	— 0.11
pH-measurement in the musc. *long. dorsi* at the last rib	Castrates	+ 0.66	+ 0.68		
	Gilts	+ 0.71	+ 0.57		

Thus the data in tables 7 and 8 are corrected for the effect of the relationship between sires and for that between dams ; further for the influence of chilled carcass weight, seasons of year, progeny test stations, and year of test.

The pH value, measured 45 minutes after killing, is included in the international recognized criteria for classifying a pig carcass to be either normal or PSE

(e. g. DUTSON *et al.*, 1971). In table 7 are given the results of the only complete test year in respect to data set including this criterion for meat quality. This is the same set of data as used for the results in table 6.

An essential fact in table 7 is the characteristic higher heritability in both criteria for the gilts than for the castrates in this sample. However, this dramatic difference between sexes is undoubtedly due to sampling variation as it is not found over the 9 years period 1956-1965 for the meat colour score (table 8 ; castrates : $h^2 = 0.27 \pm 0.06$, gilts : $h^2 = 0.36 \pm 0.06$).

TABLE 7

Analysis of variance of points for meat colour and the 45 mn pH measurement both in the m. L. dorsi
Test year 1958-59

Analyse de variance de la note de couleur et du pH à 45 mn du muscle long dorsal
Année 1958-59

Variance components per cent	Degrees of freedom		Points for meat colour		pH measurement	
	Castrates	Gilts	Castrates	Gilts	Castrates	Gilts
$V_{station}$	2	2	1.1	0.8	4.3	5.2
$V_{elite\ herd}$	283	281	9.5	— 0.8	4.7	1.5
V_{sire}	241	239	— 5.7	15.3	4.5	10.5
$V_{test\ group}$	382	384	11.7	4.5	11.8	3.6
$V_{individual}$	806	904	83.4	80.3	74.7	79.2
V_{total}	1 714	1 810	100.0	100.1	100.0	100.0

Points for meat colour.
Castrates : $\bar{y} = 2.35 \pm 0.013$; $s_y = 0.533$, $s_{intra\ litter} = 0.488$;
Gilts : $\bar{y} = 2.34 \pm 0.013$; $s_y = 0.553$, $s_{intra\ litter} = 0.496$

pH measurement
Castrates : $\bar{y} = 6.07 \pm 0.008$; $s_y = 0.350$, $s_{intra\ litter} = 0.305$
Gilts : $\bar{y} = 6.02 \pm 0.008$; $s_y = 0.349$, $s_{intra\ litter} = 0.313$

Causation components, per cent	Points for meat colour		pH measurement	
	Castrates	Gilts	Castrates	Gilts
Breeding center (*i.e.* herd) environment (c^2), per cent	10.8	— 4.0	3.9	— 0.7
Heritability or additive gene effect (h^2), per cent	— 23.6	63.4	19.4	45.3
Maternal effect, litter environment (l^2), per cent	16.7	— 8.6	8.4	— 5.5
Residue, *i.e.* % error variance (e^2), per cent	96.1	49.2	68.3	60.9
Phenotype	100.0	100.0	100.0	100.0

As an average between the two sexes, an estimate of $h^2 = 0.32$ for the 45 mn pH value (table 7) is a moderately high heritability, indicating that the additive gene effect is controlling the structural conditions in the pig ; WISMER-PEDERSEN

TABLE 8

Partitioning of the phenotypic variation between the state recognized breeding centres (elite herds) of the Danish Landrace *Pig. 3 carcass characteristics. Values expressed in per cent.*

The data are corrected for the effect of the relationship between sires and that between dams ; further from the influence of chilled carcass weight, seasons of year, progeny test stations and years of test.

Décomposition de la variance phénotypique dans les élevages d'élite Landrace danois, *du porc pour 3 caractères de carcasse.*

Les données sont corrigées pour les effets de la parenté entre les pères et entre les mères, du poids de la carcasse, de la saison, de l'année et de la station.

Year of test	Points for meat colour in the musc. *long. dorsi*				Area of the musc. *long. dorsi* cross section				Side fat measurement			
	c^2	h^2	l^2	e^2	c^2	h^2	l^2	e^2	c^2	h^2	l^2	e^2
1956-57	3	23	5	68								
1957-58	0	29	7	64								
1958-59	— 2	44	1	58	2	37	8	54	2	49	1	48
1959-60	2	23	10	66	5	7	21	68	— 2	48	8	45
1960-61	— 2	34	0	67	2	37	5	56	4	40	7	49
1961-62	— 1	46	— 4	60	5	33	7	56	0	59	6	36
1962-63	1	31	— 1	69	0	47	3	50	0	79	— 7	28
1963-64	— 2	36	9	57	4	51	5	41	0	54	10	36
1964-65	4	15	8	74	— 2	56	6	40	1	56	4	39
	1956-65 : 1 303 paternal half-sib groups				1958-65 : 1 123 paternal half-sib groups				1958-65 : 1 123 paternal half-sib groups			
Castrates	0.1 ± 1.3	27 ± 6	6 ± 3	67	1 ± 2	44 ± 7	7 ± 3	49	1 ± 2	60 ± 8	5 ± 3	35
Gilts	1 ± 1	36 ± 6	1 ± 3	63	2 ± 2	41 ± 7	6 ± 3	51	0.4 ± 1.7	52 ± 8	4 ± 3	43
Average	*0*	*31*	*3*	*65*	*2*	*42*	*7*	*50*	*1*	*56*	*4*	*39*
D. of freed.	545	726	2 198	3 379	467	630	1 900	2 889	467	630	1 900	2 889
Standard deviation :	Castrates		Gilts		Castrates		Gilts		Castrates		Gilts	
Phenotypic	0.49 pts		0.52 pts		2.51 cm²		2.65 cm²		0.41 cm		0.34 cm	
Additive genetic	0.26 pts		0.31 pts		1.66 cm²		1.69 cm²		0.31 cm		0.25 cm	

having demonstrated a fairly high phenotypic correlation of $r_P = -0.71$ between this 45 mn pH value and the water holding capacity.

The best estimate of the partitioning of the phenotypic variance in the *Danish Landrace* pig in the period prior to 1967 is given in table 8 for three characters which are important for the selection of bacon type.

PEDERSEN (1964) found that the m. *L. dorsi* area controls app. 25 p. 100 of the lean meat content in the carcass ($r_{P(castrates)} = + 0.44$ and $r_{P(gilts)} = + 0.49$), whereas he found that the side fat measurement controls 50 p. 100 of the lean meat content in the carcass ($r_{P(castrates)} = - 0.71$ and $r_{P(gilts)} = - 0.68$).

That is the reason why these two characters are included in table 8 together with the meat colour score.

Difference between sexes is not found in the colour score mean like in the two other characteristics, but the phenotypic standard deviation as well as the genetic one differ between the two sexes in all characters as demonstraded in the tables 7 and 8. This difference in variance is about 8 p. 100, and a similar difference is found in the score for nasal alterations :

Meat colour score :

1956-60

$s^2_{\text{intra litter}}$ (gilts)/$s^2_{\text{intra litter}}$ (castrates) = 0.235/0.217 = *1.08.*

Nasal alterations (rhinitis score) :

1956-60

s^2_P(gilts) /s^2_P (castrates) = 0.824/0.735 = *1.12.*

In table 8 it is clearly demonstrated that under a system of test, where it is necessary to restrict the material so that only a little more than five pigs per sire half-sib family and only 12 pigs per herd is obtained, it is necessary to include a number of test years to get sufficient unbiased estimates of the population parameters in the breed. This agrees with the theory given by ROBERTSON (1960) about experimental design on the measurement of heritabilities.

Besides having a sufficient number of individuals per subgroup to get unbiased estimates of the different intra-class correlations, the years must cover some sire generations because the sample of paternal half sib groups sent to the test station per year is not necessarily representative for the potentialities of zygotes from the breeding centres as a whole.

Sex differences in the heritabilities are not demonstrated in the muscle arae and the side fat measurement in the overall estimates within test stations and years. In the points for meat colour it should be concluded that the sire component estimated from the castrates data tends to be decreased and, therefore, the « litter environment » and the error variance is correspondingly increased. In a breeding program it should, therefore, be more efficient to base the selection on data from uncastrated animals.

It has been shown previously that the effects test stations, seasons of year, and chilled carcass weight are affecting the meat colour only slightly (tables 5 and 7). Table 8 shows that the only two causations which matter for the meat colour is the heritability and the residual error. If only gilts are included in the selection program, it is realistic to work with a heritability of 0.4 and a residual error of 0.6.

If both sexes are included in the test group, the heritability is 0.3 and the residual error is 0.7.

A rather strong maternal effect is found in the muscle area. This could to some extent be due to mothering abilities of prenatal nature.

GENETIC COVARIATION BETWEEN THE TWO SEXES IN POINTS FOR MEAT COLOUR AND TWO OTHER TRAITS

The test groups of the litters from the state recognized breeding centres consist of 2 castrated males and 2 females. Because of the uncertainty of the genetic variance of the meat colour in the castrates and also because the genetic improvement of a character is increased per year when only using 2 instead of 4 litter mates due to the increased selection intensity, it was of interest to investigate the genetic correlation between the two sexes with respect to their performance in the three carcass characteristics (table 9) (JONSSON, 1971 *b*).

TABLE 9

Genetic correlation and expected genetic improvement of two carcass quality characters and of one meat quality character

Corrélation génétique et amélioration génétique espérée et d'un critère de qualité de la viande

	Genetic correlation between castrates and gilts	Degrees of freedom	$h_{ca.}$	$h_{gi.}$	% expected genetic gain in the castrates when only selecting on the gilts
Points for meat colour (1956-63)	0.97 ± 0.11	871	0.52	0.60	112
Area of m. *long. dorsi* (1958-63)	1.18 ± 0.10	693	0.66	0.64	114
Side fat measurement (1958-63)	0.88 ± 0.06	693	0.77	0.72	82

The variance components for the interaction between sire half-sib families and the two sexes were very small in the meat colour score and in the side fat measurement, 0.003 4 points^2 and 0.002 8 cm^2, respectively ; the F-quotients were 1,09 and 1.15, respectively. This is the reason why the corresponding genetic correlations are not unity. In the musc. *Long. dorsi area*, however, the F-quotient was consistently beneath unity in the different test year-test station subgroups, so no sire-sex interaction is found in this character.

PHENOTYPIC AND GENETIC VARIATION AND COVARIATION IN SOME IMPORTANT CARCASS AND MEAT CHARACTERISTICS IN THE *DANISH LANDRACE* PIG

The two Danish carcass evaluation centres were started in 1967 to investigate the new characters for carcass quality which were to be recorded at these centres.

The material comprised *1 403* gilts and *1 400* castrates. As this first investigation on the new carcass characteristics was planned so that sires would be tested on at least two test groups (two gilts and two castrates per test group ; it was not possible, as originally planned, to set the limit at three test groups), it was impossible to include the variation between breeding centres in the hierarchical classification. So any carry-over effect from breeding centres will be included in the sire component. The hierarchical structure of the analysis was as follows :

Source of variation	1967-69 d. f.	Expected mean squares
Between sires within carcass evaluation centres and sex sub groups	456	$\sigma^2_e + 1.94\ \sigma^2_{litter} + 6.08\ \sigma^2_{sire}$
Between test-groups within sires	1 005	$\sigma^2_e + 1.90\ \sigma^2_{litter}$
Between full-sibs of the same sex.........	1 338	σ^2_e

The standard errors for the heritability estimates were computed according to the method given by B. Woolf (Falconer, 1963) as shown in Jonsson (1971 *a*).

The per cent of lean meat in the entire carcass side (character 9) is predicted by 10 individual carcass measurements and weights, including cold carcass weight and sex. The side fat measurement is a prominent x-variable in the prediction equation, controlling app. 50 per cent of the lean content in the entire side. $R = 0.87$ (Clausen *et al.*, 1968). Table 10 gives the phenotypic and genetic population parameter estimates in the *Danish Landrace* pig for six traditional and six new carcass quality characters introduced at the two carcass evaluation centres.

For the average backfat thickness the magnitude of heritability given in table 10 seems to be more reasonable, and for the m. *L. dorsi area* the value given in table 8 seems more reasonable. An estimate of $h^2 \sim 0.62$ seems too high for the area of m. *L. dorsi* ; this should also be the case for characters nr. 6, 8 and 9 in table 10.

One reason for this must be the lack of including the class for « breeding centres » in the hierarchy and the lack of having corrected for seasonal differences. The period of investigation is perhaps also a little short. The élite breeders have given considerable attention to the three characters m. *L. dorsi* area, side-fat measurement and per cent lean meat in the entire side from 1967 and onwards. This means that the

TABLE 10

Phenotypic and genetic population parameter estimates in the Danish Landrace *Pig. Within the two sexes and the two evaluation centres, corrected for carcass weight. 1967-69*

Paramètres phénotypiques et génétiques du porc Landrace danois, *estimés intra-sexe et station et corrigés pour le poids de carcasse, 1967-1969*

Characteristics	Mean value	Standard deviation		Coefficient of variation	Value		Heritability with standard error
		phenotypic	genetic		min.	max.	
1. Area of m. *L. dorsi* cross section cm²	32.1	3.0	2.13	9.3	23.9	42.1	0.62 ± 0.08
2. Ave. backfat thickness, cm	2.35	0.26	0.17	10.9	1.60	3.49	0.52 ± 0.08
3. Sidefat measurement, cm	1.82	0.43	0.27	23.8	0.70	3.39	0.55 ± 0.08
4. Ave. belly thickness, cm	3.16	0.15	0.09	4.7	2.22	3.74	0.48 ± 0.08
5. Body length, cm	96.5	1.86	1.30	1.93	77.8	103.9	0.50 ± 0.08
6. Points for meat colour in cross section of m. *L. dorsi*	2.15	0.51	0.28	23.5	0.47	3.59	0.31 ± 0.07
7. Per cent lean meat in loin	69.9	4.1	2.77	5.8	53.1	82.1	0.61 ± 0.08
8. Per cent lean meat in ham	77.9	2.5	1.77	3.2	67.2	86.3	0.62 ± 0.08
9. Per cent lean meat in the entire side	60.0	2.5	1.64	4.2	50.1	68.5	0.59 ± 0.08
10. Weight of shoulder	8.36	0.29	0.17	3.4	6.8	9.4	0.37 ± 0.07
11. Weight of loin	2.27	0.20	0.11	9.0	1.5	3.1	0.32 ± 0.07
12. Weight of ham	6.24	0.34	0.22	5.5	5.0	7.5	0.53 ± 0.07

effect of selection is included in the differences between sires' half-sib groups. Having included more years and corrected for effects from seasons and years, and having included the classification breeding centres in the hierarchy, a probable upward bias will be corrected for.

But the estimates for the additive gene effect in table 10 show that no lack of additive genetic variability in the breed ecists, which is also confirmed by the estimates given by STAUN (1968) and STAUN and JENSEN (1970) for the same breed. Their heritability estimates for the same characters, estimated from the data from the pig progeny testing stations, rank from 0.46 to 0.78.

The magnitude of the genetic standard deviation and the coefficient of variation for the important characters is striking.

Heritability estimates for colour values reported from other breeds range from 0.18 ± 0.06 for *Norwegian Landrace* (LANGHOLZ, 1966) over 0.25 ± 0.09 for *Large White* (PEASE and SMITH, 1965), 0.28 ± 0.15 (JENSEN *et al.*, 1967) as an estimate within the breeds *Duroc*, *Yorkshire*, *Hampshire*, *Poland China*, and *Spotted Swine* breeds, to 0.38 ± 0.10 for *Deutsches veredeltes Landschwein* (FLOCK, 1968). These estimates are similar to the present estimate given for the character 6.

In Denmark cross breeding experiments between the pig breeds *Large White* and *Danish Landrace* are planned. One of the main subjects to be investigated is the hypothesis of dominant gene effect on meat quality characteristics. SYBESMA (1970) has suggested that Cross breeding different breeds is a very promising means of improving meat quality.

WISMER-PEDERSEN (1959) found a correlation of $r_P = 0.71$ between 45 mn pH and 24 hours water holding capacity, both characters giving a reasonable accurate measure of structural conditions in the tissue. WENIGER *et al.* (1970, reported from WEISS, 1967) found heritability estimates of $h^2 = 0.37 \pm 0.14$ for WHC (centrifuging) and $h^2 = 0.19 \pm 0.10$ for 45 mn pH value. The estimates of heritability given among others by WENIGER *et al.* (1970) for the WHC of $h^2 = 0.37 \pm 0.14$ and that for the 45 mn pH value of $h^2 = 0.32$ from table 7 are supporting the hypothesis that structural conditions in the muscle as a meat quality criterion is controlled by additive gene effect, and, therefore, can be included in a selection program for improvement of meat quality.

In table 11, the traditional meat and carcass quality characters are given. The genetic correlations are given below the diagonal and the phenotypic correlations are given above the diagonal.

It is doubtful, whether the positive genetic correlation between colour brightness and muscle size still exists in the *Danish Landrace* pig, as reported by JONSSON (1971 *a*). This change in sign could have been forced by a change in gene frequency in the *Danish Landrace* pig because of a more direct selection for meat content during the recent years. Table 11 gives the correlation values as follows :

Correlation between	r_P	r_G
Points for meat colour in m. *L. dorsi* × m. *L. dorsi* area	— 0.08	— 0.29

This correlation is slight, but indicates a negative trend.

The negative trend between muscle colour and size of muscle agrees with

TABLE II

Traditional carcass and meat quality characters. Genetic correlations (below diagonal) *and phenotypic correlations* (above diagonal) *Within the two sexes and the two evaluation centres. Corrected for carcass weight. Designation of characters is given in table 10. 1967-69.*

Critères de carcasse et de qualité de la viande. Corrélations génétiques (au-dessous de la diagonale) *et phénotypiques* (au-dessus de la diagonale) *intra-sexe et station. Les données sont corrigées pour le poids de carcasse. La désignation des variables est donnée au tableau 10, 1967-69.*

No. of chars.	1	2	3	5	6	7	8	9	10	11	12
1		— 0.25	— 0.52	— 0.15	— *0.08*	+ 0.57	+ 0.48	+ 0.61	+ 0.06	+ 0.41	+ 0.49
2	— 0.14		+ 0.59	— 0.14	+ 0.16	— 0.66	— 0.54	— 0.64	— 0.26	— 0.22	— 0.45
3	— 0.60	+ 0.54		— 0.10	+ 0.14	— 0.83	— 0.65	— 0.83	— 0.30	— 0.29	— 0.58
5	— 0.13	— 0.41	— 0.19		+ 0.17	+ 0.02	0	+ 0.02	— 0.02	+ 0.04	— 0.15
6	— *0.29*	+ 0.26	+ 0.29	+ 0.26		— 0.19	— 0.25	— 0.22	— 0.05	— 0.15	— 0.24
7	+ 0.60	— 0.66	— 0.89	+ 0.20	— 0.41		+ 0.74	+ 0.90	+ 0.31	+ 0.42	+ 0.66
8	+ 0.64	— 0.50	— 0.76	+ 0.19	— 0.44	+ 0.86		+ 0.85	+ 0.25	+ 0.38	+ 0.70
9	+ 0.71	— 0.59	— 0.88	+ 0.19	— 0.43	+ 0.94	+ 0.91		+ 0.22	+ 0.57	+ 0.80
10	+ 0.13	— 0.37	— 0.51	— 0.21	+ 0.15	+ 0.50	+ 0.26	+ 0.37		— 0.16	+ 0.12
11	+ 0.52	— 0.20	— 0.38	+ 0.17	— 0.38	+ 0.51	+ 0.57	+ 0.61	+ 0.03		+ 0.37
12	+ 0.71	— 0.35	— 0.65	— 0.09	— 0.46	+ 0.74	+ 0.76	+ 0.87	+ 0.23	+ 0.55	

estimates from other breeds, e. g. with that given by FLOCK (1968), who estimated $r_P = -0.28$ and $r_G = -0.56$ between these two characters in the German *veredeltes Landschwein* breed.

DISCUSSION

In tables 2, 3, 4, and 5 it is demonstrated that the average environment has only a slight effect on the meat colour in the carcass. For the *Danish Landrace* pig table 7, 8 and 10 show together with estimates from other breeds that brightness of colour is influenced to a moderate degree by additive gene action, heritability estimates being of a magnitude of $h^2 \sim 0.3$ for colour values.

The high genetic correlation between sexes in meat colour as well as in other characters important for value of the carcass tells that including only one in the family selection for carcass and for meat evaluation ensures equal genetic progress in the other sex.

However, the problem of structure in meat tissue is not connected with muscle colour. It is, however, significantly related to the stress syndrome as reported e. g. by LUDVIGSEN (1968 *a* and 1968 *b*), JUDGE (1969), STEINHAUF *et al.* (1969), BRISKEY and LISTER (1968), HAASE and STEINHAUF (1971), STAUN (1968), and many others.

Undoubtedly, it is only a matter of technique to be able to obtain sufficient accurate and repeatable WHC values to ensure reasonably high heritability estimates to be included in selection programs for improvement of the meat structure, genetically.

But all these characters have only a secondary effect on the adaptability of the pig to environmental stress conditions. The main problem of the future must be to lay open the characteristics of the stress syndrome in the pig and the genetic effect behind these adaptation characters. In this way the question can be answered, whether the problem of quality and death losses, as reported from many countries (e. g. by WENIGER *et al.*, 1970) can be fought against by means of selection within the breed populations and/or by means of crossing between breeds utilizing a probable heterosis, or may be be mastered through environmental measures.

GERRITS *et al.* (1969) have shown that intense selection for meatiness in pigs has a significant correlated response to growth hormone concentration. Considerable need exists for more selection experiments like this cited to lay open these problems.

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RÉSUMÉ

ASPECTS GÉNÉTIQUES DE LA QUALITÉ DE LA VIANDE CHEZ LE PORC

Les recherches effectuées au Danemark ont montré que l'influence des conditions ambiantes, telles que la période de l'année, la température pendant le transport et le poids de la carcasse, sur un assez grand nombre d'animaux examinés est faible, du moins sur la variance de la couleur de la viande dans le muscle.

Les recherches à l'intérieur de nombreuses races porcines, y compris les recherches effectuées au Danemark sur les animaux de la *Landrace danoise*, ont permis d'évaluer à h^2 = 0,4 et h^2 = 0,3 les actions additives de gènes pour les valeurs du pH après 45 minutes et celles de la couleur de la viande, toutes les deux mesurées sur les muscles dorsaux à l'extrémité de la dernière côte. Le matériel animal suivant a été employé pour ces recherches : matériel de 1958-59 pour les valeurs du pH après 45 minutes et le pointage de la couleur de la viande, matériel de 1956 à 1965 pour le pointage de la couleur de la viande et matériel de 1967-69 également pour le pointage de la couleur de la viande.

On donne la corrélation génétique entre les sexes en ce qui concerne la couleur de la viande et deux autres caractères.

On donne en outre la variabilité phénotypique et génétique des caractéristiques relatives à la qualité de la viande ainsi que les mensurations objectives de la carcasse, et on examine la relation phénotypique et génétique existant entre ces caractéristiques.

On étudie également la possibilité de venir à bout, au moyen d'un programme de sélection approprié, du problème de la qualité de la viande ainsi que de celui de l'adaptabilité aux stress, qui s'y rattache.

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