BREEDING FOR MEAT QUALITY IN PIGS

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BREEDING FOR MEAT QUALITY IN PIGS

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ter verkrijging van de graad van
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Hovenier, R., 1993. Breeding for meat quality in pigs (Selectie op vleeskwaliteit bij varkens). The aim of this study was to investigate the possibilities of improving pig meat quality by selection. Therefore, literature is reviewed to determine the meat quality traits to be used and genetic parameters of those meat quality traits are calculated. A method is described to obtain marginal-income functions and economic values of meat quality traits. At last, consequences of including meat quality in the breeding goal for the various tiers of the pig meat production chain are analyzed. It is concluded that there are possibilities to improve meat quality by selection. Three strategies to improve meat quality by breeding are described. Effects of the various strategies on the genetic improvement of both production and meat quality traits are examined. Which strategy has to be used will depend on the current levels of the meat quality traits of the commercial pigs.

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Stellingen

1. Wil varkensvlees kunnen blijven concurreren met de andere vleessoorten, dan is verbetering van de kwaliteit van varkensvlees een voorwaarde.

2. Selectie op mesterij- en slachteigenschappen met de huidige selectie indices heeft een teruggang van de vleeskwaliteit tot gevolg.
(dit proefschrift)

3. De maximale shearforce kan als indexkenmerk gebruikt worden bij de selectie op malsheid van varkensvlees.
(dit proefschrift)

4. Een zinvolle implementatie van vleeskwaliteit in varkensfokprogramma's valt of staat met het inzicht in de huidige niveaus en de optimale waarden of ranges van vleeskwaliteitsparameters.
(dit proefschrift)

5. Voorwaarde voor het op korte termijn opnemen van vleeskwaliteit als fokdoelkenmerk in een fokkerijprogramma is het maken van afspraken over een verdeling van de kosten en opbrengsten hiervan tussen de verschillende lagen in de varkensvleesproduktiekolom.
(dit proefschrift)

6. Het is belangrijk om moleculaire technieken in de huidige staat van ontwikkeling meer te zien als een belangrijk gereedschap in het onderzoek naar het functioneren van dieren dan als directe mogelijkheid voor de veeverbetering.
(Hill, W.G. and P.D. Keightley, 1988. In: Advances in Animal Breeding: symposium in honour of Prof. R.D. Politiek; 41-55)

7. Het ontbreken van goede criteria voor de selectie op algemene ziekteresistentie en van een efficiënt registratiesysteem en het feit dat selectie op specifieke resistentie tegen de ene ziekte de gevoeligheid voor een andere ziekte kan vergroten, zijn de belangrijkste redenen voor het uitblijven van verbetering in ziekteresistentie.

   (Lie, Ø, 1990. Proc. 4th World Congress on Genetics Applied to Livestock Production, XVI; 421-426)

8. Voor de interpretatie van resultaten van moleculair- en kwantitatief genetisch onderzoek is biologisch fokkerijonderzoek onmisbaar.

9. In de Europese akte van 1986 is vastgelegd dat met ingang van 1993 er binnen de Europese Gemeenschap een volledig vrij verkeer van personen, goederen, diensten en kapitaal moet zijn bereikt; op dit moment betekent Europa '93 voor de burgers echter weinig meer dan het zonder paspoortcontrole de Europese binnengrenzen kunnen passeren.

10. Het invoeren van een zuivere speeltijd van 2x30 minuten is een effectieve maatregel om het tijdrekken in het huidige voetbal tegen te gaan.

11. As je achterom koike is 't een kort endje.

    (Westfriese zegswijze; dit proefschrift)

12. Raak nooit in paniek, dat doen anderen wel voor je !

Proefschrift van R. Hovenier
Breeding for Meat Quality in Pigs
Wageningen, 23 juni 1993

VOORWOORD

En dit is dan zo ongeveer het laatste loodje, het schrijven van het voorwoord. De tekst van het proefschrift is gereed, alles nog eenmaal printen en de figuren inplakken en dan is het gebeurd. Ruim vier jaar werk aan de vakgroep en een aantal maanden huisvlijt is dan gebundeld in het voor U liggende proefschrift.

Aan het einde van dit project zijn er, uiteraard naast de conclusies van het proefschrift, een aantal dingen die je zo te weten bent gekomen. Allereerst dat ik in één van de gezelligste kamers van Zoötechniek heb gezeten, bij sommigen bekend als de "Bourgondische" kamer, een kamer met een proefschriftdichtheid van ongeveer 35 bladzijden per m^2, een kamer die oranje kleurde ten tijde van Europese en Wereldkampioenschappen, een kamer die naast ham, kaas en kippen in het teken stond van skippyballen, de feestcommissie, Chinese ontwikkelingen, Tour de France en Aaltense wielrenners. Henk, toen wij elkaar begin februari 1988 tegen kwamen op "onze" kamer kenden we elkaar nauwelijks, ondanks dat later bleek dat we in ons eerste studiejaar in eenzelfde werkgroep hadden gezeten. Maar dat het allemaal uitstekend is uitgepakt zal een ieder bekend zijn. Bedankt voor het collega-zijn! Esther, ook jij bedankt. Ik hoop dat wij het leven niet al te zuur voor je gemaakt hebben. Je moet me alleen nog wel eens vertellen wat je nu met die fles "wijn" hebt uitgevoerd. Ming, I want to thank you too for being a nice colleague during the last years. Henk, Ming and Esther, it was a pleasure to share the room with all of you! Thanks!

Het is een bekend gegeven dat je het schrijven van een proefschrift niet alleen doet. Dat vind ik niet alleen, maar dat kun je in de voorwoorden van vele andere proefschriften ook terugvinden. Daarom dank ik hierbij Prof. Politiek, die in het begin de rol van promotor vervulde. Zijn rol is na korte tijd overgenomen door Pim Brascamp. Pim, bedankt voor alle waardevolle bijdragen en nuttige wenken gedurende de afgelopen jaren. Egbert Kanis heeft gedurende deze vier jaren gezorgd voor de dagelijkse begeleiding. Egbert, bedankt voor alle steun en begeleiding. En tenslotte wil ik ook Julius van der Werf bedanken voor het doorspitten en het van commentaar voorzien van al mijn schrijfsels. Naast genoemde begeleiding vanuit de vakgroep stond er ook nog een begeleidingsgroep vanuit de Encebe tot mijn beschikking. Ook hen dank ik voor alle opmerkingen en suggesties, met name de heren Westerink, van Asseldonk en Pieter Knap. Tenslotte wil ik alle mensen van het laboratorium van de Encebe in Boxtel bedanken voor het nauwgezet uitvoeren van de vele metingen die verwerkt zijn in dit proefschrift en de leden van het smaakpanel bedanken voor het beschikbaar stellen van hun tijd, kaken en magen. Ik hoop dat jullie er weer overheen zijn.

Tot slot wil ik Ada Wiggermans en Petra de Jong bedanken voor het uitvoeren van al die kleine klusjes die ik hen bezorgd heb vanuit het Italiaanse. En ook wil ik nu reeds mijn paranimfen Ella Luiting en Imke de Boer bedanken voor het werk wat zij al gedaan hebben voordat ik dit voorwoord schreef en voor het werk wat er ongetwijfeld na het schrijven van dit voorwoord nog eens bovenop zal komen.

Lieve lezers, dit waren de mensen die ik in ieder geval bij naam genoemd wilde hebben. Uiteraard bedank ik verder iedereen, die op welke wijze dan ook heeft bijgedragen aan de prettige werksfeer: volleyballers, bibliothecaressen, studenten, collega's, enz., enz.

Wat staat U verder nu nog te wachten? Op pagina 129 het Curriculum Vitae, de stellingen zult U vast al gelezen hebben en de Nederlandse samenvatting kunt U vinden op bladzijde 109. Voor de taalfreaks heb ik ook de Italiaanse samenvatting nog bijgevoegd (blz. 119; Paolo, grazie mille per il sommario). En voor de echte doorzetters: de volledige tekst van het proefschrift begint op pagina 1.

Ciao, Ron

CONTENTS

INTRODUCTION

INTRODUCTION

In current pig breeding schemes, main emphasis is put on economically important traits like growth rate, feed intake, lean meat percentage and litter size. However, in addition to these traits meat quality deserves increasing attention.

In 1989, worldwide pig meat production was about 40% of the total meat production and in Europe over 50% of the total amount of meat produced was pork (FAO, 1990). But, after a continuous increase in the consumption of pork in the E.E.C. for about 15 years, increase of pork consumption has tended to stagnate (P.V.V., 1989). Main reason for this stagnation seems to be the attitude of the consumer towards pork. From consumer research, it appeared that healthiness of the meat, the sensoric properties of the meat, the ease to prepare and the possibilities to use the meat and the price of the meat are of great importance when consumers compare different kinds of meat (Steenkamp and Van Trijp, 1988). Compared to beef, the consumers judged pig meat to be less healthy and to have minor sensoric properties, though easy to prepare and cheap. Compared to poultry, pork was never judged to be better on the four items given. Another point of importance may be the large variation in pig meat quality, especially in comparison with veal or poultry meat (Sebranek, 1982).

Besides the moderate image of pork to the consumers, also meat industry comments frequently about increasing incidence of meat quality problems (Kempster et al., 1986). Especially low water-holding capacity is a general complaint of processing industry and supermarkets (Russo, 1988).

An important genetically determined meat quality deficiency is pale, soft and exudative (PSE) meat. The halothane test (Eikelenboom and Minkema, 1974), made it possible to select effectively against PSE meat. Selection against halothane susceptibility resulted in a decrease of this susceptibility from 36% in 1977 to 8% in 1984 for Dutch Landrace (Eikelenboom, 1985). However, even in halothane-negative populations, a considerable amount of genetic variation for meat quality remains (e.g. Cameron, 1990).

Exploiting genetic variation by including meat quality in the breeding goal of pig breeding programs is a possibility to improve meat quality (Malmfors et al., 1980; Vestergaard, 1985). For this, specific meat quality traits to be included in the breeding goal and selection index have to be chosen and genetic and economic parameters have to be estimated. Also, consequences of including meat quality in the breeding goal for the various tiers of the pig meat production chain have to be analyzed. These topics are subject of this thesis.

Literature was reviewed to give backgrounds of the term "meat quality", to survey the most important traits determining pig meat quality and to evaluate the meat quality demands of both consumers and meat industry (Chapter 1). To indicate the potential of breeding to improve meat quality, heritabilities and genetic and phenotypic correlations of production and meat quality traits are reviewed. However, the genetic parameters reviewed may be influenced by the frequency of the halothane-positive allele because in most literature halothane susceptibility of the population(s) under study was not given.

To evaluate the possibilities to improve meat quality by breeding and to evaluate the effects of selection for a better meat quality on the genetic improvement of the production traits in a halothane-negative population, repeatabilities, heritabilities and correlations of both production and meat quality traits for such a population have to be known. In Chapter 2, a study is described in which repeatabilities of meat quality traits and their mutual correlations are estimated. Because of the importance of meat tenderness and the preference for objective measurements over the use of subjective measurements, special attention is paid to meat tenderness measurements. Meat tenderness judged by a taste panel was used as a subjective measurement, the Warner-Bratzler shearforce measurement and the assessment of total amount of collagen were used as objective tenderness measurements.

To estimate heritabilities and genetic and phenotypic correlations, production and meat quality were measured during 1½ years in over 1,100 animals of two halothane-negative lines (Dutch-Yorkshire and Duroc) and of two sexes (boars and gilts), fed ad libitum and raised until a fixed age. Estimates of the genetic parameters of the traits measured are given in Chapter 3.

Economic values have generally been used to weigh breeding goal traits. For meat quality traits, no economic values are found in literature. A problem for most meat quality traits is that they economically show an optimum range resulting in a dependency of the economic value for a particular trait on the mean of the commercial population for that trait. Approaches that can be followed in such a case include restricted selection index or incorporating an optimum trait quadratically in the aggregate genotype. Whatever method is used, it is always necessary to calculate an accurate profit or marginal-income function. For meat quality traits with an optimum, in most cases, a marginal-income function is only approximately known in terms of thresholds below or above which the product is not acceptable or only acceptable for lower prices. In Chapter 4, a method is presented to derive a marginal-income function and to calculate economic values for this case. The method is illustrated by the case of ultimate pH.

Finally, in Chapter 5, the effects of including meat quality in the breeding goal of a pig breeding program are discussed for each of the tiers of a pig meat production chain. Using the results from the earlier chapters, five cases were evaluated each describing three different breeding goals and selection criteria. These cases are chosen to illustrate the effects on response to selection of population means for the meat quality traits and consequently of different economic values. Furthermore, the effects of including meat quality traits in both breeding goal and selection index are illustrated. Based on the results of the case studies, the usefulness of inclusion of meat quality in the breeding goal of a pig breeding program is discussed.

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CHAPTER 1

BREEDING FOR PIG MEAT QUALITY IN HALOTHANE-NEGATIVE POPULATIONS - A REVIEW

R. Hovenier, E. Kanis, Th. van Asseldonk and N.G. Westerink

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BREEDING FOR PIG MEAT QUALITY IN HALOTHANE-NEGATIVE POPULATIONS - A REVIEW

ABSTRACT

In this paper a review is given about pig meat quality in general and about breeding for a better pig meat quality in halothane-negative populations. Important traits to determine organoleptic and technological meat quality are pH, meat colour, amount of intramuscular fat, water-holding capacity and meat tenderness. Methods to measure those traits are reviewed. Mean heritabilities of the meat quality traits range from 0.20 for water-holding capacity and ultimate pH to 0.50 for amount of intramuscular fat. A review of the genetic correlations between production traits and meat quality traits show large ranges, especially for correlations with water-holding capacity. Mean genetic correlations between daily gain and meat quality traits will be zero or slightly negative except for the genetic correlation with amount of intramuscular fat which will be about 0.35. Mean genetic correlations between backfat thickness and meat quality will be positive, mean genetic correlations between lean meat content will be negative. It is concluded that meat quality will become worse if no attention is paid to meat quality in future breeding programs. Finally, some further points for research are discussed.

Keywords: Pigs, Parameters, Meat Quality

INTRODUCTION

Forty percent of all meat produced in the world is pork. FAO (1990) estimated world pork production in 1989 at over 67 million tons (Table 1). In the same year beef, veal and buffalo represented about 30%, lamb, sheep and goat meat about 5% and poultry about 22%. The quantity of pork produced differs greatly in various areas due to differences in production, market conditions and alimentary customs. The largest pork producers were Asia and Europe, together producing about 72% of the world pork production (FAO, 1990).

These data demonstrate the significance of pork. After a continuous increase in the consumption of pork in the E.E.C. for 15 years, however, the increase of pork consumption has tended to stagnate and is expected to be less then 1% per year until the year 2000 (P.V.V., 1989).

To compete successfully with other meat sources, it will be necessary to produce pork conforming to the demands of consumers, distributors, processing

Table 1. World meat production in 1989.

	Total x1000 tons	Pig		Beef, Veal and Buffalo		Lamb, Sheep and Goat		Poultry	
		x1000 tons	%	x1000 tons	%	x1000 tons	%	x1000 tons	%
Europe	42,923	21,745	50.7	10,511	24.5	1,418	3.3	8,254	19.2
U.S.S.R.	19,970	6,750	33.8	8,800	44.1	878	4.4	3,250	16.3
Asia	44,340	26,606	60.0	4,838	10.9	3,348	7.6	8,587	19.4
Africa	8,230	488	5.9	3,625	44.1	1,481	18.0	1,708	20.8
North and Central America	36,299	9,547	26.3	14,028	38.7	248	0.7	12,087	33.3
South America	13,047	1,930	14.8	7,100	54.4	346	2.7	3,471	26.6
Oceania	4,052	395	9.8	2,021	49.9	1,120	27.6	460	11.4
World	168,860	67,460	40.0	50,923	30.2	8,838	5.2	37,817	22.4

Source: FAO (1990)

industry and slaughter houses. Main problems of pig meat in comparison with veal or poultry meat, for example, are the large variation in quality of pig meat and the bad health image of pork, mainly due to the image of pig meat to be fat. Especially poultry has a better health image and is more constant in quality than pig meat (Sebranek, 1982; P.V.V., 1989).

An important meat quality deficiency is pale, soft and exudative (PSE) meat. The introduction of the halothane test by Eikelenboom and Minkema (1974) made it possible to select effectively against PSE meat. Breeding strategies against halothane susceptibility resulted in a decrease of halothane susceptibility from 36% in 1977 to 8% in 1984 for Dutch Landrace (Eikelenboom, 1985). Even in halothane-negative populations however, a considerable amount of genetic variance for meat quality remains (e.g. Schmitten et al., 1984 and Cameron, 1990). In this review no attention will be paid to the influence of the halothane gene on meat quality.

Because consumers are the ultimate users, they determine the quality demands of meat. However, all operators in the production chain, from breeders to consumers, will add their demands to the demands of the next operator in the chain (Sebranek, 1982; Russo, 1988; Lundström, 1990).

This paper reviews the traits that can be used to determine pig meat quality and the meat quality demands of both consumers and industry. The review is limited to those quality aspects that are dependent on the animal and that possibly are influenced by breeding, management, feeding, slaughtering and handling, etc.

Furthermore, no attention will be paid to fat quality, which is also a part of total meat quality. Levels and variance of important meat quality traits are discussed. Heritabilities, correlations among meat quality traits and correlations between production and meat quality traits are included. Although no attention is paid to the influence of the halothane gene on meat quality it was inevitable to use information from halothane-susceptible populations because only a limited amount of literature is based on research in halothane-negative populations only. Finally, some areas for further research are discussed.

MEAT QUALITY CONCEPT

Meat quality characteristics in general can be divided in four quality factors (Hofmann, 1987; Russo, 1988):

1. Organoleptic characteristics
2. Technological characteristics
3. Nutritional characteristics
4. Hygienic characteristics (Table 2)

The organoleptic traits are those that influence the decision of the consumer to buy the meat in the shop and, after consumption, to buy it a subsequent time. Nutritive quality concerns the chemical composition and the dietetic properties of the meat. Hygienic quality concerns the absence of microorganisms and of residues of drugs, pesticides and additives. Finally, technological quality implies the suitability of the meat for preparation and packing for distribution, the suitability for cooking and processing into various products and for keeping (Sebranek, 1982; Hofmann, 1987; Russo, 1988).

Based on these four factors the following definition of meat quality can be given:

> **Meat quality is the sum of organoleptic, nutritional, hygienic and technological properties of the meat**
>
> (Hofmann, 1973)

or even shorter:

> **Quality is the sum of all the quality factors**
>
> (Hofmann, 1987).

The above characteristics are called intrinsic meat quality factors. Besides these intrinsic factors, extrinsic factors, such as motivational and psychological factors influence meat quality (Wismer-Pedersen, 1979; Russo, 1988). These factors include history, knowledge, religious ethics, fashion, price, the way meat is produced, etc.

Table 2. Four main pork quality characteristics.

I. Organoleptic characteristics	II. Technological characteristics
- colour	- water content
- exudation loss	- water holding capacity
- marbling	- connective tissue content
- smell	- pH
- taste	- salt absorption capacity
- juiciness	- unsaturated fatty acids content
- tenderness	
- texture	
III. Nutritional characteristics	**IV. Hygienic characteristics**
- protein content	- bacterial load
- caloric value	- pathogenic germs
- vitamin content	- pH value
- mineral content	- water activity
- lipid content	- reduction potential
- saturated fatty acids content	- nitrate
- cholesterol content	- pickle salt
- utilization	- drugs residues
- digestibility	- anabolic agents residues
- biological value	- pesticide residues
	- heavy metal residues

Hofmann, 1987; Russo, 1988.

Because of its importance for the purchase of meat, organoleptic quality is considered to be the most important part of meat quality and, therefore, was examined in most meat quality research (Hofmann, 1987). Nutritional and health characteristics and extrinsic factors such as animal welfare, however, are becoming more important (Lister, 1990).

Several of the characteristics in Table 2 can not be used to select for better pork quality. To improve pork quality by selection, only those traits can be focused on that are heritable, not to mention the economic values of the traits. Improving non-heritable meat quality traits must be done by improving hygiene in the whole chain from producer to consumer, by improving processing, or by correcting consumer misconception and changing consumer habits, keeping in mind the demands of different markets (Sebranek, 1982; Russo, 1988). However, hygienic quality also can be improved by breeding. When animals have increased resistance against diseases, for example, the use of medicine can be decreased and hygienic quality may be increased by for example reducing the risk of residues.

PORK QUALITY TRAITS

Organoleptic Quality

The first impression a consumer gets when buying pork is appearance. Intensity and uniformity of colour, together with the amount of visible fat and drip loss, affect the appearance of the meat (Sebranek, 1982; Barton-Gade et al., 1988; Steenkamp en Van Trijp, 1988). However, appearance of the meat is in general not a good guide to eating quality. Reason for this may be lack of knowledge of the consumer.

Colour intensity and uniformity are the result of the amount of muscle pigment present, its distribution over the muscle and its chemical state. The effect of pigment on meat colour is influenced by the pH, especially for fresh meat. Based on consumer perception tests, both low and high pH influence the colour in a negative way (Barton-Gade et al., 1988). Selection for a higher amount of pigment is necessary because paleness, caused by a faster-than-normal acidification of the muscle, is enhanced by a low muscle pigment concentration (Warriss et al., 1990). By using measurements with grading probes, that use light in the visible part of the light spectrum, selection for darker meat colour will result in a higher pigment concentration (Lundström et al., 1988; Warriss et al., 1990).

Palatability characteristics (flavour, tenderness, juiciness, texture) are subjective characteristics and are difficult to measure in an objective way. Tenderness is the most important criterion, although palatability characteristics are highly intercorrelated (Barton-Gade et al., 1988). Besides its influence on appearance, intramuscular fat content seems also to influence tenderness (Barton-Gade and Bejerholm, 1985; Bejerholm and Barton-Gade, 1986; DeVol et al., 1988; Ellis et al., 1990). Other authors did find little or only a small effect of amount of fat on tenderness (Rhodes, 1970; Wood et al., 1981; Kempster et al., 1986; Cameron, 1990). A consumer panel found a significant effect of amount of intramuscular fat on tenderness (Wood et al., 1988). In the same investigation, however, a trained taste panel did not find a significant effect. Each panel found a significant effect of amount of intramuscular fat on the juiciness of the meat. One reason for this contradiction in results may be the range of intramuscular fat levels found in the various studies (Ellis et al., 1990). In the Danish studies (Barton-Gade and Bejerholm, 1985; Bejerholm and Barton-Gade, 1986) and the study of Ellis et al. (1990) the ranges in absolute values for fatness were much greater than in the U.K. studies (Wood et al., 1981; Kempster et al., 1986; Cameron, 1990), where there were poor relationships with eating quality. A reason for these differences in absolute values for fatness may be the low slaughter weight (about 80 kg live weight) used in the U.K.

Intramuscular fat level influences meat tenderness up to an intramuscular fat level of 2.5 to 3.0% (Bejerholm and Barton-Gade, 1986 and DeVol et al., 1988). Below this level diminished eating quality is found for lower percentages of intramuscular fat. Intramuscular fat levels higher than 3.0%, however, did not improve meat tenderness. Because of these results and the fact that many consumers will reject meat with a visible and thus a high amount of intramuscular fat (Barton-Gade and Bejerholm, 1985), the optimal level of intramuscular fat will be 2.5 to 3.0%.

Water-holding capacity is also important for both appearance and tenderness. Muscles with low water-holding capacity are dryer tasting and lose more water during processing, storage, transport and display, resulting in a less pleasing visual appearance (Kauffman et al., 1986). The relationship between water-holding capacity, meat tenderness and ultimate pH was discussed by Gault (1985), who concluded that the influence of pH on meat tenderness is primarily due to the relation between pH and water-holding capacity and that higher water-holding capacity results in higher tenderness. Furthermore, Gault (1985) concluded that the relationship between water-holding capacity and tenderness is not linear but that higher water-holding capacity has diminishing benefit on tenderness.

Summarized, important traits for organoleptic quality appeared to be meat colour, amount of intramuscular fat, water-holding capacity and tenderness. Ultimate pH is also an important trait because of its relations with colour, water-holding capacity and tenderness.

Technological, Nutritional and Hygienic Quality

The characteristics given above are considered from the point of organoleptic quality. For other quality factors determining overall meat quality, however, we deal to a large extent with the same traits. Lower water-holding capacity is a general complaint of the processing industry and supermarkets (Russo, 1988). For the processing industry, water-holding capacity is of importance because of lower production yields due to higher drip losses. Total liquid loss occurring in the various distribution phases, is 4-5% of the initial weight in PSE carcasses, at maximum (Kauffman and Hedrick, 1972; cited by Russo, 1988). Because this estimate is for PSE carcasses this result will be an extreme. In France, exudation loss of fresh meat is estimated to represent at least 1.5% (Jacquet, 1988). The decrease in water-holding capacity in meat from halothane-positive pigs lowers the production yield of cooked ham by an average of 2 to 3% (Kauffman and Hedrick (1972), cited by Russo, 1988; Sellier, 1988). However, over the last twenty years in Parma ham production, where PSE cuts are not used, an average increase of 4-5% to 27-28% in seasoning loss has been calculated (Russo, 1988).

Considering ultimate pH, the processing industry requires meat ranging between 5.5 and 5.8. A higher pH is undesirable, especially for ham or salami production as it hinders salt penetration and promotes microbial alterations; a lower pH is also undesirable, especially for cooked and seasoned ham because of the coherence with larger weight losses during production (Russo, 1988).

From the nutritional point of view, meat is a good source of essential amino acids and, to a lesser extent, of certain minerals and vitamins. Seuß (1990) summarizes the nutritional value of meat and meat products of different species in comparison with other foodstuffs. Lawrie (1985) gives a comprehensive overview of the role of meat in human nutrition. Although each of the single characteristics determining nutritional quality (see Table 2) have a genetic compound, it is not possible to choose two or three traits that for the most part determine nutritional quality. Therefore, no further attention is paid to nutritional quality.

Most traits relating to hygienic quality are non-heritable traits (see Table 2) and will therefore not be discussed here. An exception is pH, which has a relation with keeping quality of the meat. As stated before discussing technological quality, keeping quality will decrease when the ultimate pH becomes higher than 5.8.

It can be concluded that there are two important criteria affecting technological quality, namely water-holding capacity and ultimate pH. For hygienic quality, ultimate pH is an important heritable trait.

MEASURING MEAT QUALITY

Meat Colour

Several methods are used to measure meat colour: Göfo-measurement (mainly used in Germany; e.g. Scheper, 1979; Horvath et al., 1984; Schmitten et al., 1984; Sönnichsen et al., 1984[a]; Busse and Groeneveld, 1986), EEL-reflectance measurement (Lundström et al., 1979; Malmfors and Nilsson, 1979; Lundström et al, 1984; Fjelkner-Modig and Persson, 1986; Johansson, 1987; Johansson et al., 1987), description of the colour according to the CIELAB colour space (Merks et al., 1989; Cameron et al., 1990; Oster and Fewson, 1990) and Japanese colour scale (Merks et al., 1989; Table 3). The Göfo- and EEL-measurements are reflectance methods at a single wavelength, CIE covers a description including lightness, hue and saturation and the Japanese colour scale refers to comparison of the colour of the meat with a standard colour scale.

For pig meat Göfo-values vary from 47.2 to 60.5 (the higher the value the darker the meat), the standard deviation is about 11 points. For EEL-reflectance, values vary from 19.5 to 25.6 (the higher the value the paler the meat), the standard deviation is about 4 points. For CIELAB colour space, colour is measured with reference to lightness (L*; 0=black, 100=white) and two colour co-ordinates

Table 3. Important meat quality traits, methods to measure, repeatabilities, means and standard deviations and average heritabilities.

Trait	Group of interest	Method of measurement	Repeatability	Means	Standard deviation	Heritability
Colour	consumer	Göfo	-	47.2-60.5	11	0.30
		E.E.L.	-	19.5-25.6	4	
		CIELAB	0.47-0.85	50.9-56.1	4	
		Japanese scale	-	-	-	
		subj. score[1]	-	-	-	
Amount of intramuscular fat	consumer/ industry	Fosslet	-			0.50
		Soxleth	0.96	0.9-4.5%	0.5-1.6%	
		infra-red	-			
Water-holding capacity	consumer/ industry	drip loss	0.39-0.82	2-8%	0.2-4.0%	0.20
		cooking loss	0.41-0.69	15-33%	2-6%	
		stand. laboratory methods[1]	0.49-1.00	-	-	
		filter paper and other fast methods[1]	0.00-0.82	-	-	
Tenderness	consumer	WB-shearforce	0.42	19-56N	4-9N	0.30
		taste panel[1]	0.55	-	-	
pH	consumer/ industry	pH_{45}	-	5.56-6.62	0.10	0.30
		ultimate pH	-	5.41-6.15	0.12	0.20

[1] Because several scales or methods are used no means and standard deviations are given.

a* and b*. The extreme colours of a* are red (positive) and green (negative), the extreme colours of b* are yellow (positive) and blue (negative; MacDougall, 1986). Values for L* range from 50.9 to 56.1 (standard deviation about 4 points), for a* from 3.9 to 7.7 (standard deviation about 1.5) and for b* from 7.2 to 14.4 (standard deviation about 1.5). The range of means and the standard deviations for a* and b* are wide. Because the muscle analyzed and the time of measuring after slaughter was the same for the given studies, reason for this may be that different breeds were analyzed.

No repeatabilities are found in literature for Göfo- and EEL colour measurements or for the meat colour measurement using Japanese colour scale (lower values for light meat, higher values for dark meat). For CIELAB colour space the repeatability of L* has been estimated to be 0.85 (Oster and Fewson, 1990). However, Cameron et al. (1990) estimated for L* a repeatability of 0.47. Repeatabilities for a* (0.57 and 0.61) and b* (0.76 and 0.67) were more in agreement for both studies.

Another way to measure meat colour is using subjective scores (e.g. Pedersen, 1979; Schwörer et al., 1980). Subjective methods are difficult to use because of the possible influence of environmental factors and difficulties in keeping the standards at a constant level (Pedersen, 1979).

Amount of Intramuscular Fat

Comparisons of amount of intramuscular fat are reviewed by Sellier (1988) and Schwörer (1988). The amount of fat ranged from 0.9% to 4.45% of the fresh meat (Table 3). The amount of fat differ to a large extent by breed: Belgian Landrace ranged from 0.9% to 2.4%, whereas Duroc ranged from 2.69% to 4.45%. The standard deviation is higher for populations with a higher mean and varies from 0.3 to 1.6. Repeatabilities of the intramuscular fat measurement are scarce in literature. Only Cameron et al. (1990) give a repeatability of 0.96 using extraction of the fat in a Soxleth apparatus with diethyl ether.

There are several methods to measure amount of intramuscular fat. Many laboratories use the Soxleth-method (Schwörer et al., 1987). Other reproducible methods are Fosslet-extraction (Merks et al., 1989) and infrared measurement (Schwörer et al., 1987). The correlation between Soxleth and Fosslet measurements was 0.99 (Van der Wal et al., 1991) and the correlation between Soxleth and infrared measurement was 0.92 (Schwörer et al., 1987).

Water-Holding Capacity

Mean values for drip loss vary from 1.9% to over 8% (Lundström et al., 1979; Malmfors and Nilsson, 1979; Scheper, 1979; Schwörer et al., 1980; Lundström and Malmfors, 1985; Kauffman et al., 1986; Merks et al., 1989; Table 3). Results are difficult to compare, however, because of the different methods used and the time over which the loss is measured. Standard deviations range from 0.2% to about 4%. Cooking losses range from 15% to 33% (Lundström et al., 1979; Malmfors and Nilsson, 1979; Scheper, 1979; Kauffman et al., 1986; Merks et al., 1989; Table 3); standard deviations range from 2% to 6%. Also cooking losses found in different studies are hard to compare because of the great number of factors influencing the cooking loss, like for example the temperature used.

Kauffman et al. (1986) investigated several methods to estimate water-holding capacity in the *M. longissimus*, namely weight loss measurements such as drip and cooking loss, standard laboratory measurements such as swelling test, high-speed centrifugation or permittivity test and filter paper press and other rapid methods. Repeatabilities for drip loss methods varied from 0.61 to 0.82, the highest for the measurement with a sample of standardized size. Repeatabilities for cooking losses varied from 0.41 to 0.69. Repeatabilities of standard laboratory measurements ranged from 0.49 to 1.00 and repeatabilities of filter paper tests and other rapid methods ranged from 0.00 to 0.82. Lundström and Malmfors (1985) found repeatabilities of 0.39 for vacuum packed samples to 0.64 for the capillary volumeter method which results were some lower than those found by Kauffman et al. (1986). Reason for this may be the fact that Lundström and Malmfors did not use consecutive slices for the measurements of one type of water-holding capacity. Therefore, non-systematic variation that might occur along the *M. longissimus* will lower the repeatability estimates (Lundström and Malmfors, 1985). Based on the repeatabilities, Kauffman et al. (1986) concluded that drip loss methods were appropriate to estimate water-holding capacity, if time required to obtain results is not important and especially when size is standardized. One disadvantage of laboratory tests is the large initial investments required for equipment.

Tenderness

Two methods are used to evaluate tenderness: assessment by a taste panel (Jensen et al., 1967; Cameron, 1990) and measurement by the Warner-Bratzler shearforce (Jensen et al., 1967; Arganosa et al., 1969; Malmfors and Nilsson, 1979; Scheper, 1979; Merks et al., 1989; Table 3). Use of panels, however, can give rise to problems due to environmental factors or to the fact that levels are hard to keep constant (Pedersen, 1979).

Mean values for Warner-Bratzler shearforce range from 26.2 to 40.7 N for recent studies (Malmfors and Nilsson, 1979; Scheper, 1979; Merks et al., 1989). However, Stumpe (1989) found a mean Warner-Bratzler shearforce of 56.0 N. Jensen et al. (1967) and Arganosa et al. (1969) found shearforce values from 18.5 to 26.0 N. Standard deviations range from 4 to 9 N.

When considering to use the Warner-Bratzler shearforce value as a measure of meat tenderness, it is necessary to know the correlations between those two traits. Absolute correlations between Warner-Bratzler shearforce and taste panel scores found in literature vary from 0.27 to 0.78 (Stumpe, 1989). Low repeatability of taste panel judgements may be a reason for a low correlation between shearforce and panel tenderness scores. However, repeatabilities for taste panel and shearforce are scarce in literature but are given by Stumpe (1989). She found a repeatability for Warner-Bratzler shearforce of 0.42 and for tenderness assessed by taste panel of 0.55.

pH

In their review Bendall and Swatland (1988) surveyed mean pH-value 45 minutes after slaughtering (pH_{45}) and mean ultimate pH-values (pH_u). The pH_{45} ranged from 5.56 to 6.62 and the pH_u ranged from 5.41 to 6.15 (Table 3). The overall mean pH_u in *M. longissimus* and *M. semimembranosus* is 5.52 with a range of ±0.12 when omitting data from England, Ireland and Canada, which had a pH_u-

value of 5.81 with a range of ±0.08. It is not clear whether those differences have a biological basis or whether they are caused by differences in the methods used to measure pH, but that the latter is most likely (Bendall and Swatland, 1988).

In general, pig meat pH is measured by using an glass electrode, but new solid-state pH electrodes are being developed. Although Bendall and Swatland give a long list of potential sources of error in the measurement of muscle pH, repeatabilities for pH-measurements are not found in literature.

GENETIC PARAMETERS

Heritabilities

Heritability estimates of meat quality traits are given graphically (Figure 1) and overall mean heritabilities are given in Table 3. Heritability estimates for meat colour are reviewed by Sellier (1988) and Matassino (1988). There were no differences for heritability estimates between the different colour measuring methods. When heritabilities for meat colour are compared by breed, only small differences can be found. Mean heritability for meat colour for Landrace is 0.35 and for Yorkshire and Large White 0.30. Overall heritability averaged 0.30.

Heritability estimates of the amount of intramuscular fat are reviewed by Sellier (1988) and Schwörer et al. (1990) and ranged from 0.26 to 0.86. Overall heritability averaged 0.50. These estimates show the possibility of preventing a decline of intramuscular fat by including the amount of intramuscular fat in a selection program.

The heritabilities for water-holding capacity show a large range from 0.00 to 0.63, probably due to the different methods used to measure the trait. However, clear differences between the methods were not found. Because of the different measuring methods it is also difficult to compare heritabilities across breeds. Heritability for Landrace pigs seem to be lower than those for Large White or Yorkshire. This was also concluded by Sellier (1988). Average heritability for water-holding capacity was about 0.20.

Heritabilities for tenderness assessed by shearforce measurement and tenderness assessed by taste panels vary from 0.21 to 0.37. No differences can be found between breeds nor between shearforce and panel results.

Heritabilities of pH_{45} and pH_u were reviewed by Sellier (1988) and Matassino (1988). Heritabilities averaged 0.18 for pH_{45} and 0.22 for pH_u. Heritabilities reviewed here average 0.30 for pH_{45} and 0.20 for pH_u. Only small differences are found between breeds. Mean heritability was 0.25 for Landrace pigs and 0.20 for Large White and Yorkshire pigs.

Genetic and Phenotypic Correlations with Production Traits

Genetic correlations between production traits and quality traits are reviewed by Sellier (1988) and Schwörer et al. (1990).

Figure 2 shows large ranges for genetic correlations between technological meat quality traits and production traits. The absolute value of the correlation depend on breed or population (Sellier, 1988). According to Sellier (1988), the genetic antagonism between production and meat quality tends to be stronger if:

- the production parameter is more related to muscular development;
- the meat quality parameter is an indicator for PSE-meat (pH_{45}, meat colour, drip loss); and
- the halothane-sensitivity gene is segregating in the population.

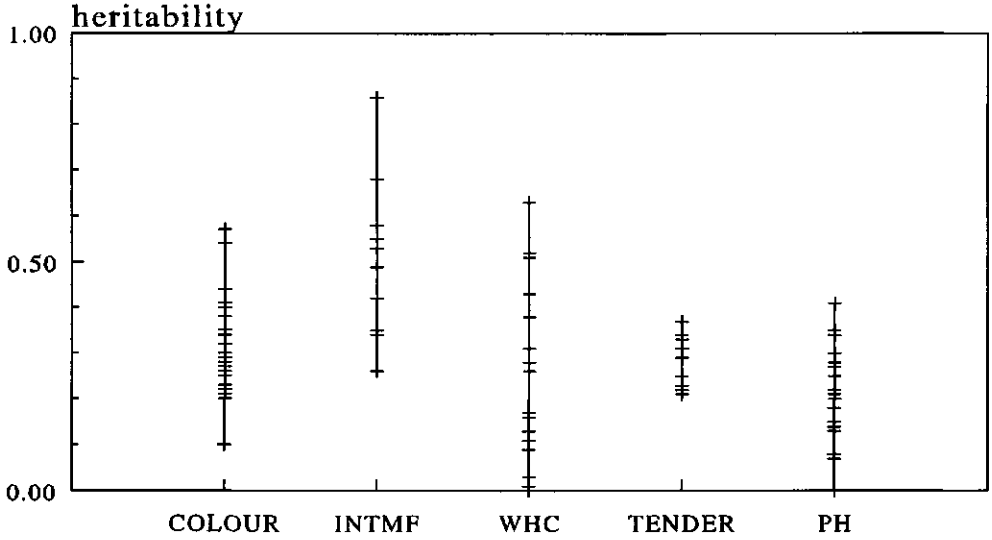

Figure 1. Heritability estimates for meat colour (COLOUR), amount of intramuscular fat (INTMF), water-holding capacity (WHC), tenderness (TENDER) en pH (PH)[1].

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[1] References: Jensen et al., 1967; Arganosa et al., 1969; Lundström, 1975; McGloughlin and McLoughlin, 1975; Malmfors and Nilsson, 1979; Pedersen, 1979; Scheper, 1979; Lundeheim et al., 1980; Schwörer et al., 1980; Ollivier et al., 1981; Ollivier, 1983; Sönnichsen et al., 1984[a]; Busse and Groeneveld, 1986; Johansson, 1987; Johansson et al., 1987; Schwörer et al., 1987; Cole et al., 1988; Bout et al., 1989; Ianssen and Sehested, 1989; Cameron, 1990.

When these conditions are met, genetic antagonism between production traits and meat quality traits can become very pronounced. This may be reason for the high negative genetic correlation between water-holding capacity and daily gain (-.80) or percentage premium cuts (-.72) for Swiss Landrace (Schwörer et al., 1980).

Genetic correlations between daily gain and meat quality parameters show a large range (Figure 2). Mean genetic correlations are zero or slightly negative, except for the correlation with amount of intramuscular fat. Genetic correlations between daily gain and amount of intramuscular fat for animals fed ad libitum range from 0.14 to 0.61. No genetic correlations between daily gain and amount of intramuscular fat are available for restricted fed animals. Ranges for the

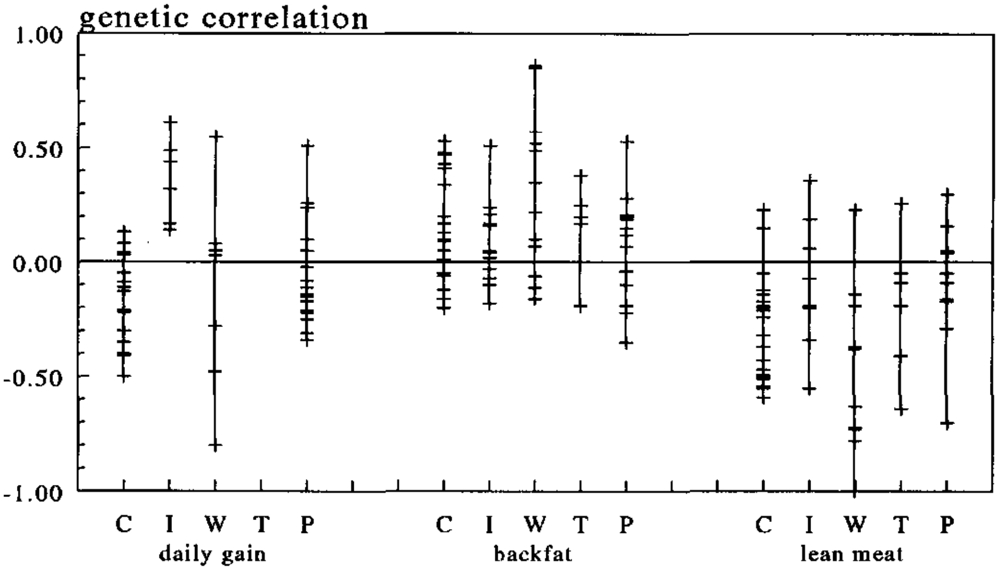

Figure 2. Genetic correlations between production traits and meat colour (C), amount of intramuscular fat (I), water-holding capacity (W), tenderness (T) and ultimate pH (P)[1].

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[1] References: Jensen et al., 1967; Arganosa et al., 1969; Lundström, 1975; McGloughlin and McLoughlin, 1975; Malmfors and Nilsson, 1979; Pedersen, 1979; Lundeheim et al., 1980; Schwörer et al., 1980; Ollivier, 1983; Sönnichsen et al., 1984^b; Busse and Groeneveld, 1986; Johansson, 1987; Johansson et al., 1987; Schwörer et al., 1987; Cole et al., 1988; Bout et al., 1989; Ianssen and Sehested, 1989; Cameron, 1990.

phenotypic correlations are smaller then for genetic correlations and all phenotypic correlations are near zero (Figure 3). Phenotypic correlations between daily gain and amount of intramuscular fat range from 0.07 to -.05 for ad libitum fed animals, for restricted fed animals from 0.06 to -.52.

Genetic correlations between backfat thickness and meat quality parameters (Figure 2) show considerable variation, but generally thicker backfat is related to better meat quality. The genetic correlation between backfat thickness and water-holding capacity shows the largest range. Reasons for this may be the different methods to measure water-holding capacity and other arguments as discussed by Sellier (1988). Mean genetic correlations are between 0.1 and 0.3. Phenotypic

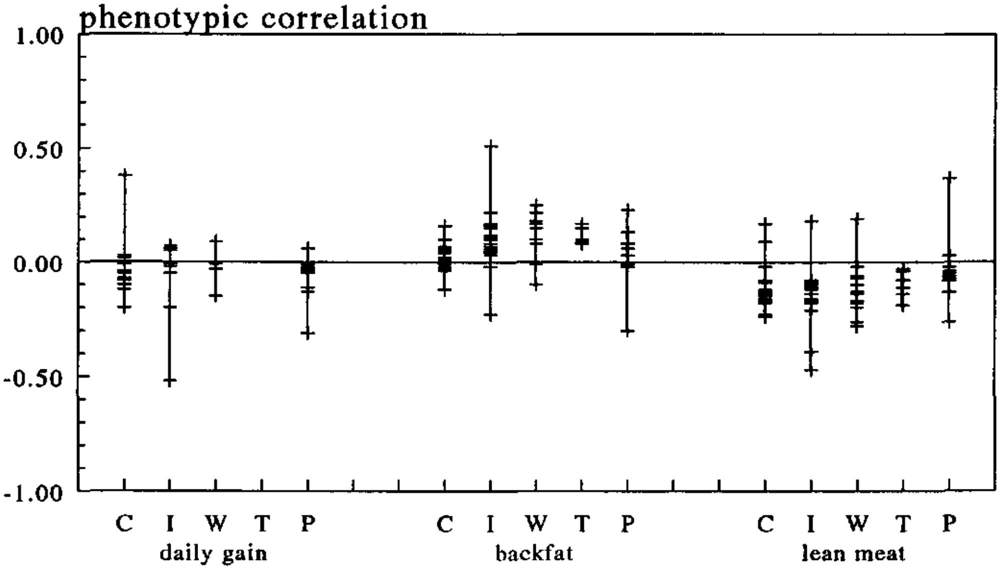

Figure 3. Phenotypic correlations between production traits and meat colour (C), amount of intramuscular fat (I), water-holding capacity (W), tenderness (T) and ultimate pH (P)[1].

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[1] References: Jensen et al., 1967; Arganosa et al., 1969; Lundström, 1975; Malmfors and Nilsson, 1979; Pedersen, 1979; Lundeheim et al., 1980; Schwörer et al., 1980; Sönnichsen et al., 1984^b; Busse and Groeneveld, 1986; Fjelkner-Modig and Persson, 1986; Johansson, 1987; Johansson et al., 1987; Schwörer et al., 1987; Bout et al., 1989; Ianssen and Sehested, 1989; Cameron, 1990.

correlations between backfat thickness and meat quality show a much smaller range than genetic correlations (Figure 3), but generally phenotypic correlations between backfat thickness and meat quality are slightly positive.

Genetic (Figure 2) and phenotypic (Figure 3) correlations between lean meat content and meat quality are negative in general and contrary to those between backfat thickness and meat quality.

Only a few studies give correlations between feed conversion ratio and meat quality (McGloughlin and McLouglin, 1975; Pedersen, 1979; Ollivier et al., 1981; Andersen and Vestergaard, 1984; Busse and Groeneveld, 1986; Johansson et al., 1987; Ianssen and Sehested, 1989). Genetic and phenotypic correlations between feed conversion ratio and meat quality are unfavourable in general. Genetic correlations average about 0.10 and range from -.34 to 0.36. Phenotypic correlations average about 0.05 and range from -.14 to 0.15.

HETEROSIS

Because of the use of crossbreeding in pig breeding programs, it is important to have knowledge about possible heterosis effects on meat quality traits. For most meat quality traits and for most breed combinations, however, it has been shown that they are additively inherited (Sellier, 1987). As stated by Sellier (1987) this assumption does not hold for:

- pH_{45} and other PSE-traits in crosses with Pietrain;
- pH_u and traits influenced by ultimate pH in crosses with Hampshire.

Crosses between Pietrain and stress-resistant breeds are closer to the stress-resistant breed for pH_{45} and for denaturation of sarcoplasmic and myofibrillar proteins (protein solubility is regarded as one of the best criteria for PSE evaluation). However, results for meat colour were somewhat less consistent (Sellier, 1987).

Looking at Hampshire crosses, the acid meat condition often exhibited by the Hampshire breed seems to be inherited in a more or less dominant way (Sellier, 1987). By assuming that the acid meat condition is due to the *RN*-gene this dominant inheritance is explained. Evidence for this assumption is given by Le Roy et al. (1990).

No estimates of the effects of heterosis on the amount of intramuscular fat are found in literature. Breed crosses seem to be more or less intermediate between parental breeds in the amount of intramuscular fat, so that additive inheritance can be assumed (Schwörer et al., 1989). However, Sellier (1988) stated that the effect of heterosis on the amount of intramuscular fat could be slightly negative which was based on results of McGloughlin et al. (1988) and Barton-Gade (1987).

DISCUSSION

A recapitulation is given of some of the subjects that are reviewed (Table 3). There are five main points of interest for meat quality: meat colour, amount of intramuscular fat, water-holding capacity, tenderness and pH. Several methods are available to measure each of them. Repeatabilities are not known for all of them, however, which makes it difficult to compare the several methods. Some information is known about relations between the several methods to measure the amount of intramuscular fat (Schwörer et al., 1987; Van der Wal et al., 1991), to measure water-holding capacity (Lundström and Malmfors, 1985; Kauffman et al., 1986) and tenderness (e.g. Stumpe, 1989).

Heritability of meat quality traits are moderate to high, ranging from 0.20 for water-holding capacity to 0.50 for amount of intramuscular fat. The ranges for heritability found in literature stress the need to estimate heritability of meat quality in the population under consideration. The same is true for the genetic correlations between production parameters and meat quality traits.

Possible reasons for the large ranges of the heritabilities and genetic correlations found are difficult to find. The first reason may be the relatively small data sets used to estimate genetic parameters, resulting in estimates with large standard errors. Another reason may be the role of the halothane gene as suggested by Brascamp et al. (1980). They theoretically deduced that over 60% of the genetic variance of meat quality was due to presence of the *n*-locus. But when heritabilities for the Landrace are compared with those for Yorkshire or Large White only small differences can be found. This may be an indication that selecting against the halothane gene will have only a minor influence on heritabilities of meat quality parameters. Brascamp et al. (1980) concluded that the Hal-locus can cause differences, but genetic correlations between production traits and meat quality will be unfavourable for both halothane-susceptible and halothane-resistant populations. In the studies reviewed here, no clear differences in genetic correlations can be found between Landrace and Yorkshire or Large White. Another possible factor of influence is the feeding regime. No clear differences can be found between ad libitum fed animals and restrictedly fed animals, however, for heritabilities of meat quality traits or correlations between production traits and meat quality traits.

Presently, main emphasis of pig breeding programs is put on increasing growth rate and lean meat content and on decreasing backfat thickness and feed conversion ratio. Based on genetic correlations between the production traits and meat quality as reviewed before, it may be concluded that meat quality will decrease if no attention is paid to meat quality in the future.

Economic values for the traits of interest are necessary for breeding for meat quality. Economic values currently used for meat quality traits result in a restriction of meat quality at the present level or give a slight improvement (Russo, 1988). However, estimates for true economic values are not available. Table 3 indicates the user of interest for each meat quality trait. This may be a starting point for research to the economic values of meat quality.

Another point that may need more research is non-linearity of economic values of meat quality traits and how to include meat quality in pig breeding programs. Amount of intramuscular fat and pH are traits with optimum values, but meat colour and tenderness may be optimum traits as well. When economic values are used for meat quality traits, it will be necessary to include them in a selection index in such a way that, when the optimum is reached, the trait is kept constant.

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CHAPTER 2

REPEATABILITY OF TASTE PANEL TENDERNESS SCORES AND THEIR RELATIONSHIPS TO OBJECTIVE PIG MEAT QUALITY TRAITS

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REPEATABILITY OF TASTE PANEL TENDERNESS SCORES AND THEIR RELATIONSHIPS TO OBJECTIVE PIG MEAT QUALITY TRAITS

ABSTRACT

Repeatabilities of 12 meat quality measurements were calculated as a value for the accuracy of those measurements. Sixty-four Duroc and Dutch-Yorkshire boars and gilts were slaughtered during 8 weeks. The repeatabilities between carcass halves within animals were 0.53 for repeated taste panel tenderness scores based on 12.4 observations of different panelists per mean, 0.08 for two repeated tenderness scores of different panelists within one animal, 0.50 for two repeated tenderness scores of one panelist within one animal and 0.41 for repeated measurements of maximum shearforce. Repeatabilities of the other meat quality traits ranged from 0.29 for cooking loss to 0.76 for the Minolta L^* colour co-ordinate. The phenotypic correlation between tenderness assessed by a panel and maximum shearforce was -.50. The phenotypic correlation between those traits corrected for measurement errors was -.74. A correlation of zero was found between the total amount of collagen and meat tenderness, between amount of intramuscular fat and tenderness and between ultimate pH and tenderness. The other correlations with meat tenderness ranged from -.00 for Minolta b^* colour co-ordinate to -.44 for drip loss. It was concluded that the measurement of maximum shearforce can be used as an effective indicator for pig meat tenderness.

Key Words: Pork, Quality, Tenderness, Collagen, Repeatabiity, Correlation

INTRODUCTION

The trend toward production of leaner pigs is accompanied by frequent comments by the meat industry about the increasing incidence of meat quality problems (Kempster et al., 1986). Furthermore, Steenkamp and Van Trijp (1988) found that consumers judge pig meat to have a low sensoric quality compared to beef, poultry and fish. To prevent further deterioration of meat quality, improvement of meat quality is included among the goals of pig breeding programs (Malmfors et al., 1980; Vestergaard, 1985). To incorporate meat quality parameters in a breeding program, objective and low-priced measurements must be available.

For tenderness two objective measurements are the Warner-Bratzler shearforce and the total amount of collagen (e.g. Gacula et al., 1971; Hovenden et al., 1979;

Stumpe, 1989). The correlation between maximum shearforce and pork tenderness measured by taste panels ranges from -.27 to -.78 (Stumpe, 1989). Low repeatability of taste panel judgments may be a reason for a low correlation between shearforce and panel tenderness scores.

With regard to the total amount of collagen, Bailey (1988) stated that the quality of the collagen (e.g. collagen solubility) should give a better correlation with texture than the total amount of collagen. However, results are conflicting. He also stated that the amount of collagen becomes important when the quality of the collagen is the same in different muscles or in different animals. Because pigs are slaughtered at a reasonably constant age the quality of the collagen in different animals may be expected to be similar (Bailey, 1988). Therefore, total amount of collagen may be an important trait.

The aim of this research is to investigate the relationships between tenderness scored by a taste panel and objectively measured meat quality parameters and to calculate repeatabilities of all meat quality measurements, including tenderness.

MATERIALS AND METHODS

Data

Data were obtained during 8 weeks in the period February until April 1990 of two breeds (Dutch-Yorkshire [DY] and Duroc [Du] of American and Danish origin) and two sexes (boars and gilts). Each week on Tuesday eight animals (two DY boars, two DY gilts, two Du boars and two Du gilts) were slaughtered. Thus, in total 64 animals were slaughtered. Hovenier et al. (1992) described the way animals were chosen for experimental slaughtering. Twenty-four hours after slaughter, 14 slices approximately 2 cm thick were taken from the *M. longissimus* from both the right and left carcass halves to measure meat quality. The junction of the last rib was the starting point for cutting out the slices for all meat quality measurements (Figure 1).

Slice no. 1 was used to measure ultimate pH (PHLD; Consort, P-914 with Scott, A-48 electrode) and to measure meat colour. The colour was scored according to a set of standard models of pork colour (Nakai et al., 1975; COLOUR) and was measured using the Fibre Optic Probe measurement (FOP; TBL Fibre Optics, Mark III) and the Minolta measurement, giving L* (L), a* (A) and b* (B) colour coordinates (Minolta Chroma Meter, CR-210). L refers to the lightness of the meat (0 = black, 100 = white), the extreme colours of A are red (positive) and green (negative), the extreme colours of B are yellow (positive) and blue (negative; MacDougall, 1986).

Slices no. 2 and 3 were used to measure drip loss and amount of intramuscular fat. Drip loss (DRIP) was measured in duplicate as weight loss over 48 hours following Honikel (1985) using samples of constant size (diameter of samples = 4 cm). After the drip loss measurement the samples were used for measuring the intramuscular fat content in duplicate by petroleum-ether extraction (INTMF).

Slices numbered from 4 to 14 were used for assessment of tenderness or associated traits. Slices 5, 7, 9, 11 and 13 were used for the assessment of tenderness by the taste panel; slices 4, 8, 10 and 14 were used for shearforce and cooking loss measurements; and slices 6 and 12 were used for measuring collagen.

For measuring cooking loss the slices were first gently dried with absorbent paper tissue and weighed, then packed and heated in water at 75°C for 1 hour. Packages were cooled by flowing cold tap water for 30 minutes, unwrapped, gently dried and weighed again. The difference before and after heating gave the cooking loss (COOK). After that, as many cylinders (1.25 cm diameter) as possible were taken out of the slice (10 to 15 cylinders per slice). Each cylinder was cut with a Warner-Bratzler blade with a speed of 100 mm/min. The mean of the maximum forces needed to shear the cylinders was defined as the shearforce (SHEAR).

The collagen value ([collagen N/total N] * 100; COLV) was derived from the

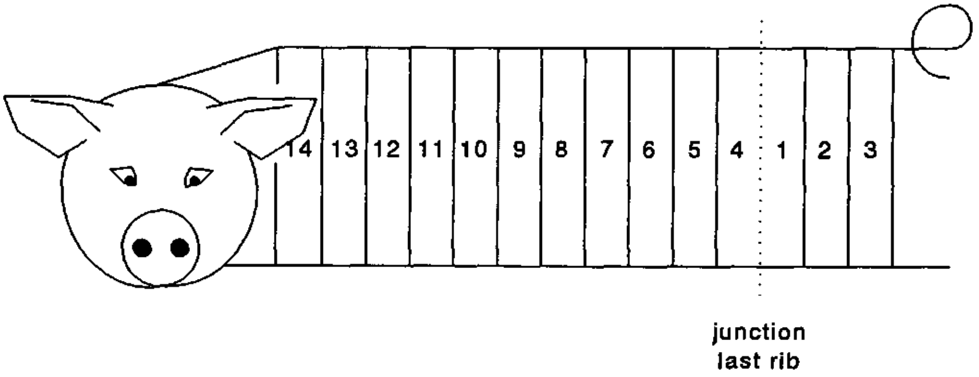

Figure 1. Assignment of the slices of the *M. longissimus* to the meat quality measurements. Measurements were taken on individual slices as follows: 1, ultimate pH, meat colour using the Japanese scale, F.O.P.-measurement, Minolta L^*, a^* and b^*-values; 2, drip loss (DRIP), intramuscular fat (INTMF); 3, DRIP, INTMF; 4, shear force (SHEAR), cooking loss (COOK); 5, taste panel tenderness (TENDER); 6, collagen value (COLV); 7, TENDER; 8, SHEAR, COOK; 9, TENDER; 10, SHEAR, COOK; 11, TENDER; 12, COLV; 13, TENDER; 14, SHEAR, COOK.

measurement of the amount of hydroxyproline in the samples. The measurements were carried out in duplicate. The amount of hydroxyproline was measured using the colouring reagent 4-dimethylaminobenzaldehyde, which binds with the hydroxyproline. After that, the extinction of the solution was measured with a colorimeter using a wavelength of 557 nm.

Taste Panel

The taste panel consisted of 20 persons who participated during the entire experiment. The panel was divided into five groups of four persons. Each group had four sessions per week, two on Thursday morning and two on Friday morning. The panelists scored four samples per session, making a total of eight sample judgments per person per day. These eight samples came from one DY boar, one DY gilt, one Du boar and one Du gilt. This means that repeated judgments within animals were carried out by each panelist and that at maximum 20 samples were scored per carcass half. Because panelists were not always present, on average 12.4 samples were scored per carcass half.

Training of the panel took place during the 2 weeks before the experiment. These weeks were used to let the panel become familiar with the procedures involved in the sensory evaluation. The training was not used to test the panelists for their ability to score meat tenderness.

A microwave oven was used to cook the slices. Four slices were heated simultaneously in the microwave oven for 4 minutes, resulting in an internal temperature of at least 75°C. The meat was not seasoned. The location in the oven of each slice was recorded (either front left or right or rear left or right). The heated slices were cut into four samples and presented to the panelists. Each panelist scored four samples per session, each sample coming from a different animal. In the second session on the same day samples from the same animals were scored. The slices were assigned to the different panelists in such a way that a panelist scored two samples from each pig that originated from slices as close to each other as possible in the *M. longissimus*. For example, when a panelist scored a sample from slice 5 of the right carcass half during the first session, then a sample from slice 7 of the right carcass half was presented to the panelist in the second session. These two samples were heated at the same location in the microwave oven to prepare the samples as similarly as possible.

The panelists were asked to give a tenderness score for the samples on an unstructured line of length 10 cm (Land and Shepherd, 1984). On the left side the line was assigned with "tough" and on the right side with "tender". The tenderness scores were derived by measuring the distance in millimetres from the left side to the point marked by the panelist. This resulted in scores (TENDER) between 0 (tough) and 100 (tender). The data per panelist were assumed to be continuous and normally distributed (Land and Shepherd, 1984).

Method

Repeatabilities. For all traits, mean values per carcass half were calculated and used in further calculations. For each trait this resulted in two observations per animal. Because the data set mainly consisted of half-sib and full-sib animals, an animal model was used. Pedigree information of three generations was taken into account. A random general environmental effect for each animal was fitted in the model because of repeated measurements per animal. General environmental effect was assumed to be uncorrelated with the additive genetic effects. To estimate variance and covariance components all traits were analyzed using the following multi-trait mixed model:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Zu} + \mathbf{e} \qquad [1]$$

where: $\mathbf{y}$ = the vector of observations, $\mathbf{X}$ = the design matrix for the fixed effects, $\mathbf{b}$ = the vector of fixed effects, $\mathbf{Z}$ = the design matrix for the random effects, $\mathbf{u'} = (\mathbf{a'}\ \mathbf{eg'})$ = the vector of random animal and general environmental effects and $\mathbf{e}$ = the vector of residual error effects.

Furthermore, it was assumed $V(\mathbf{u}) = \mathbf{G} = \text{Diag}\ \{\mathbf{A}^*\mathbf{T}_A;\ \mathbf{I}^*\mathbf{T}_{EG}\}$, $V(\mathbf{e}) = \mathbf{R}$, $\text{Cov}(\mathbf{u},\mathbf{e'}) = 0$, where: $\mathbf{A}$ = the numerator relationship matrix between animals, $\mathbf{T}_A$ = the matrix of additive genetic covariances among traits, $\mathbf{I}$ = the identity matrix, $\mathbf{T}_{EG}$ = the matrix of general environmental covariances among traits and * denotes the direct matrix product, which gave $V(\mathbf{y}) = \mathbf{Z\ G\ Z'} + \mathbf{R}$.

For all traits, three fixed effects and their interactions were included in the model: week of slaughter (eight classes), breed (two classes) and sex of the animal (two classes). Variance and covariance components were estimated using REML, using a derivative-free algorithm (Meyer, 1991). Iterations were stopped when the variance of the log likelihood values was less then 1.0×10^{-5}.

During the calculation of the repeatabilities heritabilities were fixed. This was done because in a relatively small data set it is possible to estimate the phenotypic variances more accurately than additive genetic and general environmental variances. By fixation of heritabilities, for INTMF, PHLD, DRIP and COLOUR the phenotypic variation estimated in this data set and the ratio between the additive genetic and phenotypic variance found in a much larger data set (Hovenier et al., 1992) were combined. Heritabilities of the traits TENDER, SHEAR, CV, COOK, FOP, L, A and B were derived from other studies (Jensen et al., 1967; Malmfors and Nilsson, 1979; Scheper, 1979; Ollivier et al., 1981; Ollivier, 1983; Cole et al.,

Table 1. Meat quality traits, their abbreviations, means, phenotypic standard deviations and heritabilities[1].

Measured trait	Abbrev.	mean	st.dev.	h^2_{prior}
Taste panel tenderness	TENDER	43.1	10.1	0.30
Shearforce, N	SHEAR	36.7	4.0	0.30
Collagen value, %	COLV	2.3	0.7	0.30
Intramuscular fat, %	INTMF	2.3	1.4	0.61
Ultimate pH	PHLD	5.46	0.09	0.39
Drip loss, %	DRIP	5.4	2.2	0.30
Cooking loss, %	COOK	28.3	1.8	0.20
Meat colour, Japanese scale	COLOUR	3.1	0.4	0.29
F.O.P.-measurement	FOP	40.5	9.8	0.30
Minolta L^*-value	L	56.2	3.0	0.30
Minolta a^*-value	A	15.4	0.8	0.30
Minolta b^*-value	B	8.5	0.8	0.30

[1] Heritabilities of TENDER, SHEAR, COLV, COOK, FOP, L, A and B are based on Jensen et al., 1967; Malmfors and Nilsson, 1979; Scheper, 1979; Ollivier et al., 1981; Ollivier, 1983; Cole et al., 1988; and Cameron, 1990. Heritabilities of INTMF, PHLD, DRIP and COLOUR are based on Hovenier et al., 1992.

1988; Cameron, 1990). However, these traits were analyzed using fixed heritabilities as well to keep the method of analysis constant. The prior heritabilities used are given in Table 1.

Repeatabilities were calculated using the variance components:

$$r = \frac{(s_a^2 + s_{eg}^2)}{(s_a^2 + s_{eg}^2 + s_e^2)} \qquad [2]$$

where: r = repeatability, s_a^2 = estimate of additive genetic variance, s_{eg}^2 = estimate of general environmental variance and s_e^2 = estimate of the error variance.

Six of the meat quality traits measured (TENDER, SHEAR, COLV, INTMF, DRIP and COOK) are means of more than one measurement. To calculate the repeatability for the case of only one measurement per carcass half instead of the mean of n measurements the estimate of the error variance was multiplied by n:

$$r^* = \frac{(s_a^2 + s_{eg}^2)}{(s_a^2 + s_{eg}^2 + s_e^2 n)} \qquad [3]$$

where: r^* = repeatability in case observations within a class are based on only one measurement and n = number of measurements per mean.

This formula holds assuming that the errors within one carcass half are uncorrelated, which means that correlations between measurements within carcass halves are equal to the correlations between measurements between carcass halves.

For the trait TENDER, the repeatability according to **[2]** in fact is the repeatability of scores within an animal, but between panelists. However, we are interested in a repeatability within animal and panelist. Therefore, all single panel judgments (n = 1.554) were analyzed using a model similar to Model **[1]**. Week of slaughter (eight classes), breed and sex of the animal (two classes both) and their interactions, carcass half (two classes) and position of the slice in the microwave during preparation (four classes), were fitted in the model as fixed effects. Slice number was fitted in the model as a covariable in a linear and quadratic form. Animals and the general environment x panelist interaction were fitted in the model as random effects. The repeatability was calculated as follows:

$$r = \frac{(s_a^2 + s_{eg\cdot pan}^2)}{(s_a^2 + s_{eg\cdot pan}^2 + s_e^2)} \qquad [4]$$

where: $s_{eg\cdot pan}^2$ = estimate of variance component due to general environment x panelist.

Phenotypic Correlations. Phenotypic correlation coefficients are calculated after analyzing the data using Model **[1]**:

$$r_{x1,x2} = \frac{cov_a(x1,x2) + cov_{eg}(x1,x2) + cov_e(x1,x2)}{\sqrt{(s^2_{a,x1} + s^2_{eg,x1} + s^2_{e,x1}) * (s^2_{a,x2} + s^2_{eg,x2} + s^2_{e,x2})}} \qquad [5]$$

where: $r_{x1,x2}$ = phenotypic correlation coefficient between Trait 1 and 2, $cov_a(x1,x2)$ = estimate of additive genetic covariance between Trait 1 and 2, $cov_{eg}(x1,x2)$ = estimate of general environmental covariance between Trait 1 and 2, $cov_e(x1,x2)$ = estimate of error covariance between Trait 1 and 2, $s^2_{a,x1}$, $s^2_{a,x2}$ = estimate of additive genetic variance for Trait 1 and 2, respectively, $s^2_{eg,x1}$, $s^2_{eg,x2}$ = estimate of general environmental variance for Trait 1 and 2, respectively and $s^2_{e,x1}$, $s^2_{e,x2}$ = estimate of error variance for Trait 1 and 2, respectively.

Correlation coefficients are influenced by the accuracy of the measurements of the traits. Therefore, correlation coefficients were calculated for the case that accuracy (or repeatability) of the traits measured is equal to one. The repeatability of a trait is equal to 1 when the number of measurements on which the mean values are based (n) becomes very large resulting in σ^2_e equal to zero. Formula **[5]** then reduces to:

$$r_{corr} = \frac{cov_a(x1,x2) + cov_{eg}(x1,x2)}{\sqrt{(s^2_{a,x1} + s^2_{eg,x1}) \times (s^2_{a,x2} + s^2_{eg,x2})}} \qquad [6]$$

which gives the correlation between two traits corrected for measurement errors.

RESULTS

Repeatabilities

In Table 1, the means and phenotypic standard deviations of all measured meat quality traits are given. In Table 2, the estimates for the three variance components and the repeatabilities are given. Repeatabilities ranged from 0.43 for the collagen value to 0.76 for the Minolta L^*-value. Looking at the repeatabilities of the mean values per carcass half, maximum shearforce had the highest repeatability of the three tenderness traits. The repeatability for amount of intramuscular fat was the same as the prior heritability of this trait, 0.61. The repeatability of PHLD and both water-binding capacity traits were comparable. Of the colour measurements, Minolta L^*-value had the highest repeatability (r = 0.76) and meat colour scored using the Japanese scale had the lowest repeatability (r = 0.49).

Repeatabilities corrected for the number of measurements per carcass half for

Table 2. Variance components (s_a^2, s_{eg}^2, s_e^2)[1], repeatability (r), number of observations per mean (n obs.) and repeatability corrected for n obs (r^*).

Trait	s_a^2	s_{eg}^2	s_e^2	r	n obs.	r^*
TENDER	30.7	23.6	48.0	0.53	12.4	0.08
SHEAR	4.71	6.79	4.20	0.73	4.0	0.41
COLV	0.13	0.05	0.26	0.43	1.5	0.33
INTMF	1.25	0.00	0.80	0.61	2.0	0.44
PHLD	0.003	0.002	0.003	0.64	[2)]	
DRIP	1.42	1.58	1.70	0.64	2.0	0.47
COOK	0.62	1.30	1.19	0.62	4.0	0.29
COLOUR	0.04	0.03	0.07	0.49	[2)]	
FOP	28.9	27.9	39.5	0.59	[2)]	
L	2.76	4.24	2.19	0.76	[2)]	
A	0.21	0.27	0.22	0.69	[2)]	
B	0.21	0.17	0.32	0.54	[2)]	

[1] s_a^2 estimate of additive genetic variance, s_{eg}^2 estimate of general environmental variance and s_e^2 estimate of error variance.

[2] Only one measurement per carcass half.

Table 3. Variance components (s_a^2, s_{eg*pan}^2, s_e^2)[1] and repeatability (r) for the single panel tenderness judgements.

Trait	s_a^2	s_{eg*pan}^2	s_e^2	r
TENDER	148.6	97.2	249.5	0.50

[1] s_a^2 estimate of additive genetic variance, s_{eg*pan}^2 estimate of general environmental x panelist variance and s_e^2 estimate of error variance.

six of the meat quality traits are given in Table 2. The differences for repeatability of TENDER and SHEAR became more pronounced when the repeatabilities were corrected. The repeatability for TENDER decreased from 0.53 to 0.08 and the repeatability for SHEAR decreased from 0.73 to 0.41. The repeatability of COLV declined only 0.10 because of the low number of measurements per carcass half.

Table 4. Phenotypic correlation coefficients between meat quality traits.

	SHEAR	COLV	INTMF	PHLD	DRIP	COOK	COLOUR	FOP	L	A	B
TENDER	-.50	0.01	0.00	0.00	-.44	-.16	-.08	-.19	-.20	-.13	-.00
SHEAR		-.10	0.10	-.17	0.53	0.08	-.22	0.10	0.30	-.04	0.23
COLV			-.11	0.06	-.26	0.14	-.02	-.02	-.03	0.11	-.02
INTMF				0.23	0.18	-.21	-.02	0.01	0.28	0.41	-.21
PHLD					-.45	-.18	0.28	-.35	-.35	-.01	-.44
DRIP						0.15	-.29	0.46	0.57	0.15	0.41
COOK							0.01	-.11	0.11	-.01	0.00
COLOUR								-.30	-.34	-.27	0.30
FOP									0.47	-.06	0.47
L										-.23	0.45
A											0.22

For n = 128: $p \leq .10$ for $r \geq .15$, $p \leq .05$ for $r \geq .18$ and $p \leq .01$ for $r \geq .23$.

Furthermore, it can be concluded that the equal repeatabilities for drip loss and cooking loss originally found were a result of the unequal number of measurements per carcass half. In Table 2, it can be seen that the repeatability corrected for the number of measurements per carcass half of COOK was almost half the repeatability of DRIP.

In Table 3, repeatability is given for TENDER within animal x panelist. This value gives an idea about the accuracy of the tenderness score when one panelist judges meat of one animal. As may be expected, this repeatability was higher than the repeatability corrected for number of observations because the latter gives an idea about accuracy when different panelists judge meat of one animal.

Phenotypic Correlations

In Table 4, phenotypic correlations between all meat quality traits are presented. Most important correlations in this experiment were the correlations between meat tenderness and shearforce and between tenderness and collagen value. The correlation between TENDER and SHEAR was -.50 and the correlation between TENDER and CV was only 0.01. The correlations between INTMF and TENDER and between INTMF and SHEAR were not significantly different from zero. All absolute phenotypic correlations between COLV and the other meat quality traits were within the range of 0 to 0.11, except for drip loss (-.26) and

Table 5. Correlation coefficients between meat quality traits corrected for measurement errors.

	SHEAR	COLV	INTMF	PHLD	DRIP	COOK	COLOUR	FOP	L	A	B
TENDER	-.74	0.02	0.00	0.00	-.64	-.27	0.05	-.26	-.33	-.15	0.00
SHEAR		-.18	0.11	-.24	0.31	0.06	-.46	0.23	0.36	-.04	0.35
COLV			-.02	0.22	-.35	0.24	-.05	-.02	-.05	0.35	0.08
INTMF				0.28	0.17	-.26	-.07	0.14	0.28	0.54	-.21
PHLD					-.66	-.34	0.48	-.37	-.44	0.07	-.56
DRIP						0.24	-.46	0.57	0.74	0.14	0.54
COOK							0.02	-.14	0.09	0.16	-.02
COLOUR								-.50	-.40	-.28	0.40
FOP									0.53	-.13	0.44
L										-.23	0.33
A											0.26

For $n = 128$, $p \le .10$ for $r \ge .15$, $p \le .05$ for $r \ge .18$ and $p \le .01$ for $r \ge .23$.

cooking loss (.14). Also, the phenotypic correlations including cooking loss were rather low in general, the correlation between cooking loss and INTMF being highest ($r = -.21$). In general, correlations including DRIP were reasonably high. These correlations ranged from 0.15 with A to 0.57 with L. Absolute phenotypic correlations between colour traits ranged from 0.22 to 0.47, except for the correlation between FOP and A, which was only -.06.

In Table 5, correlations corrected for measurement errors between the meat quality traits are given. The correlation between TENDER and SHEAR was then -.74. Also, from Table 5 it can be observed that correlations between COLV and TENDER and between COLV and SHEAR were low. From both Tables 4 and 5 it can be concluded that corrected correlations were in general somewhat higher than phenotypic correlations. Furthermore, it can be concluded that all remarks made on the phenotypic correlations in Table 4 also hold for the corrected correlations found in Table 5.

DISCUSSION

Repeatabilities

Analyzing the data with fixed heritabilities gives repeatabilities at least as large as the heritabilities used. To examine how this way of analyzing influenced the results, the data were also analyzed without fixed heritabilities. This means that all variances necessary were estimated in the present data set. It was concluded that σ_a^2 and σ_{eg}^2 differed for the different analyses but that $(\sigma_a^2 + \sigma_{eg}^2)$ was rather constant. The absolute differences for r were at maximum 0.05 for COLV except for INTMF. Without fixation of the heritability for this trait the variances $\sigma_a^2 = 0.29$, $\sigma_{eg}^2 = 0.00$ and $\sigma_e^2 = 1.00$ were found, resulting in an $r = 0.23$. Reasons for this very low repeatability could not be found.

Repeatabilities in this study are calculated using measurements in both carcass halves. Therefore, the values will be biased by measurement site, which leads to overestimation of σ_e^2 and to underestimation of the repeatabilities.

Repeatabilities corrected for number of observations per mean were calculated assuming that the errors within one carcass half are uncorrelated. If this assumption doesn't hold, an underestimation of the repeatability will result. In the extreme case that all errors within one carcass half are equal, r^* will be equal to r. Therefore, the repeatabilities corrected for number of observations given in Table 2 have to be interpreted as lower bounds.

If we want to compare the results found for TENDER with the results of Stumpe (1989) we have to use the repeatability from Table 3 ($r = 0.50$) because this value gives the repeatability for tenderness judged by one panelist. Stumpe (1989) found a repeatability of 0.55, also corrected for number of observations and for tenderness judged by one panelist. For SHEAR the corrected repeatability was found to be 0.41; Stumpe (1989) found a repeatability of 0.42.

In the analysis of Stumpe (1989) the data were not corrected for breed or sex of the animals, which would result in an overestimation of the variance due to animals and an overestimation of repeatability. However, the difference between the present analysis and that of Stumpe (1989) for TENDER was small. The fact that repeatabilities for SHEAR were similar may be a combination of the way the data were analyzed and the way the traits were measured. Stumpe (1989) heated the slices in a microwave oven up to 80°C and took three cylinders (1.27 cm diameter) out of each slice. The mean of the maximum shearforce of those three measurements resulted in a maximum shearforce value for each slice. However, in our experiment the shearforce value of a slice was based on 10 to 15 measurements. This will result in a repeatability higher than the repeatability found by Stumpe (1989). This, combined with the fact that Stumpe (1989) did not correct for breed and sex of animals, may result in similar repeatabilities.

The repeatabilities of the traits L, A and B were in the same range as those found by Cameron et al. (1990). In the present experiment, L had the highest repeatability (.76) and B the lowest (.54). Cameron et al. (1990) found the highest repeatability for B (.67) and the lowest repeatability for L (.47).

Phenotypic Correlations

With respect to the phenotypic correlations in Table 4, it should be noted that results are the correlations between the traits in the way they were measured here. This means for example that the correlation between TENDER and SHEAR in fact is the correlation between the mean of the tenderness scores in five slices after preparation in a microwave oven and the mean of the maximum shearforce values in four slices after heating in water.

From formulae [5] and [6] it can be derived that correlations corrected for the number of observations per mean can be either stronger or weaker than the phenotypic correlations given in Table 4. Examples for this are the correlations between TENDER and SHEAR (r_p = -.50, r_{corr} = -.74) and between DRIP and SHEAR (r_p = 0.53, r_{corr} = 0.31). In theory, it is even possible that the phenotypic and corrected phenotypic correlations each have different signs when the error covariance is opposite in sign to the sum of the additive genetic and general environmental covariances.

The two strongest correlations with TENDER were found to be the correlations with SHEAR (r_p = -.50) and DRIP (r_p = -.44). These correlations are in line with those found by Stumpe (1989). Stumpe (1989) also found high correlations between TENDER and INTMF (r_p = 0.33), between TENDER and Göfo-value (r_p = 0.48) and between TENDER and Elrepho-Y_E-value (r_p = -.39). However, in our experiment correlations between TENDER and INTMF and between TENDER and colour measurements were much lower. The influence of INTMF on TENDER as found by Bejerholm and Barton-Gade (1986) and Cameron et al. (1990) was not found her, although INTMF ranged from 0.1% to 6.6%. Also the literature is conflicting on the relationship between amount of intramuscular fat and tenderness (for references see Fjelkner-Modig and Persson, 1986 and DeVol et al., 1988). As suggested by Cameron et al. (1990), the low correlation between INTMF and TENDER can be a result of a quadratic relationship between those traits. However, when a plot is made of INTMF against TENDER no relation between those traits can be seen. Cameron et al. (1990) also found a significant positive correlation between ultimate pH and meat tenderness but no significant correlation between TENDER and PHLD was found here.

From Table 5, it can be concluded that the phenotypic correlation corrected for measurement errors between TENDER and SHEAR is rather high (r_{corr} = -.74). This means that if true meat tenderness (that is, tenderness measured without measurement errors or tenderness measured by an infinitely large panel) is a breeding goal trait, the maximum shearforce measurement may be used as an effective index trait instead of the use of a panel assuming similar genetic parameters are associated with the two measures. Main disadvantages of the use of a panel are the high costs involved and organizing problems, especially when these measurements have to be done routinely. When using an expert panel consisting of six persons the repeatability of the tenderness measurement will be approximately 0.35 resulting in a correlation between true meat tenderness and meat tenderness scored by the panel of 0.60. Because this repeatability of 0.35 is based on the panel used in the present study, the repeatability and the correlation between true meat tenderness and tenderness judged by the panel will be underestimated. However, the assumption is that all expert panelists will judge samples from each animal. If this assumption does not hold, the repeatability and the correlation between true and measured tenderness will become lower because σ_e^2 will become larger. The repeatability of the shearforce measurement based on measurements in only one slice per animal is 0.41 (Table 2). Phenotypic correlation between this shearforce measurement and true meat tenderness will then be -.47. Using calculations such as given here, the disadvantages of using a taste panel can be weighed against the lower improvement of tenderness using the shearforce measurement. In general, however, an expert panel for routinely measuring tenderness as an index trait will not be used because of financial and organizing disadvantages, problems with calibration of the scale used and problems with standardization when scoring is done over a longer period.

IMPLICATIONS

The repeatability of two repeated tenderness scores of different panelists within one animal was found to be low (.08). Repeatability of two repeated tenderness scores of panelist within animal was found to be 0.50, the repeatability of two repeated maximum shearforce measurements was found to be 0.41. Phenotypic correlation corrected for measurement errors between tenderness scored by a taste panel and maximum shearforce was rather high (-.74). Those results imply that the measurement of maximum shearforce can be used as an effective indicator of pig meat tenderness and as an effective index trait assuming similar genetic parameters are associated with the two tenderness measures.

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CHAPTER 3

GENETIC PARAMETERS OF PIG MEAT QUALITY TRAITS IN A HALOTHANE-NEGATIVE POPULATION

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GENETIC PARAMETERS OF PIG MEAT QUALITY TRAITS IN A HALOTHANE-NEGATIVE POPULATION

ABSTRACT

Genetic and phenotypic parameters were estimated for Duroc and Dutch-Yorkshire pigs. The data-set consisted of in total 1,113 boars and gilts, slaughtered between January 1988 and June 1990. Four production and five meat quality traits were considered. Parameters were estimated using an animal model, bivariate unequal design REML algorithm. Heritabilities for production traits varied from 0.27 for type score to 0.63 for lean meat content. Heritabilities for meat quality traits ranged from 0.20 for ultimate pH in the *M. semimembranosus* to 0.61 for amount of intramuscular fat. Phenotypic correlations between production traits and meat quality traits hardly differ from zero, except for amount of intramuscular fat. Genetic correlations between liveweight gain and meat quality traits are favourable, genetic correlations of backfat thickness and lean meat content with meat quality traits are unfavourable. Considering the heritabilities, genetic correlations of both production and meat quality traits and economic weights of production traits currently used in The Netherlands, it is concluded that meat quality will decrease as a result of correlated response. However, meat quality can be improved if less emphasis is put on lowering backfat thickness or increasing lean meat content.

Keywords: Pigs, Genetic Parameters, Meat Quality.

INTRODUCTION

Besides the demand of consumers for leaner pork at low prices, increasing attention is paid by both producers and consumers to intrinsic meat quality aspects. Breeding against halothane susceptibility resulted in lower incidence of P.S.E.- and D.F.D. meat (Eikelenboom, 1985). Despite the low incidence of P.S.E. and D.F.D. meat in The Netherlands now, there is still considerable variation in meat quality. Therefore, attention to meat quality is still required and new ways to improve meat quality are to be investigated.

Knowledge of heritabilities and correlations for both meat quality and production traits is necessary to investigate possibilities for improving meat quality by selection and to investigate correlated responses of meat quality traits by selection for production traits.

From literature it can be concluded that meat colour, water-binding capacity, ultimate pH and content of intramuscular fat are important traits for objectively determining meat quality (Russo, 1988). Furthermore, heritabilities for meat quality traits seem to be substantial. However, genetic correlations between meat quality traits and production traits seem to be unfavourable (Sellier, 1988).

Brascamp et al. (1980) concluded that both heritabilities and genetic correlations of production and meat quality traits are reduced when the *N*-locus is eliminated from a population. Selection against halothane susceptibility resulted in a decrease of halothane susceptibility from 36% in 1977 to 8% in 1984 for the Dutch Landrace breed (Eikelenboom, 1985). Calculation of genetic parameters in a population selected against halothane susceptibility will reveal the amount of genetic variance left for both production and meat quality traits and the correlations between all traits.

In the literature large ranges of heritabilities of and genetic correlations between production and meat quality traits are found. Reasons for the large ranges could be the relatively small data-sets used to estimate those heritabilities and genetic correlations, resulting in large standard errors and the fact that in larger data-sets only one or two meat quality parameters are measured. This makes it necessary to combine results of several researches for getting a complete set of genetic parameters. Two other points that may influence genetic parameters are the feeding regime during performance testing and the strategy to end the test. Results given in literature are based both on restricted and ad libitum feeding. However, no consistent differences between the two feeding regimes were found for the heritabilities of meat quality traits and the genetic correlations between production and meat quality traits. Besides, most results given in literature are based on finishing the test at a constant liveweight. However, from a management point of view testing until a fixed age is often used (e.g. using all in, all out). Therefore, genetic parameters should be estimated in the population in which they are going to be used and under the appropriate testing system.

The aim of this study is to estimate genetic parameters for meat quality and production traits in a Dutch pig population with a low halothane susceptibility tested under ad libitum feeding and slaughtered at a fixed age.

MATERIALS AND METHODS

Data

Data were obtained between January 1988 and June 1990 from two nucleus sire lines. In this period in total 1,113 animals (progeny of 142 boars and 738 gilts) of two sexes (boars and gilts) and two breeds (Dutch-Yorkshire and Duroc of

Table 1. Number of animals by sex and by breed, number of sires and number of litters by breed.

Sex	Breed		Total
	Dutch Yorkshire	Duroc	
Boars	613	305	918
Gilts	141	54	195
Total	754	359	1,113
No. of sires	59	78	137
No. of litters	552	273	825

American and Danish origin) were measured for production and meat quality traits. Halothane susceptibility of animals of both populations was measured at random. During the experiment in total 500 animals were halothane tested at random but no animals were found to be halothane positive. The numbers of animals by sex and breed are given in Table 1.

The pigs were tested in batches. A batch consisted of pigs housed in 8 or 14 pens per unit of the testing station. In each pen 6 animals (both gilts and boars, littermates when possible) were housed. Units were populated within a week and no new pigs entered the unit until all pigs in that unit finished the test. Animals started the test at an average weight of 33.2 kg (Table 2). The animals were fed ad libitum, up to an age of 100 days a mixture containing 9.3 MJ kg^{-1} net energy and 16.9% crude protein and from 100 days till the end of the test a mixture containing 9.0 MJ kg^{-1} net energy and 16.2% crude protein. The test ended at an age of 171 ± 6 days.

A total of 5,359 pigs were performance tested and 460 pigs were selected for breeding and multiplying purposes. A total of 1,113 pigs were allocated for meat quality studies, according to three criteria. Pigs chosen for the meat quality study should be a littermate of a pig selected for breeding or multiplying and have an end of test weight of 100-110 kg. The number of sire families represented in the sample of pigs was maximised. The result of this procedure will be that experimentally slaughtered animals will have about average testing results, but also that no animals with very high results will be chosen (they are used for breeding purposes) and no animals with very low results will be chosen (because if possible at least one littermate is used for breeding purposes).

In Table 2 the means and standard deviations are given for start and end

Table 2. Means and standard deviations for start and end of test weight (kg), live weight gain (gd^{-1}) and backfat thickness (mm) for all tested animals (n=5,359) and the experimentally slaughtered animals (n=1,113).

Trait	All tested animals		Experimental group	
	mean	st.dev.	mean	st.dev.
Start of test weight	33.2	4.3	32.8	4.2
End of test weight	106.2	12.5	106.7	7.4
Live weight gain	621	64	624	46
Backfat thickness	11.9	2.1	11.5	1.8

weight, liveweight gain and backfat thickness of all the tested animals and of the animals slaughtered experimentally. From this table it may be concluded that the means of all tested animals and the experimentally slaughtered group are similar. However, except for weight at the start of the test standard deviations are lower in the experimentally slaughtered group.

The animals were slaughtered after resting in the slaughter-house for at least 2 hours. Animals slaughtered at a particular day had been fattened in the same unit and they were offspring of only a few dams. Those dams had no offspring slaughtered at other days. This resulted in a nesting of dams within day of slaughter within unit.

At the end of the test liveweight of the pigs was measured and backfat thickness was measured ultrasonically. Average daily liveweight gain (LWG) was then calculated as liveweight divided by the age at end of test of the pig. Backfat thickness (BF) was calculated as the average of 3 measurements 5 cm beside the midline at the back (Minkema, 1973).

After slaughtering, lean meat content (LMC) was measured by dissection of the right carcass half following the I.V.O.-standard method (Bergström and Kroeske, 1968). The carcasses were scored for type reflecting muscular development according to EEC regulations (TYPE; 1 (=good) to 4 (=poor); De Boer, 1982).

For measuring meat quality in the *M. longissimus*, 24 hours after slaughtering a piece of the loin of 15 to 20 cm length was taken from the right carcass half, starting near the junction of the last rib in caudal direction. From this piece three 2 cm thick transverse slices were taken starting from the cranial side of the piece. The first slice was used for measuring ultimate pH (PHLD) and scoring the colour of the *M. longissimus* (COLOR) according to a set of standard models of pork colour (0.5 (=light) to 6.5 (=dark); Nakai et al., 1975). The second and the third slice were used to measure drip losses (DRIP). Drip loss was measured in duplo as weight loss over 48 hours following Honikel (1985), apart from taking samples of constant size (diameter of samples 4 cm) in stead of taking samples of constant weight. After the drip loss measurement the samples were used for measuring the intramuscular fat content in duplo by petroleum-ether extraction (INTMF). Furthermore, ultimate pH in the *M. semimembranosus* was measured 24 hours after slaughter (PHSM).

Model

The production data of in total 5,359 animals were known. However, for computational reasons only the records of the experimentally slaughtered animals were used. Because only 1,032 of the 1,113 animals had complete records a multivariate unequal design Restricted Maximum Likelihood (REML) algorithm was used. For computational reasons the calculations were done pairwise.

The data were first analyzed with the Statistical Analysis System (SAS Institute Inc., 1982) using the General Linear Models (GLM) procedure. For all traits three fixed effects appeared to be significant and were therefore fitted in the model: week of slaughter (108 classes), sex of the animal (2 classes; 1 = gilts, 2 = boars) and breed of the animal (2 classes; 1 = Dutch Yorkshire, 2 = Duroc). Interactions between week of slaughter and breed of the animal appeared to be significant for most traits and were therefore included in the model. Age at day of slaughtering was included in the model as covariable.

Genetic and residual variance and covariance components were estimated from bivariate analyses using a derivative-free REML algorithm (Meyer, 1991). Iterations were terminated when the variance of the log likelihood values was less than 0.001. For heritability estimates approximated standard errors were calculated (Meyer, 1991). For computational reasons this approach did not work for the calculation of approximated standard errors of genetic correlations. Therefore, approximated standard errors for estimates of the genetic correlations were calculated using the formula given by Falconer (1989; p. 317).

To get starting values for the variance and covariance components for this algorithm the data were first analyzed with SAS using the GLM-procedure regarding sires as random effects giving Henderson III variance and covariance estimates.

RESULTS

Means and Heritabilities

In Table 3 generalized least squares means of the production and meat quality traits are given for both sexes and both breeds. Breed differences were significant for all traits ($p \leq 0.01$) except for DRIP. Sex differences were significant for LWG, BF, LMC and INTMF ($p \leq 0.01$).

Dutch-Yorkshire pigs had a higher LWG than Duroc pigs and boars grew faster than gilts. In both cases the difference was about 25 gd^{-1}. Dutch-Yorkshire pigs had lower BF and a higher LMC compared to the Duroc, the same holds for boars compared to gilts. Dutch-Yorkshire pigs scored better for TYPE than Duroc pigs, but for boars and gilts there was no difference in TYPE.

Considering INTMF there is a significant difference between the breeds, the Duroc having fatter meat. Gilts have a higher INTMF but the difference between sexes is not as pronounced as between breeds. Dutch-Yorkshire pigs had lower pH-values and a lower score for colour (this means lighter meat) than Duroc pigs but had also a lower value for DRIP. However, this difference for DRIP was not significant. No significant differences were found between sexes for DRIP, PHLD, PHSM and COLOR.

Heritabilities for the production traits ranged from 0.27 for TYPE to 0.63 for LMC. Heritability estimates for meat quality traits ranged from 0.20 for PHSM to 0.39 for PHLD and 0.61 for INTMF. Heritabilities of traits indicating the carcass composition (BF, LMC and INTMF) range from 0.51 to 0.63, heritabilities of all other traits range from 0.20 to 0.39. Approximated standard errors of the heritability estimates ranged from 0.08 to 0.10.

Phenotypic and Genetic Correlations

Phenotypic and genetic correlations are given in Table 4. Absolute phenotypic correlations among the production traits vary from 0.16 to 0.75 and absolute genetic correlations among the production traits vary from 0.23 to 0.79. Note that a positive genetic correlation between LWG and TYPE means that faster growing animals had a less appreciated type.

Phenotypic correlations between production traits and meat quality traits are very low except for correlations with INTMF. Absolute values for phenotypic correlations between production traits and INTMF range from 0.11 to 0.31. Absolute values for genetic correlations between production traits and meat quality vary from 0.00 to 0.55. Absolute values for genetic correlations between production traits and INTMF range from 0.19 to 0.44.

Both phenotypic and genetic correlations between INTMF and the other meat quality traits are low with absolute phenotypic correlations ranging from 0.01 to

Table 3. Number of animals per trait, generalized least squares means for breeds and sexes, standard error of the differences (sed), genetic variances and heritabilities (standard errors between brackets).

trait[1]	n	breed			sex			σ_a^2	h^2
		Dutch-Yorkshire	Duroc	sed[2]	boars	gilts	sed[2]		
LWG (gd^{-1})	1,110	621.2	599.8	3.7*	624.4	596.7	3.7*	398.6	0.29 (0.11)
BF (mm)	1,110	11.27	12.42	0.16*	11.56	12.12	0.16*	1.32	0.51 (0.09)
LMC (%)	1,106	60.95	59.49	0.21*	60.78	59.67	0.21*	2.89	0.63 (0.10)
TYPE	1,113	1.80	2.15	0.04*	1.98	1.98	0.05	0.05	0.27 (0.09)
INTMF (%)	1,075	1.65	3.20	0.09*	2.24	2.62	0.09*	0.51	0.61 (0.09)
DRIP (%)	1,086	4.40	4.81	0.23	4.44	4.77	0.23	1.62	0.30 (0.09)
PHLD	1,110	5.522	5.586	0.013*	5.561	5.548	0.013	0.007	0.39 (0.08)
PHSM	1,100	5.612	5.636	0.012*	5.624	5.624	0.012	0.003	0.20 (0.08)
COLOR	1,111	2.91	3.25	0.05*	3.07	3.09	0.05	0.07	0.29 (0.09)

[1] LWG = average daily live weight gain; BF = ultrasonic backfat thickness; LMC = lean meat content; TYPE = carcass type score; INTMF = intramuscular fat; DRIP = drip loss; PHLD = $pH_{24hours}$ in *M. longissimus* dorsi; PHSM = $pH_{24hours}$ in *M. semimembranosus*; COLOR = meat colour;

[2] significance of difference: * $p \leq 0.01$.

0.11 and absolute genetic correlations ranging from 0.07 to 0.36. Correlations among the other meat quality traits are much higher. Absolute phenotypic correlations range from 0.27 to 0.46, absolute genetic correlations range from 0.60 to 0.80.

Standard errors of the estimates for genetic correlation between production traits ranged from 0.05 to 0.17 except for the genetic correlation between LWG and TYPE (s.e. = 0.28). Standard errors of the estimates for the genetic correlations between production traits and INTMF ranged from 0.09 to 0.19 and between production traits and the other meat quality traits from 0.18 to 0.33. Standard

Table 4. Genetic correlations (below diagonal; standard errors between brackets) and phenotypic correlations (above diagonal).

	LWG	BF	LMC	TYPE	INTMF	DRIP	PHLD	PHSM	COLOR
LWG		0.55	-.34	0.16	0.13	0.00	-.04	0.05	0.05
BF	0.57 (0.11)		-.75	0.38	0.30	-.03	0.01	0.03	0.00
LMC	-.27 (0.17)	-.71 (0.05)		-.43	-.31	0.11	-.04	-.03	0.01
TYPE	0.23 (0.28)	0.75 (0.07)	-.79 (0.05)		0.11	-.06	-.03	-.10	0.01
INTMF	0.19 (0.19)	0.37 (0.11)	-.44 (0.09)	0.31 (0.17)		-.03	-.09	0.01	-.11
DRIP	-.06 (0.32)	-.07 (0.24)	0.11 (0.20)	0.07 (0.33)	-.07 (0.22)		-.46	-.27	-.36
PHLD	0.12 (0.26)	0.15 (0.19)	-.11 (0.18)	-.03 (0.30)	-.18 (0.17)	-.80 (0.06)		0.45	0.43
PHSM	0.26 (0.31)	0.25 (0.23)	-.05 (0.27)	-.55 (0.19)	0.36 (0.18)	-.60 (0.16)	0.64 (0.13)		0.33
COLOR	0.46 (0.19)	0.00 (0.26)	0.17 (0.19)	-.18 (0.29)	-.33 (0.16)	-.73 (0.09)	0.71 (0.09)	0.80 (0.08)	

errors of the genetic correlation estimates between INTMF and meat quality traits ranged from 0.16 to 0.22 and the standard errors of the genetic correlation estimates between the meat quality traits vary between 0.06 and 0.16.

DISCUSSION

Means

The means for INTMF do agree well with results found by Schwörer (1988). The means for PHSM agree with results found by e.g. Gallwey and Tarrant (1979), Fjelkner-Modig and Persson (1986), Schmitten et al. (1986, 1987), but the means for PHLD are somewhat higher than found by those authors. Possible reasons for the differences found may be the origin of the animals from different populations, different feeding systems, different procedures for pre-slaughter handling and transport, or differences in time of measuring or the measuring-instrument. The means for PHLD do agree well with results found by e.g. Gallwey and Tarrant (1979) and McGloughlin et al. (1988). The means for DRIP are higher than found by e.g. Lundström et al. (1979, 1984), Malmfors and Nillson (1979) and Scheper (1979). Probable reasons for these differences may be differences between the populations under study and the methods used to determine drip losses.

Compared to the criterion given by Bejerholm and Barton-Gade (1986) the intramuscular fat content of the Dutch-Yorkshire pigs in this experiment is below the desired range and the intramuscular fat content of the Duroc pig in this experiment is slightly above the desired range of 2.0% to 2.5%. Following Bejerholm and Barton-Gade (1986) and Schwörer (1988) this results in a lower eating quality of Dutch-Yorkshire meat compared with Duroc meat. Cameron et al. (1990) found a higher intramuscular fat content for Duroc in comparison with British Landrace pigs. However, taste and consumer panels scored Duroc meat to be more juicy, but less tender, having poorer flavour and being less acceptable than British Landrace meat.

Heritabilities

The heritability estimates for LWG, BF and LMC do agree with results found by others (Lundström, 1975; Andersen and Vestergaard, 1984; Johansson et al., 1987). The heritability estimates for COLOR, DRIP, PHSM and INTMF agree with heritabilities found in literature (e.g. Malmfors and Nilsson, 1979; Scheper, 1979; Schwörer et al., 1980; Cole et al, 1988; Cameron, 1990), the heritability estimate for PHLD is somewhat higher than found in literature.

Brascamp et al. (1980) calculated that about 60% of the additive genetic variance of subjectively scored meat quality was due to the presence of the halothane gene and concluded that heritability of meat quality would be reduced when the recessive halothane gene was eliminated from the population. Although the frequency of halothane-susceptible pigs in the population under study was zero, heritabilities of meat quality traits are still considerable.

Correlations

The positive correlations between liveweight gain and backfat thickness can be explained by the ad libitum feeding strategy. The correlations found agree well with literature (e.g. Schwörer et al., 1980; Ollivier, 1983; Sönnichsen et al., 1984). With ad libitum feeding an animal that eats more grows faster, will be heavier at the end of the test and will probably have a higher backfat thickness. Finishing the test at a fixed age can make this correlation even stronger because differences between animals will be more pronounced in comparison with finishing at a fixed weight.

The genetic correlation between meat colour and growth found in literature ranges from -.50 to 0.13, a positive correlation meaning darker meat when animals grow faster (e.g. Lundström, 1975; Malmfors and Nilsson, 1979; Johansson, 1987; Schwörer et al., 1980; Cole et al, 1988; Cameron, 1990). However, the genetic correlation found in this study is higher (0.46). The other genetic correlations between production and meat quality traits are within the ranges found in literature.

Considering the correlations among the meat quality traits, correlations including INTMF are the lowest. The correlations between INTMF and production traits have the same direction as correlations including backfat thickness. Noteworthy are the high genetic correlations between the pH-values, drip losses and colour, indicating that meat with a higher ultimate pH-value has a darker color and less drip losses and that the mechanism of pH, water-holding capacity and meat colour still exists in absence of the halothane gene. Considering the high correlations between PHSM and PHLD and between PHSM and COLOR it could be argued to drop the measurement of pH in the *M. semimembranosus* because this trait does not add much to the knowledge about the meat quality of an animal. Another reason is the fact that this pH-measurement is the only measurement done in the *M. semimembranosus*, which means that it costs extra labour.

The correlations found between production and meat quality traits suggest a better meat quality for faster growing animals, animals with higher backfat thickness and animals with a lower content of lean meat. This means that the correlated response of meat quality will depend on the emphasis put on growth and on backfat thickness or lean meat content. When economic values for production traits given by De Vries (1989) and the genetic parameters given in Tables 3 and 4 are used, it can be concluded that meat quality will lower as a result of correlated response. When higher economic values for daily gain or lower economic values for backfat thickness or lean meat content are used, correlated response will result in less diminishing meat quality or even improving meat quality. However, this also results in lower profit of the breeding program assuming meat quality traits having no economic value.

Because calculation of correlations is done pairwise, non-positive definite variance and covariance matrices can be the result. To check this the eigenvalues of both genetic and error variance- and covariance matrices are calculated. For both genetic and error variance- and covariance matrices only one eigenvalue appeared to be slightly negative, being -.02 and -.03, respectively. A possible way to obtain valid matrices, is to apply bending (Hayes and Hill, 1981).

Selection

The best tested animals were selected for breeding purposes and therefore not slaughtered. Animals for experimental slaughter were chosen from the remaining animals and if possible from litters with littermates selected for breeding purposes. This means that the experimentally slaughtered animals were chosen from the middle part of the production range, which is affirmed by Table 2. It can be concluded that the phenotypic variation in the analyzed data-set is smaller than in the total data-set for both LWG and BF. This way of selection results in underestimated heritability estimates for at least those two traits, but probably also for LMC and TYPE due to negative linkage disequilibrium (Felsenstein, 1965).

The effect of the selection mentioned above for the genetic parameters of the meat quality traits is not quite clear. Villanueva and Kennedy (1990) conclude that changes in genetic correlations between directly and indirectly selected traits are maximum when initial genetic correlations are about 0.6 and insignificant when initial genetic correlations are close to zero or one. Furthermore, they conclude that heritability of traits indirectly selected and genetic correlations between directly and indirectly selected traits always decrease in absolute value. Looking at the results found in this study it may be concluded that the influence of selection will be rather small because of the in general rather small genetic correlations between the directly selected traits (LWG and BF) and the meat quality traits.

CONCLUSIONS

It is concluded that after reducing the frequency of halothane-susceptible pigs genetic variations and heritabilities for meat quality traits are still considerable. Considering the heritabilities, genetic correlations of both production and meat quality traits and economic weights of production traits currently used in The Netherlands, it is concluded that meat quality will be decreased as a result of correlated response. However, meat quality can be improved if less emphasis is put on lowering backfat thickness or increasing lean meat content.

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CHAPTER 4

ECONOMIC VALUES OF OPTIMUM TRAITS; THE EXAMPLE OF MEAT QUALITY IN PIGS

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ECONOMIC VALUES OF OPTIMUM TRAITS; THE EXAMPLE OF MEAT QUALITY IN PIGS

ABSTRACT

In this paper a method is outlined to derive marginal-income functions and to calculate economic values for traits with an intermediate optimum such as meat quality traits. A normal distribution of the quality trait was assumed, but the method can be used for other distributions as well. The parameters necessary to use this method are distribution of the quality trait, population mean and the standard deviation of the quality trait, optimum range and price differences between products within and outside the optimum range. Especially, the optimum range for the quality trait and the price differences to be used have to be derived from consumer and processing research. Some alternative methods that can be used for selection on quality traits, such as restricted-selection index, desired-gains index and indices based on a quadratic aggregate genotype, are discussed.

Key Words: Economic Value, Optimum Trait, Meat Quality

INTRODUCTION

In breeding programs, attention is payed to several traits combined in a breeding goal. In most present applications the economic value is assumed to be independent of the population mean of these traits. However, various traits economically present an optimum range, resulting in a dependency between the economic value and the population mean. Examples of this can be found especially in traits related to quality.

An approach that can be followed in those cases is the use of a restricted selection index (Kempthorne and Nordskog, 1959). The purpose of this approach is to keep a trait at a particular level. Tomar (1983) concluded that in selection experiments the use of a restricted selection index has proved to be effective and in agreement with the theory. However, the seriousness of a deviation from the optimum is not taken into account. An alternative might be to incorporate quadratically an optimum trait in the aggregate genotype (Wilton et al., 1968). Using this method the profit (defined as "a linear combination of measurable traits") of the parents is maximized, although the profit of the offspring should be maximized (Goddard, 1983).

Whatever method is used, it is always necessary to calculate an accurate profit function. However, for quality traits a profit function or a function of marginal income is in most cases only approximately known in terms of thresholds below and above which the product is not acceptable or only acceptable for lower prices. This paper addresses such a situation and a method is developed to derive a marginal-income function and to calculate economic values for this case. The derivation of a marginal-income function and the calculation of the economic value of ultimate pH of pig meat will be given as an example of the method described in this paper.

DERIVATION OF THE METHOD

The calculation of economic values for traits with an optimum range (hereafter called "optimum traits") assumes that this optimum range can be defined. Given a certain distribution for the optimum trait under study (e.g. a normal distribution), the fraction of the population that is within the optimum range (p_w)

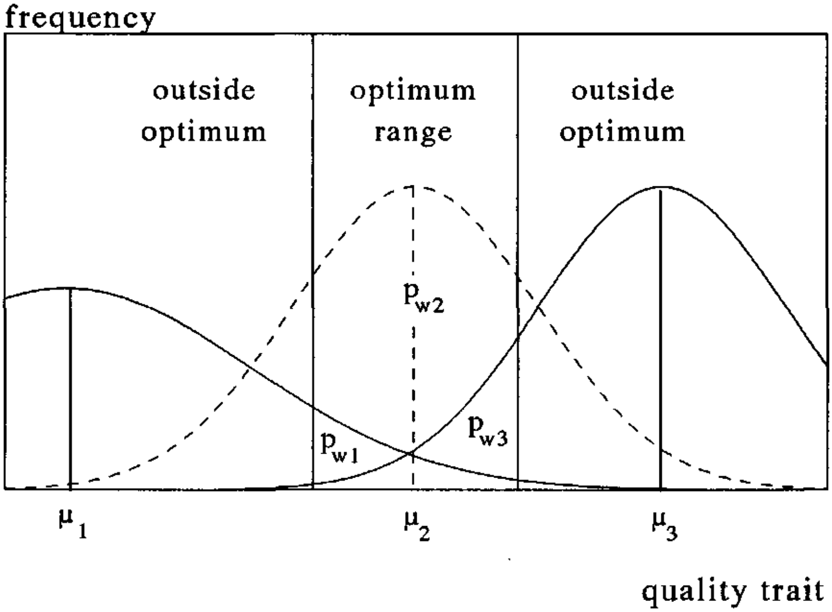

Figure 1. Normal distributions with different means and standard deviations with respect to the optimum range (p_{wi} = fraction within optimum range; μ_i = population mean).

can be derived (Figure 1). As illustrated in Figure 1, this fraction depends on the population level, the standard deviation of the optimum trait and the width of the optimum range. Furthermore, it is necessary to know the price difference between products with the quality within and products with quality outside the optimum range. We first assume only two different price levels. The price difference may result from the fact that products with a deviating quality cannot be sold for the same prices as products within the optimum range. An example is pig meat that has to be sold to the meat processing industry because the quality is not sufficient for consumption as fresh meat. The magnitude of this price difference has to be generated by the market.

Using this information the marginal income can be calculated, where marginal income is defined as "the average value of animals in the population relative to the average value in a situation in which all animals are outside the optimum range":

$$\mathrm{MI} = p_w \times \mathrm{PD} \times \mathrm{W} \qquad [1]$$

where: MI = mean marginal income per animal, p_w = fraction of the population within the optimum range, PD = price difference between products within and outside the optimum range and W = product produced per animal.

A marginal-income function can be calculated using Equation **[1]** for a range of population means for the optimum trait under study. This marginal-income function will be dependent on the standard deviation of the optimum trait for the population, the width of the optimum range, the price difference between products within and outside the optimum range and the amount of product produced per animal. Therefore, a more general form of Equation **[1]** is:

$$\mathrm{MI}(\mu) = f(\mu \mid \sigma, \mathrm{LB}, \mathrm{UB}, \mathrm{PD}, \mathrm{W}) \qquad [2]$$

where: μ = population mean of the quality trait, σ = population standard deviation of the quality trait, LB = lower boundary of the optimum range and UB = upper boundary of the optimum range.

For the derivation of economic values we are interested in the marginal change in marginal income if the population mean is changed by selection. Therefore, the first derivative of **[2]** to μ describes the function of the economic value of the quality trait.

EXAMPLE

For pig meat, one of the quality traits found to be important from a sensory and technological point of view is ultimate pH (i.e. pH 24 hours after slaughtering, pH_u; Russo, 1988; Steenkamp and Van Trijp, 1988). According to Russo (1988), the optimum range for pH_u is from 5.5 to 5.8. The trait pH_u is assumed to be normally distributed with a phenotypic standard deviation equal to 0.15 (Hovenier et al., 1992). The price difference between meat within the optimum range and meat outside the optimum range is assumed to be Dfl. 0.50 (current Dfl 0.50 = US$ 0.29). This price difference is based on the consumers' willingness to pay approximately Dfl 0.46 per kilogram of meat extra for chops of a better quality (Steenkamp and Van Trijp, 1988). The lean meat production per pig is assumed to be 45 kg, based on a mean carcass weight of 83.3 kg and a mean lean meat percentage of 53.8% in The Netherlands in 1991 (P.V.V., 1992).

Equation [2] can be written as:

$$MI(\mu) = PD \times W \times \int_{LB}^{UB} f(\mu)d(\mu) \qquad [3]$$

To calculate p_w, the function of the normal distribution was numerically integrated using Simpson's rule (Press et al., 1989):

$$\int_{LB}^{UB} f(\mu)d(\mu) \approx \frac{1}{3}h\left[y_0 + 4(y_1 + y_3 + y_5 + \dots) + 2(y_2 + y_4 + \dots) + y_n\right] \qquad [4]$$

where:

$$y_n(\mu) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{1}{2}\left(\frac{(LB+nh)-\mu}{\sigma}\right)^2} \qquad [5]$$

where: $f(\mu)$ = the function that describes the distribution of the quality trait (here assumed to be the normal distribution), n = number of steps between LB and UB and h = width of the steps (n and h are iteratively determined).

In Figure 2, the marginal-income function for this specific example is shown. This figure gives the marginal income per pig as a function of μ. So, when the population mean is 5.0, the fraction of animals within the optimum range will be zero and the marginal income will be zero as well because a small increase in μ will not result in marginal income. Maximum marginal income is found when the population mean is in the middle of the optimum range (5.65). For that mean the largest fraction of the population (p_w = 68.3%) is within the optimum range.

The first derivative of **[3]** gives the economic value (EV) of the trait pH_u as a function of μ. This first derivative can be written as:

$$\begin{aligned} EV(\mu) = \frac{\delta MI}{\delta\mu} &= (PD x W x \frac{1}{3} h)\left[y_0 + 4(y_1 + y_3 + y_5 + \ldots) + 2(y_2 + y_4 + \ldots) + y_n \right]' \\ &= (PD x W x \frac{1}{3} h)\left[y_0' + 4(y_1' + y_3' + y_5' + \ldots) + 2(y_2' + y_4' + \ldots) + y_n' \right] \end{aligned} \qquad \textbf{[6]}$$

and

$$y_n' = \frac{\delta y_n}{\delta\mu} = \frac{(LB+nh)-\mu}{\sigma^2\sqrt{2\pi\sigma^2}} \; e^{-\frac{1}{2}\left(\frac{(LB+nh)-\mu}{\sigma}\right)^2} \qquad \textbf{[7]}$$

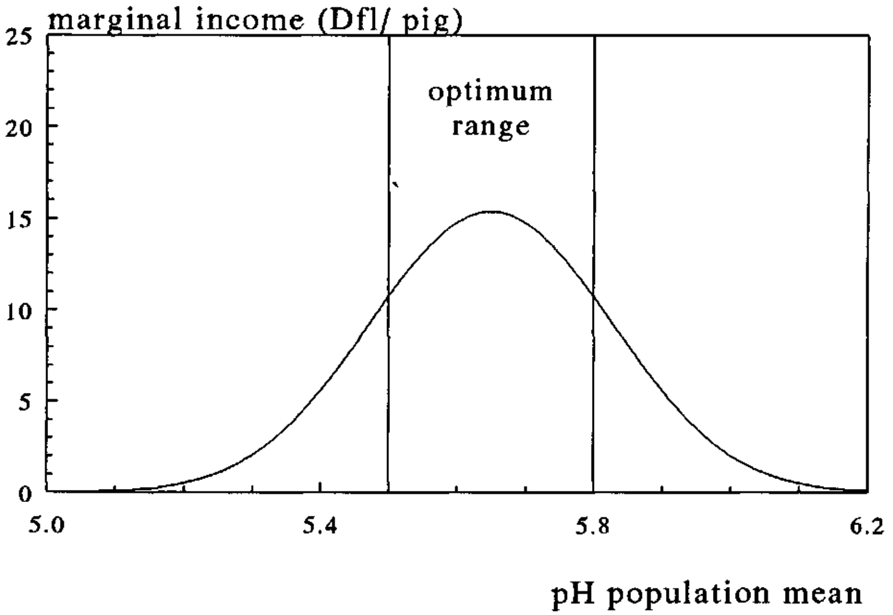

Figure 2. Marginal-income function for pH_u assuming σ = 0.15, a price difference between meat within and outside the optimum range equal to Dfl 0.50 (current US$ 0.29) and 45 kg lean meat per pig.

In Figure 3, the economic value as a function of μ is given. When average pH_u of the population is below 5.65 (i.e. the optimum pH_u) economic values are positive because marginal income rises with increasing population mean. When pH_u population mean is higher than 5.65 economic values are negative. The function of the economic values (and also the marginal-income function given in Figure 2) is symmetric around pH_u 5.65 because price differences between meat within the optimum range and meat below or above the optimum are supposed to be equal.

DISCUSSION

In general, profit functions include both returns and costs of production (e.g. Smith et al., 1986). In our example, no costs are included, assuming that no extra costs are associated with the production of meat of various quality levels.

The method given here was illustrated by a trait with a normal distribution. However, any function describing the distribution of a certain optimum trait of a

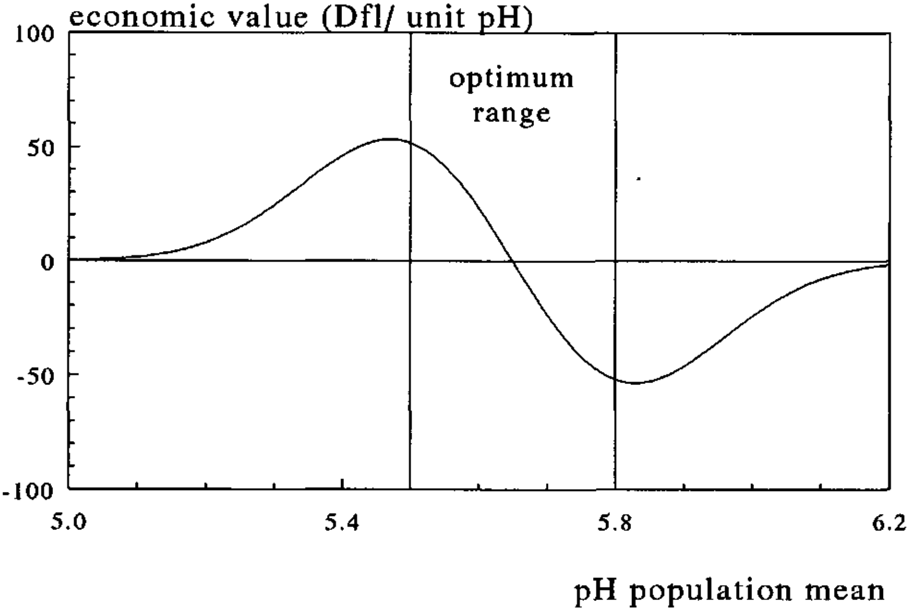

Figure 3. Function for economic value for pH_u assuming $\sigma = 0.15$, a price difference between meat within and outside the optimum range equal to Dfl 0.50 (current US$ 0.29) and 45 kg lean meat per pig.

population can be used. An example of a quality trait with a possible other function describing the distribution is the amount of intramuscular fat or drip loss. Especially for very low population means of these traits, the function will be skewed. When another function is used, Equations **[6]** and **[7]** have to be adopted, but the principle does not change. The same holds for the price differences between products outside and within the optimum range. We assumed only one price difference for meat outside and within the optimum range. However, often the value of meat under the optimum range will differ from the value of meat above the optimum range. Furthermore, not only one clear distinction between meat outside and within the optimum range may exist, but more classes of meat quality may be distinguished. Instead of calculating only one p_w, for each class the fraction of the meat has to be calculated. The extension of the method given here is straightforward.

The example given is based on a trait for which both an upper and a lower boundary of the optimum range could be defined. For a trait such as meat tenderness it can be argued that only an upper boundary exists above which meat is unacceptable for consumption as fresh meat. The same method can be used defining the optimum range from zero to the upper boundary.

The effects of changes in standard deviation on the marginal-income function and the economic value function are shown in Figures 4 and 5. The different curves are a result of the fact that, with a large standard deviation already at a low population mean p_w will be unequal to zero. Moreover, with the population mean equal to the optimum, the marginal income will be lower because a larger fraction of the population will be outside the optimum range. In other words, for a population with a large standard deviation, the marginal income is unequal to zero for a larger range of population means and the marginal income will be lower when the population mean is equal to the optimum value of the quality trait. Consequently, for a population with a large standard deviation economic values will be unequal to zero for a larger range of population means and will vary less. Comparatively, a smaller optimum range has the same effect as a larger standard deviation.

Two other factors that will influence the marginal-income function and the economic-value function are the price differences between meat within and outside the optimum range and the amount of product produced per animal. However, these effects only influence the level of both functions because they are just multiplicative factors and do not influence p_w.

Under the assumptions considered in the example given, maximum economic values will be found for population means equal to the boundaries of the optimum range or just outside the optimum range, as can be seen in Figure 5. Maximum economic values will not be found within the optimum range because, assuming a normal distribution, maximum change of p_w will never occur when the population mean is within the optimum range.

It should be emphasized that the economic values as calculated here are based on a nonlinear, marginal-income function and are therefore valid for small genetic changes only. Consequently, in theory it may be necessary to calculate new economic values each generation based on the new population mean. So far, genetic changes are not taken into account. For nonlinear profit functions or nonlinear, marginal-income functions, this is a serious shortcoming, as was shown by Goddard (1983). The following example illustrates this problem. Assuming a population mean equal to 5.0, then from Figure 3 it can be seen that the economic value equals zero. However, if in one round of selection the population mean could change from 5.0 to 5.2 and the marginal incomes for pH_u = 5.0 and for pH_u = 5.2 (see Figure 2) are compared, then it must be concluded that the economic value is not equal to zero. From this point of view it might be concluded that using marginal incomes may result in biased economic values. Therefore, it might be useful to include the possible change of the population mean due to selection and

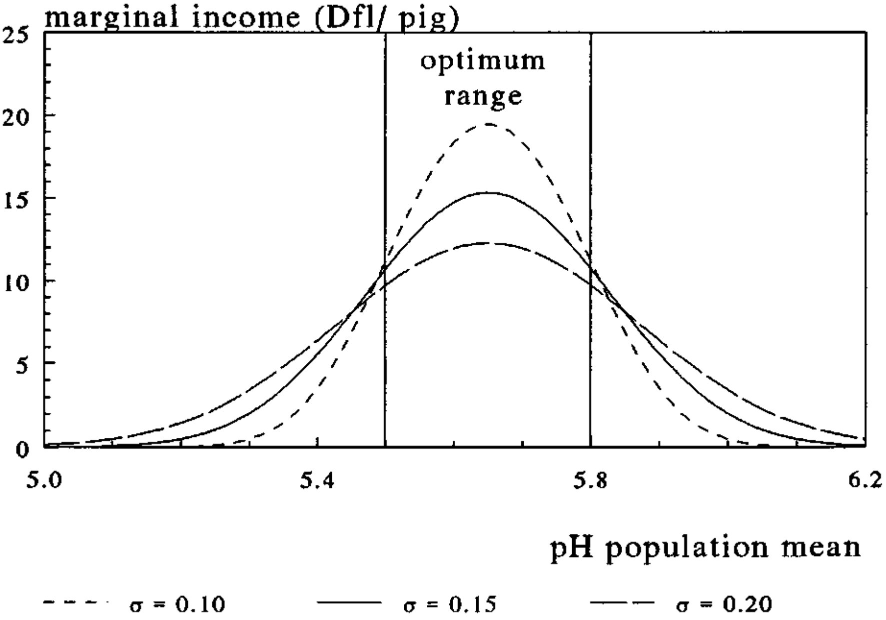

Figure 4. Marginal-income functions for pH_u assuming σ = 0.10, 0.15 and 0.20 (price difference: Dfl 0.50 [current US$ 0.29]; 45 kg lean meat per pig).

the time span in which selection will take place in the calculation of the economic values. An iterative procedure based on the graphical method of Moav and Hill (1966) may then be an option.

As stated before, the use of a restricted-selection index is a possible approach to keep a trait at a particular level (Kempthorne and Nordskog, 1959). It must be noted that this approach can be used when the population mean of the optimum trait is equal to the optimum value. If this is not the case, maximum marginal income will not be reached.

Beside restricted-selection index, desired-gains index is a possibility too (Brascamp, 1984). However, for both restricted-selection and desired-gains indices, the traits in the aggregate genotype are not weighted according to there economic weights, but the weights are more or less influenced by feel.

Another possible approach mentioned before is to incorporate quadratically an optimum trait in the aggregate genotype (Wilton et al., 1968). The aim of a breeding program is to change the population mean in a certain direction or, in case of optimum traits, to a certain value. All selected animals contribute linearly to the change of the population level assuming additive inheritance. Therefore, it can be

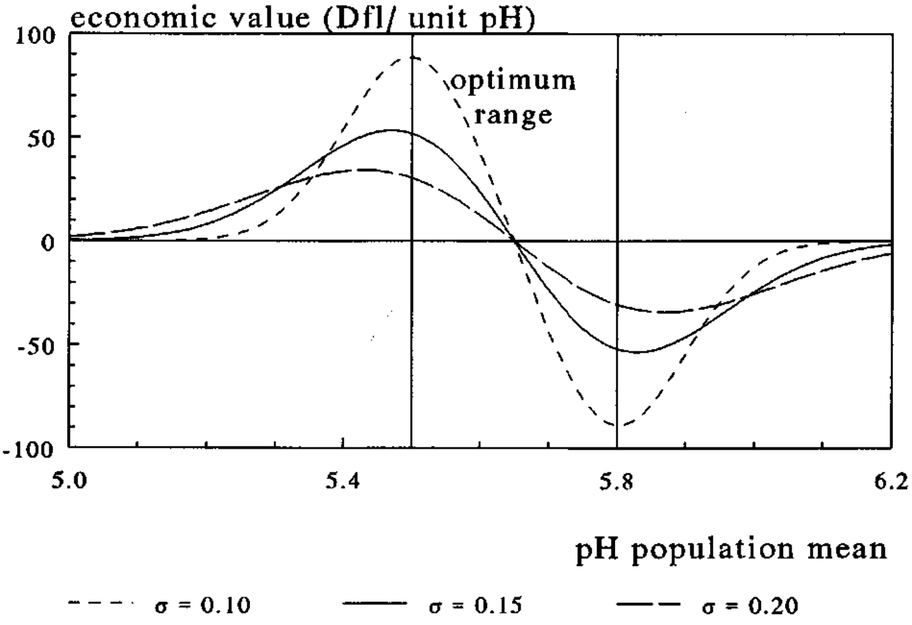

Figure 5. Functions of economic values for pH_u assuming $\sigma = 0.10, 0.15$ and 0.20 (price difference: Dfl 0.50 [current US$ 0.29]; 45 kg lean meat per pig).

concluded that using an index based on a linear aggregate genotype is the best way to select parents for the next generation (Goddard, 1983).

IMPLICATIONS

A method is outlined to derive marginal-income functions and to calculate economic values for traits with an intermediate optimum, such as meat quality traits. For population levels around the optimum range, the use of this method will give economic values that can be used in the standard selection index theory. However, if the population mean deviates considerably from the optimum range, an economic value equal to zero will result, indicating that selection for the quality trait will not result in marginal income. In that case, replacing the particular line or breed may be more useful than selecting within the line.

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CHAPTER 5

IMPLICATIONS OF INCLUDING MEAT QUALITY IN PIG BREEDING PROGRAMS

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IMPLICATIONS OF INCLUDING MEAT QUALITY IN PIG BREEDING PROGRAMS

ABSTRACT

In this paper, the consequences of selection for meat quality are analyzed for the various tiers of the pig meat production chain. The first three levels, the breeding organisations, the weaner producers and the growers are the levels that will make costs when meat quality is included in the breeding program. Slaughterhouses and boning plants, processing industry and retail trade and consumers will profit because of improved technological and sensory quality of the pig meat.

The effect of the inclusion of pig meat quality on the expected genetic change is illustrated by five case studies, each different for the mean of one of the meat quality traits and the corresponding economic values. When the current breeding goal and selection index are used (which means that no attention is paid to meat quality; option 1), financial superiority for production traits of the selected animals after one round of selection ($\Delta G_{prod,1}$; i = 1) was equal to Dfl 5.21. However, when the economic values of the five case studies were supposed to be true, correlated financial superiorities for meat quality ($\Delta G_{qual,1}$) were calculated to range from -3.5 to +21.9% of $\Delta G_{prod,1}$, depending on the current population mean of the meat quality traits with respect to the optimum level. This resulted in total financial superiorities ($\Delta G_{tot,1}$) ranging from Dfl 5.03 to Dfl 6.35.

When meat quality was included only in the breeding goal, ΔG_{qual} improved up to 12.5% of $\Delta G_{prod,1}$ for the various cases, ΔG_{prod} decreased up to 6% of $\Delta G_{prod,1}$, both changes resulting in an improvement of ΔG_{tot} up to 6.6% of $\Delta G_{tot,1}$. When meat quality was included in both index and breeding goal, ΔG_{qual} improved with 22.3 to 40.7%, ΔG_{prod} decreased with 12.1 to 19.6% and ΔG_{tot} improved with 10.3 to 22.7%.

Key Words: Pig, Meat Quality, Breeding Program, Production Chain

INTRODUCTION

Consumers increasingly pay attention to the quality of the products they buy. This also holds for pig meat. From a study of the meat consumption until the year 2000, it was concluded that the increase in total meat consumption in the U.S.A. and the E.E.C. will stagnate and that the market share of poultry meat will increase strongly (P.V.V., 1989). The Dutch Commodity Board for Livestock and Meat (P.V.V.) stated that problems to increase pork consumption are satiation of the market, the image of pork to be unhealthy and fat and the low sensoric properties of pork. But also the meat industry frequently comments on the increasing incidence of meat quality problems (Kempster et al., 1986). Therefore, attention should be paid to improve meat quality, among others by breeding.

Studies of Hovenier et al. (1992, 1993[b]) showed that there are possibilities to effect genetic improvement in meat quality traits. Repeatabilities of meat quality traits in a halothane-negative pig population were estimated to range from 0.29 for cooking loss to 0.76 for Minolta L^* and heritabilities from 0.20 for ultimate pH in the *M. semimembranosus* to 0.61 for amount of intramuscular fat. Phenotypic correlations between production traits and meat quality traits differed hardly from zero except for amount of intramuscular fat. Genetic correlations were found to be favourable between daily gain and meat quality and to be unfavourable between lean meat content and meat quality.

Economic weights are used to combine traits in a breeding goal. In most present applications, the economic values are assumed to be independent of the population mean of the traits. However, various traits like meat quality traits show an optimum range resulting in a dependency between the economic value of a change of the population mean on the one hand and the actual value of the population mean on the other. Hovenier et al. (1993[a]) developed a method to derive economic values for this case, based on the knowledge of threshold levels beyond which the product is not acceptable or only acceptable for lower prices.

Pig meat is produced by several tiers forming the pig meat production chain. Selection for meat quality will have divergent consequences for the different tiers. Aim of this article is to study these consequences. Furthermore, it is tried to give an indication of the tiers in which extra costs will be made or extra revenues may be expected when meat quality is improved by selection.

TIERS OF THE PORK PRODUCTION CHAIN

When improvement of pork quality becomes an aim of the production chain, this will influence each of the tiers in the chain. First, some general points will be discussed and after that some points of interest specific for the different tiers. In Table 1, the tiers are listed and some consequences for each of the tiers are summarized.

General

For all tiers, a consequence of inclusion of meat quality in the breeding goal will be an altered genetic change of the production traits and, in case selection for

Table 1. Indication of the different tiers in the pig production chain that will make costs (-) and tiers that will profit (+) of improvement of meat quality by breeding (zero if no costs nor profits are expected).

tiers	effects	costs/ profits
breeding and multiplication	- measurements of quality traits in breeding stock and slaughter pigs - correlated effects on breeding stock and by-products	---
weaner production	- correlated effects on reproduction traits	-/0
growing and finishing	- correlated effects on production traits - payment system	--
slaughtering and boning	- improved water-holding capacity - changed lean meat content of the carcasses - measurements for grading and payment	+
processing industry and retail trade	- improved meat quality influencing technological meat quality and keeping ability	+ +
consumers	- improved pig meat quality	+ + +

meat quality is carried out in dam lines too, of the reproduction traits. These changes occur when additional traits are included in the breeding goal or if the additional meat quality traits are correlated with the production and reproduction traits.

Correlations between production and meat quality traits are given by Hovenier et al. (1992). Relationships between reproduction traits and meat quality are not known. Considering reproduction, especially litter size is of importance. Brien (1986) concluded that relationships between growth rate and litter size are not consistent in pig research literature. Both traits appeared to be positively correlated genetically in sows rather than in gilts. Furthermore, he concluded that the literature is not clear about the relationship between backfat thickness and litter size. Combining these conclusions with the relationships between production traits and meat quality given before, it may be concluded that the correlations between reproduction and meat quality will be about zero or slightly favourable. Results of Willeke et al. (1984), Lampo et al. (1985) and Willeke (1986), showing smaller litters for halothane-sensitive animals, support this conclusion.

Nucleus and Multiplication

Main consequence for breeding companies will be the need to reconsider the breeding goal and the selection criteria used. Therefore, costs will have to be made to estimate genetic parameters, to obtain trait means and variances of the end products produced by the breeding company and to obtain data for selection.

With respect to the estimates of trait means and variances, it must be noted that these parameters are needed especially for the meat quality traits to quantify economic values (Hovenier et al., 1993[a]). Regarding the measurements for selection, the cheapest option is to measure no meat quality traits at all. In that case, compared to the current situation, no extra costs are made for measuring, but because meat quality is included in the breeding goal, index weights for the production traits will change. When meat quality traits have to be included in the index, additional measurements are required. To optimize the number of those measurements, economic evaluations will have to be made to estimate the genetic improvement and the costs of the extra measurements for the different options. Measurements of meat quality traits are also necessary to estimate genetic parameters. It must be noted that those same measurements also can be used for selection, because the optimum data structure to estimate genetic parameters comprises measurements of animals of a large number of families. For example, meat quality measurements on one animal per litter may well be used for both selection and genetic parameter estimation purposes.

Weaner Production

The tier of weaner production is a link between the tiers "nucleus and multiplication" and "growing and finishing". Therefore, for this tier the only consequences of including meat quality in the breeding goal will be because of correlated genetic changes, the choice of the line(s) in which selection for a better meat quality is carried out and the inclusion of additional traits in the breeding goal as discussed before.

Growing and Finishing

The breeding goal for production traits and meat quality traits should be defined at the level of growing and finishing. Therefore, inclusion of meat quality in the breeding goal may have several consequences for this tier. First, depending on the correlations between the production and meat quality traits and the relative emphasis put on the traits, it will affect the genetic changes of all traits. When the farmers are paid based on both carcass composition and meat quality of their pigs, they will be rewarded completely for their genetically improved slaughter pigs. When meat quality is not included in the payment of pigs, the financial consequences for the farmers can be calculated by comparing the revenues of current and future breeding programs. This will be shown later.

Slaughtering and Boning

For slaughter-houses and boning plants there are two points of interest. First, improved meat quality will result among others in a better water-holding capacity and as a result in lower weight losses of the carcasses. Besides that, selection for meat quality will influence improvement of the lean meat content of the carcasses. Both facts will influence the amount of lean meat produced per carcass and therefore the profits of slaughter-houses and boning plants.

Direct costs, that possibly have to be made by the slaughter-houses, are the costs of carrying out meat quality measurements, not only for grading carcasses to be sold but, when meat quality is included in payment of slaughter pigs, also for classifying carcasses.

Processing Industry and Retail Trade

Genetic improvement of meat quality will result in products better suitable to be used by the processing industry and the retail trade. For these tiers, ultimate pH is an important meat quality trait because of its relation with meat colour and water-holding capacity and with keeping properties of the meat. Optimum ultimate pH is between 5.5 and 5.8 (Russo, 1988). Below this range, meat will be paler and will have a lower water-holding capacity, above this range the meat will have poorer keeping abilities. Another important meat quality trait is water-holding capacity. Meat with a low water-holding capacity will result in larger weight losses during processing and storage of the meat (Kauffman et al., 1986).

Consumers

The consumers are not really a part of the pig meat production chain but nevertheless are mentioned here because they form the group that ultimately benefits of improved meat quality. The demand for payable meat will result in the inclusion in the breeding goal of economically important traits for the weaner producers and for the growers and finishers. The demand for good quality meat will result in the inclusion of important sensoric meat quality traits in the breeding goal.

For sensoric meat quality, there are five traits of importance. First trait is ultimate pH. From consumer research, it was concluded that the pig meat preferred by consumers when they are in the shop has a relatively low ultimate pH, but that meat with a relatively high ultimate pH is desired from an organoleptic point of view (Steenkamp and Van Trijp, 1988). This means that also for sensoric meat quality, ultimate pH between 5.5 and 5.8 may be optimum.

Ultimate pH has a causal relationship with the traits water-holding capacity and meat colour. A high water-holding capacity is desirable from an organoleptic point of view (Kauffman et al., 1986). However, it should be noted that consumers judge pig meat with a somewhat lower water-holding capacity to be more fresh (Steenkamp and Van Trijp, 1988).

Meat colour is of importance for the organoleptic meat quality. From consumer research, it was concluded that relatively dark meat has a better sensoric quality. Furthermore, it appeared that a constant and uniform colour of the meat is desired by consumers.

Fourth meat quality trait is the amount of intramuscular fat which is related to the eating quality of pig meat. Several studies showed a positive relationship between amount of intramuscular fat and eating quality (e.g. Fjelkner-Modig, 1985; Bejerholm and Barton-Gade, 1986). However, there are indications that those relationships are found only for populations with intramuscular fat levels lower than about 2% (Fjelkner-Modig, 1985) and that at higher levels no relationship exists between amount of intramuscular fat and eating quality. For higher levels of intramuscular fat, a positive relationship was found with taste (Bejerholm and Barton-Gade, 1986) but there is also a possibility that the meat is rejected by the consumer because of the visible fat (Steenkamp and Van Trijp, 1988). Therefore, a valid optimum range for amount of intramuscular fat seems to be from 1.5 to 2.5%.

Fifth meat quality trait is meat tenderness. Steenkamp and Van Trijp (1988) concluded that consumers judged meat to be tender and juicy if it had relatively low maximum shearforce values. But the level of maximum shearforce above which meat tenderness is unacceptable is not known. Furthermore, it is unknown if there is a level of maximum shearforce below which meat tenderness becomes unacceptably high.

SELECTION PROCEDURES

In the previous section, for each tier of the pig production chain points of interest related to selection for meat quality were discussed. In the present section, these points will be combined into three selection procedures and some examples of using those procedures will be given. The effects of selection using the selection procedures given for the different tiers will be discussed in the next section.

Breeding Goal

Breeding goal traits for production can be considered to consist of several parts (e.g. growth and feed intake in several stages; De Vries, 1989) but for simplicity we only include daily gain (DG; gd^{-1}), feed intake (FI; gd^{-1}) and lean meat content (LMC; %) at the level of growing and finishing as production traits in the breeding goal. Economic values for these traits for the Dutch situation were quantified by De Vries (1989) as Dfl 0.262 for DG, Dfl -0.064 for FI and Dfl 3.10 for LMC.

For meat quality, the five traits given before are used as breeding goal traits. Optimum ranges of the meat quality traits are given in Table 2. For ultimate pH (PH), the optimum range between 5.5 and 5.8 is used. Because no clear optimum range for meat colour (COLOR) is found in literature, a relatively wide range (based on the Japanese colour scale; Nakai et al., 1975) was supposed to be optimum. Water-holding capacity expressed as drip loss (DRIP; %) is treated as a linear trait (like the production traits) and it is supposed that it should be diminished. For amount of intramuscular fat (INTMF; %), the optimum range of 1.5 to 2.5% is used as argued before. Assuming that the current level of maximum shearforce (SHEAR; N) gives rise to complaints about meat tenderness, the optimum range for SHEAR was chosen to be from zero up to the current mean for slaughter pigs.

Fertility traits were not considered in the breeding goal. The assumption is that correlations between fertility and production traits (Brien, 1986) and between fertility and meat quality traits are zero.

Heritabilities and Correlations

In Table 3, the heritabilities and genetic and phenotypic correlations used in this study are given for the traits in the breeding goal and for backfat thickness (BF; mm). The latter trait is used as an index trait because lean meat content is not measured on live animals.

The parameters are mainly based on results of Hovenier et al. (1992), completed with results of Cameron (1990) for correlations with tenderness and with results of Buddiger (1988) for correlations with food intake.

Cases

Using selection index theory, three options were evaluated. In the first option, the breeding goal is defined only for production traits:

Table 2. Breeding goal traits, optimum ranges, standard deviations and economic values (for the optimum traits population means between brackets) for the five case studies[1].

Trait	optimum range[2]	stand. dev.	economic values, Dfl/slaughter pig[3]				
			Case 1	Case 2	Case 3	Case 4	Case 5
daily gain, gd^{-1}		100	0.262	0.262	0.262	0.262	0.262
feed intake, gd^{-1}		200	-.064	-.064	-.064	-.064	-.064
lean meat content, %		4.0	3.1	3.1	3.1	3.1	3.1
ultimate pH	5.5-5.8	0.10	88.76 (5.50)	**-88.76** **(5.80)**	88.76 (5.50)	88.76 (5.50)	88.76 (5.50)
meat colour[4]	2.0-4.0	0.4	0.00 (3.0)	0.00 (3.0)	**22.44** **(2.0)**	0.00 (3.0)	0.00 (3.0)
drip loss, %		2.2	-2.25	-2.25	-2.25	-2.25	-2.25
intramuscular fat content, %	1.5-2.5	0.6	9.90 (1.6)	9.90 (1.6)	9.90 (1.6)	**-11.23** **(2.5)**	9.90 (1.6)
maximum shearforce, N	0-35.0	4.0	-2.24 (35.0)	-2.24 (35.0)	-2.24 (35.0)	-2.24 (35.0)	**0.00** **(<35.0)**

[1] For the Cases 2 to 5, changed population means and economic values have been printed bold.

[2] Not given when value is not of interest for the calculation of the economic value.

[3] Economic values of the optimum traits based on 45 kg lean meat per pig, price difference between meat within and outside the optimum range Dfl 0.50 kg^{-1}.

[4] Meat colour based on Japanese colour scale.

$$H = v_1 DG + v_2 FI + v_3 LMC \qquad [1]$$

where: H = aggregate genotype and v_i = economic value of trait i.

Index traits are DG and BF measured on the performance tested animal, its full sibs and paternal half sibs, its sire and dam and the full sibs of both the sire and the dam. It is assumed that five animals per litter are tested which means that information on four full sibs is known. Furthermore, it is assumed that each sire produces twenty litters resulting in 95 tested paternal half sibs per tested animal. This option is supposed to reflect current pig breeding programs.

In the second option, the same index traits are used but the breeding goal is extended with meat quality traits:

Table 3. Heritabilities (diagonal) and genetic (below) and phenotypic (above diagonal) correlations between production and meat quality traits[1].

	DG	FI	BF	LMC	PH	COLOR	DRIP	INTMF	SHEAR
DG	**0.30**	0.60	0.55	-.35	-.05	0.05	0.00	0.15	-.05
FI	0.55	**0.30**	0.40	-.45	0.05	0.05	-.05	0.10	-.05
BF	0.55	0.40	**0.50**	-.75	0.00	0.00	-.05	0.30	-.10
LMC	-.25	-.55	-.70	**0.50**	-.05	0.00	0.10	-.30	0.10
PH	0.10	0.10	0.15	-.10	**0.30**	0.45	-.45	-.10	-.10
COLOR	0.45	0.10	0.00	0.15	0.70	**0.30**	-.35	-.10	-.20
DRIP	-.05	-.10	-.05	0.10	-.80	-.75	**0.30**	-.05	0.10
INTMF	0.20	0.20	0.35	-.45	-.20	-.35	-.05	**0.60**	-.05
SHEAR	-.10	-.10	-.15	0.15	-.10	-.25	0.15	-.20	**0.30**

[1] Daily gain (gd^{-1}; DG), feed intake (gd^{-1}; FI), lean meat content (%; LMC), ultimate pH (PH), meat colour (based on Japanese colour scale; COLOR), drip loss (%; DRIP), intramuscular fat content (%; INTMF) and maximum shearforce (N; SHEAR).

$$
\begin{aligned}
H = {} & v_1\,DG + v_2\,FI + v_3\,LMC \\
& + v_4\,PH + v_5\,COLOR + v_6\,DRIP + v_7\,INTMF + v_8\,SHEAR
\end{aligned}
\qquad [2]
$$

So, meat quality is included in the breeding goal but meat quality measurements are not carried out. Genetic change of meat quality is achieved as a result of (and quantified by using) the relations between the production traits and the meat quality traits.

In option 3, the same aggregate genotype is used as in option 2. But in option 3 one animal from each litter is slaughtered experimentally to measure meat quality traits. Because of the high correlations among PH, COLOR and DRIP and for simplicity of the calculations, only PH, INTMF and SHEAR are considered here as meat quality index traits.

To illustrate the effects of selection in case of different population means for the various meat quality traits, five cases are studied for each option. For Case 1, the mean values of the meat quality traits given in Table 2 are based on a sample taken at random of about 100 Dutch slaughter pigs (Hovenier, unpublished results). Economic values for the meat quality traits PH, COLOR, INTMF and SHEAR are calculated using the method described by Hovenier et al. (1993[a]). This method requires the knowledge of the optimum range of a trait and the price difference between meat within and outside this range. Based on the population mean and standard deviation of the trait, the percentage of the animals within the optimum range and the marginal income from a better meat quality are calculated. The first derivative of this marginal-income function gives the economic value of the trait for a range of population means. The economic value of 1% drip loss is calculated as the loss of 1% of the amount of lean meat, being:

$$-1\% \text{ x } 45\text{kg x Dfl } 5.00\text{kg}^{-1} = \text{Dfl } -2.25$$

In Case 2, the population mean of PH is changed from 5.50 to 5.80, a mean value found in studies from England, Eire and Canada (Bendall and Swatland, 1988). The population means of all other traits are kept unchanged. In Case 3, the population mean for meat colour is set to 2.0. This means that the meat is too light on average and that the economic value for meat colour will be maximum because the population mean is at the lower bound of the optimum range. In Sweden, meat colour is included in the breeding goal to keep the colour at the current level or to slightly improve it (Johansson, 1987). In Case 4, a population mean of 2.5% is used for INTMF, a higher value than 1.6% that can be found in Hampshire or Duroc pigs (Sellier, 1988). In Case 5, SHEAR is assumed to cause no problems at all, resulting in an economic value of zero.

Finally, it is emphasized that all figures given here are case studies to browse the effect of different population means on the economic values and the resulting expected genetic changes. Therefore, relations among the different traits were not taken into account when changing the mean of one of the meat quality parameters for the various cases.

Results

In Table 4, the results of option 1 are given. The expected genetic superiorities after one round of selection, the correlation between the breeding goal and the index (r_{IH}) and the financial superiorities for the production traits (ΔG_{prod}; expressed as Dfl per pig after one round of selection with selection intensity equal to one) are equal for all five cases because they are independent of the economic values of the meat quality traits and therefore also independent of the population means of those traits. The total financial superiorities (ΔG_{tot}) and the financial superiorities for the meat quality traits (ΔG_{qual}) given in Table 4 are calculated assuming the economic values given for the five cases in Table 2. It can be seen that the correlated response of the meat quality traits results in a ΔG_{qual} varying from Dfl -.18 to Dfl 1.14 and in a ΔG_{tot} from Dfl 5.03 to Dfl 6.35, depending on the population

Table 4. Breeding goal traits, genetic superiorities as a percentage of the phenotypic standard deviation ($\%\sigma_p$), correlation between index and breeding goal (r_{IH}), total financial superiorities ($\Delta G_{tot,1}$) and financial superiorities for production ($\Delta G_{prod,1}$) and meat quality traits ($\Delta G_{qual,1}$) after one round of selection (i = 1) for option 1[1].

Trait	Genetic superiority[2], $\%\sigma_p$				
	Case 1	Case 2	Case 3	Case 4	Case 5
daily gain	19.5	19.5	19.5	19.5	19.5
feed intake	8.8	8.8	8.8	8.8	8.8
lean meat content	9.9	9.9	9.9	9.9	9.9
ultimate pH	-.4	**-.4**	-.4	-.4	-.4
meat colour	14.7	14.7	**14.7**	14.7	14.7
drip loss	-.5	-.5	-.5	-.5	-.5
intramuscular fat content	-2.4	-2.4	-2.4	**-2.4**	-2.4
maximum shearforce	0.4	0.4	0.4	0.4	**0.4**
r_{IH}	0.35	0.35	0.35	0.35	0.35
$\Delta G_{tot,1}$, Dfl	5.03	5.10	6.35	5.34	5.06
$\Delta G_{prod,1}$, Dfl	5.21	5.21	5.21	5.21	5.21
$\Delta G_{qual,1}$, Dfl	-.18	-.12	1.14	0.12	-.15

[1] Option 1: only production traits in the breeding goal and the index.

[2] For Cases 2 to 5, genetic superiorities of traits with changed population mean and economic value have been printed bold.

means for the meat quality traits. The large ΔG_{qual} for Case 3 is mainly the effect of the large favourable correlated change of COLOR (Dfl 1.32). It must be noted that the large correlated change of COLOR does not affect the results of the other cases because the economic value of COLOR is zero for those cases. Also for Case 4, ΔG_{qual} is positive because of the favourable correlated superiority of INTMF (Dfl 0.16).

In Table 5, the results of the five case studies for option 2 are given. The expected financial superiorities are given as the difference between option 2 and option 1. Thus, a positive value means that the financial superiority for option 2 is higher than for option 1. From Table 5, it can be seen that for option 2 the

Table 5. For the five case studies under option 2, genetic superiorities of the breeding goal traits as a percentage of the phenotypic standard deviation ($\%\sigma_p$), correlations between index and breeding goal (r_{IH}), total financial superiorities (ΔG_{tot}) and financial superiorities for production (ΔG_{prod}) and meat quality (ΔG_{qual}) traits after one round of selection (i = 1; financial gains expressed as the difference between the financial gains of option 2 and option 1)[1].

Trait	Genetic superiority[2], $\%\sigma_p$				
	Case 1	Case 2	Case 3	Case 4	Case 5
daily gain	24.9	22.8	24.3	19.2	23.9
feed intake	12.8	11.2	12.3	8.6	12.0
lean meat content	0.1	4.6	1.6	10.4	2.4
ultimate pH	1.3	**0.6**	1.1	-.4	0.9
meat colour	14.3	14.7	**14.5**	14.7	14.6
drip loss	-1.1	-.9	-1.1	-.5	-1.0
intramuscular fat content	3.0	0.6	2.2	**-2.7**	1.8
maximum shearforce	-1.3	-.6	-1.1	0.4	**-.9**
r_{IH}	0.31	0.32	0.32	0.28	0.32
$\Delta G_{tot,2}$ - $\Delta G_{tot,1}$, Dfl	0.33	0.10	0.30	0.00	0.20
$\Delta G_{prod,2}$ - $\Delta G_{prod,1}$, Dfl	-.32	-.10	-.24	0.00	-.19
$\Delta G_{qual,2}$ - $\Delta G_{qual,1}$, Dfl	0.65	0.19	0.54	0.00	0.39

[1] Option 1: only production traits in the breeding goal and the index. Option 2: production and meat quality traits in the breeding goal, only production traits in the index.

[2] For Cases 2 to 5, genetic superiorities of traits with changed population mean and economic value have been printed bold.

expected genetic superiorities are somewhat larger for DG and FI and lower for LMC. In general, the expected genetic superiorities for the meat quality traits are higher and in the desired direction for option 2 compared with option 1. Exceptions are the genetic superiorities of PH for the Cases 2 and 4 and of SHEAR for Case 4, which, due to the economic values and genetic parameters, change in an undesired direction. The changes result in lower ΔG_{prod} values and larger ΔG_{qual} and ΔG_{tot} values compared with option 1 for all case studies except Case 4. For this case, the

Table 6. For the five case studies under option 3, genetic superiorities of the breeding goal traits as a percentage of the phenotypic standard deviation ($\%\sigma_p$), correlations between index and breeding goal (r_{IH}), total financial superiorities (ΔG_{tot}) and financial superiorities for production (ΔG_{prod}) and meat quality (ΔG_{qual}) traits after one round of selection (i = 1; financial gains expressed as the differences between the financial gains of option 3 and option 2 and as the differences between option 3 and option 1)[1].

Trait	Genetic superiority[2], $\%\sigma_p$				
	Case 1	Case 2	Case 3	Case 4	Case 5
daily gain	22.1	20.8	21.1	15.5	22.4
feed intake	11.8	10.4	11.0	6.7	11.6
lean meat content	-.7	3.0	1.1	10.6	1.6
ultimate pH	6.5	**-3.3**	7.7	7.1	6.1
meat colour	17.0	11.1	**18.2**	19.6	16.9
drip loss	-6.3	1.0	-6.9	-4.6	-5.9
intramuscular fat content	5.1	7.4	1.4	**-13.8**	2.9
maximum shearforce	-6.2	-5.1	-5.8	-2.6	**-1.5**
r_{IH}	0.34	0.34	0.36	0.35	0.34
$\Delta G_{tot,3} - \Delta G_{tot,2}$, Dfl	0.58	0.44	0.87	1.21	0.33
$\Delta G_{tot,3} - \Delta G_{tot,1}$, Dfl	0.91	0.53	1.17	1.21	0.52
$\Delta G_{prod,3} - \Delta G_{prod,2}$, Dfl	-.70	-.62	-.72	-.69	-.44
$\Delta G_{prod,3} - \Delta G_{prod,1}$, Dfl	-1.02	-.72	-.95	-.69	-.63
$\Delta G_{qual,3} - \Delta G_{qual,2}$, Dfl	1.28	1.06	1.58	1.90	0.77
$\Delta G_{qual,3} - \Delta G_{qual,1}$, Dfl	1.93	1.25	2.12	1.91	1.16

[1] Option 1: only production traits in the breeding goal and the index. Option 2: production and meat quality traits in the breeding goal, only production traits in the index. Option 3: production and meat quality traits in both breeding goal and index.

[2] For Cases 2 to 5, genetic superiorities of traits with changed population mean and economic value have been printed bold.

expected genetic superiorities of all traits are about equal for both options 1 and 2, resulting in zero financial changes.

Largest change in genetic superiority for the production traits is found for

Case 1. The decrease of LMC lowers ΔG_{prod} with Dfl 1.22. The higher FI means a reduction of ΔG_{prod} of Dfl 0.51, the increase of DG an improvement of Dfl 1.41 which means a total reduction of ΔG_{prod} of Dfl 0.32 for option 2 compared to option 1.

In Table 6, the results are given for option 3. Compared to the results given for option 2 (Table 5), we see a shift in gain from the production traits to the meat quality traits. All expected genetic superiorities of the production traits are lower compared to option 2, the expected genetic superiority of LMC for Case 1 is even negative. All expected genetic superiorities of the meat quality traits are larger except for COLOR for Case 2 and INTMF for Case 3. The expected superiority of DRIP for Case 2 is in the undesired direction. This, together with the lower expected genetic superiority of COLOR for Case 2, is a result of the attempts to lower PH in combination with the correlations among those traits. For all case studies, the changes in genetic superiorities result in larger ΔG_{tot} and ΔG_{qual} and lower ΔG_{prod}, both compared with option 1 and with option 2.

The differences in ΔG_{tot} between option 2 and 3 range from Dfl 0.33 for Case 5 to Dfl 1.21 for Case 4. It can be concluded that the step from option 2 to option 3 largely determines the total change of ΔG_{tot} from option 1 to 3 (63.5% for Case 5, 100% for Case 4). For all cases, these changes of ΔG_{tot} originate from a reduced ΔG_{prod} and an increased ΔG_{qual}. Largest ΔG_{qual} from option 1 to 3 is found for Case 3, mainly as a result of the large change for PH which accounts for Dfl 0.72. For this case, COLOR accounts for Dfl 0.32.

Further calculations showed that trends of the results are similar when the price difference between meat within and outside the optimum range is changed. When this price difference is lowered from Dfl 0.50 kg^{-1}, as used in the examples, to Dfl 0.25 kg^{-1} this halves the economic values for the optimum traits. As a result, more emphasis is put on the production traits and less on the meat quality traits, but trends are similar. Changing the price difference from Dfl 0.50 kg^{-1} to Dfl 1.00 kg^{-1} shows the opposite effect.

PROFITS AND COSTS

When we combine the results from the sections 'Tiers of the Pork Production Chain' and 'Selection Procedures', it is possible to get an overview of the tiers that will profit from improvement of pig meat quality and tiers that will have to incur expenses (Table 1). In Table 1, it is assumed that meat quality is included in the breeding program but that meat quality of the slaughter pigs is not included in the payment that farmers receive from slaughter-houses. This assumption is made because inclusion of individual (on-line) meat quality measurements in the payment of farmers is not expected in the near future.

As concluded before, the nucleus and multipliers will have to make costs to include meat quality in the breeding program. However, for this tier no profits are to be expected, surely not when meat quality is not included in the payment. For the weaner producers, only costs are expected when selection for meat quality is carried out in dam lines too, due to reduced genetic changes as a result of the inclusion of additional traits in the breeding goal. However, no costs are expected when selection for meat quality is only carried out in sire lines, resulting in -/0 in Table 1. The costs for growers and finishers will exist of lower production results compared to the situation that meat quality is not included in the breeding goal, as can be derived from the Tables 4, 5 and 6. In Table 1, two minus signs are given for the growers and finishers. The costs for this tier will be lower compared to the costs of the breeders and multipliers. On the other hand, the costs will be higher than those made by the weaner producers because production traits are correlated with the meat quality traits which results in a lowered improvement of the production traits, as can be concluded from Tables 4 and 5.

For the slaughter-houses and boning plants, profits of including improvement of meat quality in the breeding goal may be expected because of an improved water-holding capacity (Tables 5 and 6). Also, the levels of production traits will influence the results of the slaughter-houses and boning plants (e.g. lean meat content), but profits or costs because of changed levels of those traits are assumed to be settled by the payment to the farmers. Processing and retail trade will have profits because of improved technological quality and keeping ability (PH, DRIP, COLOR; Tables 5 and 6). Finally, the consumers will profit from the inclusion of meat quality in the breeding goal because of an overall improved pig meat quality. The reason why more plus signs have been given for the lower levels of the production chain is the fact that, coming lower in the production chain, the total profits become relatively less dependent on production traits (such as lean meat content) and more on quality traits. Furthermore, it must be stated that the profits depend on the market produced for. For example, improvement of meat quality will be of much more importance for enterprises producing fresh meat than for enterprises producing for the processing industry.

When the current breeding goal is maintained (option 1), results given in Table 4 are expected. This means that production is improved and that meat quality will change only due to the current correlations. When those changes are unfavourable, they are in fact costs for the lower tiers (Cases 1, 2 and 5). The maximum allowable costs for all tiers of including meat quality in the breeding goal (option 2) can be derived from the total financial superiorities (ΔG_{tot}) given in

Table 5. The ΔG_{tot} values given in Table 6 ($\Delta G_{tot,3}$ - $\Delta G_{tot,1}$) give an indication of the total costs that can be justified to include meat quality in both the index and the breeding goal.

As long as there are no methods available to measure the quality of the products that are marketed between the different tiers, it will not be possible to partly base the prices of the products on their individual quality. In that situation, it may not be expected that the first three tiers of the production chain will be prepared to make costs to improve meat quality because it will not be clear to what extent their costs will be refunded by the lower tiers. However, a possible way to improve meat quality by breeding after all is that companies from the different tiers make agreements about sharing and dividing costs and profits. In that case, the profits of the improved meat quality have to be realized by one of the lower tiers in this chain (slaughter-houses and boning plants or processing industry and retail trade), which tiers at least will have to refund the costs of all higher tiers. Again, the distribution of the profits over the various tiers will create problems; these might be solved at least partly by making good agreements a priori. However, it is clear that research on the effects of improving meat quality has to be done for all tiers.

DISCUSSION

In the example, three options have been given to consider the influence of including meat quality in a pig breeding program. In the selection criteria considered in these options, information of most purebred relatives was included. From further calculations, it was concluded that including information of crossbred relatives of the breeding animals (F_1's and slaughter pigs) in the selection index did not influence the results for current pig breeding schemes. However, the use of data of crossbred relatives of nucleus animals may improve results when the information infrastructure of breeding schemes is changed to make optimum use of this information. Again, economic evaluations will have to be made to optimize the costs of using these data and the profits that may be expected.

As is shown by the results of the five cases, the economic values of the traits in the breeding goal have a large influence on the results. In all cases, economic values are dependent on the mean levels of the breeding goal traits in the relevant tiers. However, this point needs extra attention for traits with an economically optimum level. Not only the level of the economic weight changes when the current population mean is changed, but even the sign of the economic value may change when the population mean passes the optimum value of the trait considered.

This means that a regular determination of the levels and standard deviations of the breeding goal traits will be necessary.

The economic values used in the examples are based on a price difference of Dfl 0.50 kg^{-1} between meat within and outside the optimum range. However, the validity of this value is questionable. From a study among Dutch consumers (Steenkamp and Van Trijp, 1988), it was concluded that consumers are not willing to pay more for a better quality of pork-steak, but that consumers are willing to pay about Dfl 0.46 kg^{-1} extra for a better quality chops. Furthermore, it was stressed that the willingness to pay for a better quality of the product depends on the age of the consumer and the attitude of the consumer towards quality. From meat industry, no information is known about price differences between meat of different qualities. When we assume that the Dfl 0.50 kg^{-1} at least for the time being will be a maximum value, this means that the results given in the examples will be the extremes to be expected. Using lower price differences will reduce ΔG_{prod} and ΔG_{qual} to values between those given in Tables 5 and 6 and zero. This also holds for the ΔG_{qual} values given in Table 4.

In Tables 4, 5 and 6, results are given for one round of selection. It must be noted that, when products from two breeding programs are compared (one with and the other without meat quality in the breeding goal), differences between the levels of production and meat quality traits will increase each generation. When meat quality is included in the breeding goal, this difference will be disadvantageous for the production traits; for the meat quality traits, however, the differences will be positive. The ultimate difference will depend on the change of the levels of the meat quality traits and the resulting change of the index used.

The Dutch Commodity Board for Livestock and Meat stated that problems to increase pig meat consumption are satiation of the market, the image of pork to be unhealthy and fat and the low sensoric properties of pork (P.V.V., 1989). Because of the considerable influences of including meat quality in a breeding program, as shown by the results given, it is important to know to what extent the sensory meat quality (and thus physical parameters of the meat) influences the purchase decisions of consumers. Therefore, first research priority must be to study the relative importance of intrinsic quality of pig meat as a raw material compared to the image of pork, packaging methods, etc. and second to obtain information about the optimum levels of the meat quality traits that correspond to a good sensory quality.

Selection is only one of many ways to improve pig meat quality. There are many more factors influencing ultimate meat quality of the animals, which among others is indicated by the large uncontrolled batch effects ("day of slaughter") in all studies concerning meat quality. For the data described by Hovenier et al. (1992), the fraction of variance explained by day of slaughter (s^2) was equal to or larger than the heritability for all meat quality traits except INTMF. The s^2 varied from 0.30 for DRIP to 0.56 for PH. For INTMF, the s^2 was 0.29 (Hovenier, unpublished results). Also De Vries et al. (1992) found for all meat quality traits (except INTMF) s^2 values about equal to the heritabilities.

Effects influencing ultimate meat quality may be for example the treatment of the animals before slaughter (Warriss et al., 1990; Eikelenboom et al., 1991) or treatment of the carcasses after slaughtering (Eikelenboom and Smulders, 1987; Dransfield et al., 1991). As genetically improved animals can be utilized optimally only when environmental circumstances are optimized, investments to improve and maintain these will be necessary.

CONCLUSIONS

Depending on the means of the meat quality traits of the end products, three strategies can be applied to improve meat quality: no change of the currently breeding goal and selection index and make use of correlated responses of the meat quality traits, inclusion of meat quality traits only in the breeding goal or inclusion of meat quality traits in both breeding goal and selection index. Inclusion of meat quality traits only in the breeding goal or in both breeding goal and selection index results in lower improvement of the production traits, improvement of the meat quality traits and an increase of the total financial gain. Furthermore, it is concluded that inclusion of meat quality in the breeding goal will only be achieved when, a priori, appointments are made between parties of the various tiers of the pig meat production chain about a distribution of the profit from improved meat quality among the different tiers.

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SUMMARY

SUMMARY

Introduction

After a continuous increase of pig meat consumption in the E.E.C. for about 15 years, the increase of pork consumption has tended to stagnate. Main reason for this stagnation is the attitude of the consumer towards pork. Consumers judge pig meat to be easy to prepare and cheap, but also to be unhealthy and of low sensoric quality. Besides consumers, also meat industry comments frequently about increasing incidence of meat quality problems.

One of the possibilities to improve meat quality is by selection. To indicate the potential of breeding, certain information is necessary like which meat quality traits to use, repeatabilities, heritabilities, phenotypic and genetic correlations and economic values of both production and meat quality traits and possible consequences for the several tiers of the pig production chain. This thesis describes a study of these topics.

Literature

Meat quality can be divided in four factors: organoleptic, technological, nutritional and hygienic quality (Chapter 1). In this thesis, only organoleptic and technological meat quality are considered.

Important traits to determine organoleptic and technological meat quality are ultimate pH, meat colour, amount of intramuscular fat, water-holding capacity and meat tenderness. Different methods used to measure each of those traits are reviewed.

Mean heritabilities of the meat quality traits range from 0.20 for water-holding capacity and ultimate pH to 0.50 for amount of intramuscular fat. A review of the genetic correlations between production traits and meat quality traits shows large ranges, especially for correlations with water-holding capacity. Mean genetic correlations between daily gain and meat quality traits were zero or slightly negative except for the genetic correlation with amount of intramuscular fat, which was found to be about 0.35. Mean genetic correlations between backfat thickness and meat quality were found to be positive, mean genetic correlations between lean meat content and meat quality were found to be negative. It was concluded that meat quality will become worse if no attention is paid to meat quality in future breeding programs.

Repeatabilities

In Chapter 2, a study is described in which repeatabilities of meat quality traits and their mutual correlations are estimated. Because of the importance of meat tenderness and the preference for the use of objective measurements over the use of subjective measurements in a breeding program, special attention was paid to meat tenderness measurements.

The experiment was carried out using 64 Duroc and Dutch-Yorkshire boars and gilts slaughtered during eight weeks. Twenty-four hours after slaughter, in total 14 slices of about 2 cm thickness were taken from the *M. longissimus* from both carcass halves. Five slices were used to measure meat tenderness by a taste panel consisting of 20 persons, four slices to measure meat tenderness by the Warner-Bratzler shearforce and two slices to measure meat tenderness by determining the total amount of collagen. Furthermore, measurements were carried out for meat colour, ultimate pH, water-holding capacity and amount of intramuscular fat.

The repeatabilities between carcass halves within animals were 0.53 for taste panel tenderness scores based on 12.4 observations of different panelists per mean, 0.08 for two tenderness scores of different panelists within one animal, 0.50 for two tenderness scores of one panelist within one animal and 0.41 for measurements of maximum shearforce. Repeatabilities of the other meat quality traits ranged from 0.29 for cooking loss to 0.76 for the Minolta L^* colour co-ordinate.

The phenotypic correlation between tenderness assessed by a panel and maximum shearforce was -.50. The phenotypic correlation between those traits corrected for measurement errors was -.74. A correlation of zero was found between the total amount of collagen and meat tenderness, between amount of intramuscular fat and tenderness and between ultimate pH and tenderness. The other correlations with meat tenderness ranged from -.00 for Minolta b^* colour coordinate to -.44 for drip loss.

Considering the correlations between tenderness assessed by a panel and maximum shearforce, it was concluded that the measurement of maximum shearforce can be used to improve pig meat tenderness.

Genetic Parameters

Knowledge of heritabilities and correlations for both meat quality and production traits is necessary to investigate possibilities for improving meat quality by selection and to investigate correlated responses of meat quality traits by selection for production traits. Therefore, genetic and phenotypic parameters were estimated for halothane-negative Duroc and Dutch-Yorkshire pigs (Chapter 3).

The data-set consisted of in all 1,113 Dutch-Yorkshire and Duroc boars and gilts, slaughtered between January 1988 and June 1990. Four production traits: daily live weight gain, backfat thickness, lean meat content and type score and five meat quality traits: ultimate pH in *M. longissimus* and *M. semimembranosus*, meat colour, water-holding capacity and amount of intramuscular fat in *M. longissimus* were considered. Parameters were estimated using an animal model, bivariate unequal design REML algorithm.

Heritabilities for production traits ranged from 0.27 for type score to 0.63 for lean meat content. Heritabilities for meat quality traits ranged from 0.20 for ultimate pH in the *M. semimembranosus* to 0.61 for amount of intramuscular fat. Phenotypic correlations between production traits and meat quality traits hardly differed from zero, except for amount of intramuscular fat. Genetic correlations between liveweight gain and meat quality traits were favourable, genetic correlations of backfat thickness and lean meat content with meat quality traits were unfavourable.

Considering the heritabilities, genetic correlations of both production and meat quality traits and economic weights of production traits currently used in The Netherlands, it was concluded that meat quality is expected to decrease as a correlated response. However, meat quality might be improved if less emphasis is put on lowering backfat thickness or increasing lean meat content.

Economic Values

In most present applications, economic values used to weigh the traits in a breeding goal are assumed to be independent of the population mean. However, various traits economically show an optimum range resulting in a dependency of the economic value for a particular trait on the mean of the commercial population for that trait. Approaches that can be followed in those cases are the use of a restricted selection index or a quadratic aggregate genotype. Whichever method is used, it is always necessary to calculate an accurate profit or marginal-income function. However, for quality traits such a function is in most cases only approximately known in terms of thresholds below or above which the product is not acceptable or only acceptable for lower prices.

In Chapter 4, a method is outlined to derive a marginal-income function and to calculate economic values for traits with an optimum range such as meat quality traits. Parameters necessary to use this method are the distribution of the quality trait, the population mean and the standard deviation of the quality trait, the optimum range and the price differences between products within and outside the optimum range. Especially the optimum range for the quality trait and the price differences to be used have to be derived from consumer research and from research of the processing industry.

Other methods that possibly could be used for selection on quality traits, like restricted selection index, desired gains index and indices based on a quadratic aggregate genotype, are discussed. The method given here is based on a non-linear marginal-income function and therefore valid for small changes only. Consequently, in theory it is necessary to calculate new economic values each generation. However, in the case of desired gains and restricted selection indices, traits in the aggregate genotype are not weighed according to their economic values but according to weights that implicitly are based on the breeder's assumption about the economic importance of the traits. Incorporation of the optimum trait quadratically in the aggregate genotype is another approach given in literature. However, in this case the profit or marginal income of the parents is maximized although maximization of the profit of the offspring is the goal of a breeding program.

Prospects

In Chapter 5, the consequences of selection for meat quality for the various tiers of the pig meat production chain are analyzed. The first three levels, breeding organisations, weaner producers and growers are the levels that will make costs when meat quality is included in the breeding goal. Those costs will consist of direct costs like costs for measuring meat quality traits in pure-line animals and in slaughter pigs or indirect costs like decreased genetic improvement for the production traits.

Slaughterhouses and boning plants, processing industry and retail trade and consumers will profit from the inclusion of meat quality in the breeding goal because of improved technological and sensory quality of the pig meat. On the other hand, lower improvement of lean meat content of the carcasses may lower the profits of especially the slaughterhouses and boning plants. However, no economic evaluations about the effects of changed lean meat content or changed meat quality for these layers are known.

Five case studies were carried out to browse the effect of inclusion of pig meat quality in the breeding goal on the expected genetic change. Each case study was different for the mean value of one of the meat quality traits and therefore different for its corresponding economic value. When no attention is paid to meat quality (like in the currently used breeding goals and selection indices), financial superiority for production traits of the selected animals after one round of selection ($\Delta G_{prod,1}$; i = 1) was equal to Dfl 5.21. However, when the economic values of the five case studies were used, correlated financial superiorities for meat quality ($\Delta G_{qual,1}$) was calculated to range from -3.5 to 21.9% of $\Delta G_{prod,1}$, depending on the population mean. This resulted in total financial superiorities of the selected animals ($\Delta G_{tot,1}$) ranging from Dfl 5.03 to Dfl 6.35.

When meat quality was included only in the breeding goal, ΔG_{qual} improved with zero to 12.5% of $\Delta G_{prod,1}$ for the various cases, ΔG_{prod} decreased with zero to 6% of $\Delta G_{prod,1}$, both changes resulting in an improvement of ΔG_{tot} of zero to 6.6% of $\Delta G_{tot,1}$. When meat quality traits were included in both index and breeding goal,

ΔG_{qual} improved with 22.3 to 40.7%, ΔG_{prod} decreased with 12.1 to 19.6% and ΔG_{tot} improved with 10.3 to 22.7% for the various cases.

It is not likely that meat quality will be included in the breeding program when costs of the first three tiers are not refunded by the other tiers. In the near future, no on-line measurements of ultimate meat quality may be expected on which payment of the individual animals can be based. Therefore, inclusion of meat quality in the breeding program is only to be expected if agreements are made between parties in the different tiers about a distribution of the profit of improved meat quality among the different tiers.

Main Conclusions

- with respect to sensoric and technological meat quality, three groups of meat quality traits can be distinguished: 1. ultimate pH, water-holding capacity and meat colour; 2. meat tenderness; and 3. amount of intramuscular fat.
- repeatabilities between carcass halves of the first group of meat quality parameters ranged from 0.29 for cooking loss to 0.76 for Minolta L^* colour measurement; repeatability of amount of intramuscular fat was 0.44, repeatability of meat tenderness measurements ranged from 0.08 to 0.50.
- maximum shearforce can be used to improve pig meat tenderness.
- heritabilities of the first group of meat quality traits ranged from 0.20 to 0.40, heritability of amount of intramuscular fat was 0.61.
- genetic correlations between meat quality traits and daily gain are favourable and range up to 0.46, genetic correlations between meat quality traits and backfat thickness and lean meat content are unfavourable and range up to -.25, except for amount of intramuscular fat. Phenotypic correlations between meat quality traits and production traits are about zero. Absolute genetic correlations of amount of intramuscular fat with backfat thickness and lean meat content are around 0.40, absolute phenotypic correlations are about 0.30.
- marginal-income functions and economic values of meat quality traits can be derived from the means and standard deviations of the quality traits in the commercial population, the optimum range and the price differences between products within and outside the optimum range of the meat quality trait.
- the correlated responses of meat quality traits resulting from currently used breeding goals and selection indices can be both favourable or unfavourable, depending on the actual population mean of the meat quality traits of the end products.
- three strategies can be applied to improve meat quality: no change of the currently breeding goal and selection index and make use of correlated responses of the meat quality traits, inclusion of meat quality traits only in the aggregate

genotype, or inclusion of meat quality traits in both aggregate genotype and selection index. Compared to the first strategy, the second strategy influences the genetic changes only slightly, forcing meat quality traits in the desired direction but lowering the genetic improvement of the production traits slightly. The third strategy strongly influences genetic changes, improving meat quality traits and reducing the genetic improvement of production traits considerably.

- at short notice, inclusion of meat quality in the breeding goal will only be achieved when appointments are made between parties of the various tiers of the pig meat production chain about a distribution among the different tiers of the profit from improved meat quality.

SAMENVATTING

SAMENVATTING

Introductie

Na een continue stijging van de varkensvleesconsumptie in de E.E.G. gedurende de laatste 15 jaren, lijkt deze stijging momenteel te stagneren. De belangrijkste reden hiervoor lijkt het imago van varkensvlees bij de consumenten. Consumenten vinden varkensvlees weliswaar gemakkelijk te bereiden en goedkoop, maar ook ongezond en van een lage sensorische kwaliteit (smaak, geur, uiterlijk). Daarnaast komen er vanuit de industrie regelmatig geluiden over het frequenter vóórkomen van problemen op het gebied van de vleeskwaliteit.

Een van de mogelijkheden om vleeskwaliteit te verbeteren is middels fokkerij. Om de mogelijkheden daarvan te kunnen beoordelen is extra informatie nodig zoals welke vleeskwaliteitskenmerken gebruikt moeten worden, herhaalbaarheden, erfelijkheidsgraden, fenotypische en genetische correlaties en economische waarden van zowel de produktie- als de vleeskwaliteitskenmerken en mogelijke gevolgen van selectie op vleeskwaliteit voor de verschillende lagen van de varkensvleesproduktiekolom. In dit proefschrift is het onderzoek naar bovenstaande punten beschreven.

Literatuur

Met betrekking tot vleeskwaliteit kunnen vier aspecten onderscheiden worden, te weten de sensorische kwaliteit, de technologische kwaliteit (o.a. verwerkingseigenschappen), voedingsaspecten (o.a. samenstelling van het vlees, voedingswaarde) en de hygiënische kwaliteit (o.a. afwezigheid van residuen, bacteriën). In dit proefschrift is slechts aandacht geschonken aan de sensorische en technologische vleeskwaliteit.

Belangrijke kenmerken die een indruk geven van sensorische en technologische vleeskwaliteit zijn pH na 24 uur (pH_{24}), de vleeskleur, de hoeveelheid intramusculair vet, het waterbindend vermogen en de malsheid van het vlees (Hoofdstuk 1). De verschillende methoden om deze kenmerken te meten worden besproken.

De gemiddelde erfelijkheidsgraden van de vleeskwaliteitskenmerken variëren van 0.20 voor het waterbindend vermogen en pH_{24} tot 0.50 voor de hoeveelheid intramusculair vet. Een overzicht van de genetische correlaties tussen produktie- en vleeskwaliteitskenmerken laat een grote range zien, vooral voor de correlaties met het waterbindend vermogen. Gemiddelde genetische correlaties tussen groeisnelheid en vleeskwaliteit zijn nul of licht negatief, behalve voor de correlatie met de hoeveelheid intramusculair vet, welke ongeveer 0.35 is. De gevonden gemiddelde genetische correlaties tussen rugspekdikte en vleeskwaliteit zijn positief, die tussen mager vleespercentage en vleeskwaliteit zijn negatief. Er is geconcludeerd dat de vleeskwaliteit zal afnemen indien er in toekomstige fokkerij programma's geen aandacht geschonken wordt aan vleeskwaliteit.

Herhaalbaarheden

In Hoofdstuk 2 is het onderzoek beschreven waarin de herhaalbaarheden van vleeskwaliteitskenmerken en hun onderlinge correlaties zijn geschat. Vanwege het belang van de malsheid van het vlees en de voorkeur voor het gebruik van objectieve metingen in een fokkerij programma boven het gebruik van subjectieve metingen, is er extra aandacht geschonken aan malsheidsmetingen.

Voor het experiment zijn 64 Duroc en Groot-Yorkshire beren en zeugen geslacht in een periode van acht weken. Vierentwintig uren na het slachten zijn er uit iedere karkashelft uit de *M. Longissimus* 14 plakken van ongeveer 2 cm dikte genomen. Hiervan werden vijf plakken gebruikt om door een uit 20 personen bestaand smaakpanel de malsheid te laten beoordelen, vier plakken werden gebruikt om de malsheid te meten door het bepalen van de Warner-Bratzler snijweerstand en twee plakken voor het bepalen van de totale hoeveelheid collageen. Verder zijn de vleeskleur, de pH_{24}, het waterbindend vermogen en de hoeveelheid intramusculair vet bepaald.

De herhaalbaarheid tussen karkashelften binnen dieren voor smaakpanel scores, gebaseerd op 12.4 waarnemingen van verschillende panelleden per gemiddelde score, was 0.53, voor twee scores voor malsheid door verschillende panelleden binnen één dier 0.08, voor twee scores voor malsheid door één panellid binnen één dier 0.50 en voor metingen van de Warner-Bratzler snijweerstand 0.41. Herhaalbaarheden van de andere vleeskwaliteitsmetingen varieerden van 0.29 voor het kookverlies tot 0.76 voor de Minolta L^* kleur coördinaat.

De fenotypische correlatie tussen malsheid beoordeeld door het smaakpanel en de maximale snijweerstand was -.50. De fenotypische correlatie tussen deze kenmerken gecorrigeerd voor meetfouten was -.74. Een correlatie van nul werd gevonden tussen de totale hoeveelheid collageen en malsheid, tussen de hoeveelheid intramusculair vet en malsheid en tussen pH_{24} en malsheid. De overige correlaties met malsheid varieerden van -.00 voor de Minolta b^* kleur coördinaat tot -.44 voor het vochtverlies.

Gezien de gevonden correlaties is geconcludeerd dat de meting van de maximale snijweerstand kan worden gebruikt om de malsheid van varkensvlees te verbeteren.

Genetische Parameters

Kennis van de erfelijkheidsgraden en correlaties voor zowel de vleeskwaliteits- als de produktiekenmerken is nodig om de mogelijkheden te kunnen onderzoeken van het verbeteren van de vleeskwaliteit middels fokkerij en voor het kunnen onderzoeken van de gecorreleerde respons van vleeskwaliteitskenmerken als gevolg van de selectie op produktiekenmerken. Daarom zijn de genetische en fenotypische parameters geschat voor halothaan-negatieve Duroc en Groot-Yorkshire varkens (Hoofdstuk 3).

De dataset bestond uit in totaal 1113 Groot-Yorkshire en Duroc beren en gelten, welke zijn geslacht tussen januari 1988 en juni 1990. Vier produktiekenmerken zijn gemeten, te weten groeisnelheid, rugspekdikte, mager vleespercentage en type score voor het karkas en vijf vleeskwaliteitskenmerken, te weten pH_{24} in *M. longissimus* en *M. semimembranosus* en verder vleeskleur, waterbindend vermogen en hoeveelheid intramusculair vet in *M. longissimus*. Voor het schatten van de parameters is gebruik gemaakt van een dier model DFREML algoritme, waarbij de kenmerken twee aan twee zijn geanalyseerd.

De schattingen voor de erfelijkheidsgraden van de produktiekenmerken varieerden van 0.27 voor de type score tot 0.63 voor het mager vleespercentage. Schattingen voor de erfelijkheidsgraden voor de vleeskwaliteitskenmerken varieerden van 0.20 voor pH_{24} in de *M. semimembranosus* tot 0.61 voor de hoeveelheid intramusculair vet. De fenotypische correlaties tussen produktie- en vleeskwaliteitskenmerken verschilden nauwelijks van nul, behalve voor hoeveelheid intramusculair vet. De genetische correlaties tussen groeisnelheid en vleeskwaliteitskenmerken waren gunstig, genetische correlaties van rugspekdikte en mager vleespercentage met vleeskwaliteit waren ongunstig.

Op grond van de gevonden erfelijkheidsgraden, genetische correlaties tussen produktie- en vleeskwaliteitskenmerken en de economische waarden van de produktiekenmerken, zoals die momenteel in Nederland worden gebruikt, is geconcludeerd dat de vleeskwaliteit naar verwachting geleidelijk zal afnemen als gevolg van selectie op produktiekenmerken. Daarentegen kan de vleeskwaliteit verbeterd worden indien minder nadruk wordt gelegd op het laten afnemen van de rugspekdikte of het laten toenemen van het mager vleespercentage.

Economische Waarden

Bij het gebruik van economische waarden als wegingsfactoren van fokdoelkenmerken in een fokkerij programma wordt over het algemeen aangenomen dat deze onafhankelijk zijn van het populatiegemiddelde. Verschillende kenmerken hebben echter economisch gezien een optimaal gebied, waardoor de economische waarden sterk afhankelijk worden van het populatieniveau. Een aanpak die in dergelijke gevallen gevolgd kan worden, is het gebruik maken van selectie-indices met restricties ("restricted selection index") of van fokdoelen waarin kenmerken kwadratisch zijn opgenomen. Ongeacht welke methode gebruikt wordt, is het altijd noodzakelijk een nauwkeurige opbrengstfunctie te berekenen. Voor kwaliteitskenmerken is een dergelijke opbrengstfunctie echter in de meeste gevallen slechts bij benadering bekend in termen van drempelniveau's waaronder of waarboven het produkt niet acceptabel is of slechts acceptabel is tegen lagere prijzen.

In Hoofdstuk 4 is een methode uitgewerkt om een marginale opbrengstfunctie af te leiden en economische waarden te berekenen voor optimumkenmerken zoals bijvoorbeeld vleeskwaliteitskenmerken. De informatie, die nodig is voor het gebruik van deze methode, omvat de functie volgens welke het kwaliteitskenmerk verdeeld is, het populatiegemiddelde en de spreiding, de grenzen waarbinnen het optimale gebied zich bevindt en de prijsverschillen tussen produkten binnen en buiten het optimale gebied. De grenzen van het optimale gebied en de prijsverschillen zullen moeten worden afgeleid uit consumentenonderzoek en uit onderzoek uit de verwerkende industrie.

Andere methoden, die gebruikt kunnen worden voor de selectie op kwaliteitskenmerken, zoals "restricted selection indices", indices met vooraf gedefinieerde genetische vooruitgang ("desired gains indices") of indices gebaseerd op fokdoelen met kwadratisch opgenomen kenmerken, worden bediscussieerd. De hier gepresenteerde methode is gebaseerd op een niet-lineaire opbrengstfunctie en is daarom slechts geldig voor kleine genetische veranderingen. Als gevolg daarvan is het in theorie noodzakelijk om iedere generatie nieuwe economische waarden te berekenen. Het gebruik van "restricted selection indices" of "desired gains indices" zijn andere mogelijkheden. In deze gevallen worden de kenmerken in het fokdoel echter niet ingewogen naar hun economische waarden, maar naar min of meer subjectief vastgestelde wegingsfactoren. Het kwadratisch opnemen in het fokdoel van een kwaliteitskenmerk is een andere, in de literatuur gegeven, mogelijkheid. In dit geval worden echter de genetische waarden van de ouders gemaximaliseerd terwijl maximalisatie van de opbrengst van de nakomelingen het doel is van een fokkerij programma.

Perspectieven

In Hoofdstuk 5 zijn de gevolgen bekeken van selectie op vleeskwaliteit voor de verschillende lagen van de produktiekolom van varkensvlees. De eerste drie lagen, fokkerij organisaties, vermeerderaars en de vleesvarkenshouders zullen te maken krijgen met extra kosten wanneer vleeskwaliteit in het fokdoel wordt opgenomen. Deze kosten zullen bestaan uit directe kosten, zoals kosten voor het meten van vleeskwaliteit van dieren uit de zuivere lijnen en van vleesvarkens, en uit indirecte kosten, zoals een verminderde genetische vooruitgang voor de produktiekenmerken.

De slachthuizen en uitbeenderijen, verwerkende industrie, groothandel en consumenten zullen baat hebben van het inbrengen van vleeskwaliteit in het fokdoel door de verbeterde technologische en sensorische kwaliteit van het varkensvlees. Daarentegen kan de verminderde verbetering van het mager vleespercentage de opbrengsten van met name de slachterijen en uitbeenderijen nadelig beïnvloeden. Er zijn echter geen onderzoeken bekend naar de economische consequenties van veranderende mager vleespercentages of veranderende vleeskwaliteit voor deze lagen van de produktiekolom.

Vijf voorbeelden zijn uitgewerkt om het effect van het opnemen van vleeskwaliteit in het fokdoel op de te verwachten genetische veranderingen in kaart te brengen. De voorbeelden verschilden voor wat betreft het gemiddelde van één van de vleeskwaliteitskenmerken en daarmee voor de economische waarde voor het betreffende kenmerk. Het bleek dat, wanneer geen aandacht wordt besteed aan vleeskwaliteit in een fokkerijprogramma (wat vergelijkbaar is met de huidige situatie), de financiële superioriteit van de geselecteerde dieren na één ronde van selectie gelijk is aan fl 5,21 ($\Delta G_{prod,1}$; i = 1). Wanneer echter de economische waarden voor de vijf verschillende

voorbeelden werden gebruikt, resulteerde de gecorreleerde respons van de vleeskwaliteitskenmerken in een financiële superioriteit voor vleeskwaliteit ($\Delta G_{qual,1}$) van -3.5% tot 21.9% van $\Delta G_{prod,1}$, afhankelijk van het populatieniveau. Dit alles resulteerde in een totale financiële superioriteit ($\Delta G_{tot,1}$) van de geselecteerde dieren variërend van fl 5,03 tot fl 6,35.

Indien vleeskwaliteit alleen in het fokdoel werd opgenomen, verbeterde ΔG_{qual} tot maximaal 12.5% van $\Delta G_{prod,1}$, ΔG_{prod} daalde met maximaal 6% van $\Delta G_{prod,1}$, welke veranderingen resulteerden in een toename van ΔG_{tot} met maximaal 6.6% van $\Delta G_{tot,1}$. Indien vleeskwaliteitskenmerken zowel in het fokdoel als in de index werden opgenomen, varieerde de verbetering van ΔG_{qual} van 22.3% tot 40.7%, nam ΔG_{prod} af met minimaal 12.1% tot maximaal 19.6% en verbeterde ΔG_{tot} met minimaal 10.3% tot maximaal 22.7% voor de verschillende voorbeelden.

Het is niet waarschijnlijk dat vleeskwaliteit in een fokkerij programma zal worden opgenomen indien de kosten van de bovenste drie lagen van de produktiekolom niet worden vergoed door de onderliggende lagen. In de nabije toekomst zijn metingen van uiteindelijke vleeskwaliteit in de slachtlijn, op basis waarvan de betaling van vleesvarkens kan worden gebaseerd, niet te verwachten. Daarom mag het opnemen van vleeskwaliteit in een fokkerij programma alleen dan worden verwacht indien afspraken gemaakt worden tussen alle partijen uit de verschillende lagen van de produktiekolom over de onderlinge verdeling van de opbrengsten van een verbeterde varkensvleeskwaliteit.

Conclusies

- met betrekking tot de sensorische en technologische vleeskwaliteit kunnen drie groepen vleeskwaliteitskenmerken worden onderscheiden: 1. pH 24 uren na slachten, waterbindend vermogen en vleeskleur; 2. malsheid van het vlees; 3. hoeveelheid intramusculair vet.

- de herhaalbaarheden tussen karkashelften voor de eerste groep kenmerken varieerden van 0.29 voor kookverlies tot 0.76 voor de Minolta L^* kleurmeting; de herhaalbaarheid voor de hoeveelheid intramusculair vet was 0.44, de herhaalbaarheden voor metingen met betrekking tot de malsheid van het vlees varieerden van 0.08 tot 0.50.
- de meting van de maximale snijweerstand kan worden gebruikt om de malsheid van het vlees te verbeteren.
- de erfelijkheidsgraden van de eerste groep kenmerken varieerden van 0.20 tot 0.40, de erfelijkheidsgraad van de hoeveelheid intramusculair vet was 0.61.
- de vleeskwaliteitskenmerken zijn genetisch gunstig gecorreleerd met groeisnelheid, met correlaties varierend tot maximaal 0.46; de vleeskwaliteitskenmerken, met uitzondering van hoeveelheid intramusculair vet, zijn genetisch ongunstig gecorreleerd met rugspekdikte en mager vleespercentage, welke correlaties varieerden tot maximaal -.25. De fenotypische correlaties van de vleeskwaliteitskenmerken met de produktiekenmerken zijn ongeveer nul. De absolute genetische correlaties van de hoeveelheid intramusculair vet met rugspekdikte en mager vleespercentage waren ongeveer 0.40, de absolute fenotypische correlaties waren ongeveer 0.30.
- marginale inkomstenfuncties en economische waarden van vleeskwaliteitskenmerken kunnen worden afgeleid op basis van het niveau en de spreiding van het betreffende kenmerk bij vleesvarkens, het optimale gebied voor het niveau van het kwaliteitskenmerk en het prijsverschil tussen vlees binnen en buiten dit optimale gebied.
- de veranderingen van de niveaus van de vleeskwaliteitskenmerken als gevolg van het gebruik van de huidige fokdoelen en indices kunnen zowel gunstig als ongunstig zijn, afhankelijk van het huidige niveau van de kwaliteitskenmerken.
- er zijn drie alternatieven voorhanden om vleeskwaliteit middels selectie te verbeteren: de huidige fokdoelen en indices handhaven en derhalve gebruik maken van de gecorreleerde respons van de vleeskwaliteitskenmerken, het opnemen van vleeskwaliteitskenmerken alleen in het fokdoel en het opnemen van vleeskwaliteitskenmerken zowel in het fokdoel als in de index. In vergelijking met het eerste alternatief laat het tweede alternatief slechts weinig veranderingen zien, waarbij echter de niveaus van de vleeskwaliteitskenmerken in de gewenste richting veranderen en genetische vooruitgang van de produktiekenmerken licht afneemt. Het derde alternatief beïnvloedt de genetische veranderingen sterk, waarbij de vleeskwaliteitskenmerken verbeterd worden en de genetische vooruitgang van de produktiekenmerken sterk gereduceerd wordt.

- op korte termijn zal de opname van vleeskwaliteit in het fokdoel alleen dan geschieden, indien tussen de partijen van de verschillende lagen van de produktiekolom afspraken gemaakt worden over een onderlinge verdeling van de opbrengsten van de verbeterde vleeskwaliteit.

SOMMARIO

SOMMARIO

Introduzione

Dopo 15 anni di costante crescita, il consumo di carne suina nella CEE evidenzia sintomi di rallentamento le cui cause vanno individuate nei rapporti tra esigenze della domanda e caratteristiche del prodotto. Se da un lato il consumatore apprezza alcune caratteristiche della carne suina quali la semplicità di preparazione e il prezzo contenuto, dall'altro ritiene insoddisfacenti soprattutto gli aspetti organolettici e le proprietà nutrizionali del prodotto.

La selezione rappresenta uno dei possibili strumenti per il miglioramento qualitativo della carne ma la sua utilizzazione è condizionata all'individuazione dei caratteri da migliorare, alla conoscenza di parametri quali la ripetibilità, ereditabilità, correlazioni genetiche e fenotipiche, importanza economica dei caratteri sia qualitativi sia produttivi nonché alla valutazione delle conseguenze, derivanti dalla selezione, per i diversi soggetti che partecipano al processo produttivo. Obiettivo di questa tesi è lo studio di tali aspetti.

Letteratura

Le caratteristiche qualitative della carne possono essere suddivise in 4 categorie: tecnologiche, organolettiche, nutrizionali e igienico-sanitarie. Questa tesi è limitata all'analisi degli aspetti tecnologico-organolettici della carne suina.

Tra gli elementi in grado di condizionare le proprietà tecnologiche e organolettiche della carne i più importanti sono il pH finale, il colore, il tenore di grasso intramuscolare, la capacità di ritenzione idrica e la tenerezza (Capitolo 1). Alcune delle metodologie utilizzate per la determinazione di tali caratteristiche sono state prese in esame e discusse in quasta tesi.

I valori medi di ereditabilità dei principali caratteri qualitativi della carne suina riportati dalla letteratura scientifica, risultano compresi tra 0.20 per la capacità di ritenzione idrica e il pH finale e 0.50 per il tenore di grasso intramuscolare. Molto variabili risultano le correlazioni genetiche esistenti tra caratteri produttivi e carateristiche qualitative della carne suina e in modo particolare quello tra la capacità di ritenzione idrica e caratteri produttivi. Mediamente le correlazioni genetiche tra l'accrescimento giornaliero e gli aspetti qualitativi della carne risultano nulle o leggermente negative ad eccezione di quella tra accrescimento e tasso di grasso intramuscolare che è pari a 0.35. Lo spessore del grasso dorsale e la qualità della carne evidenziano correlazioni positive mentre negative risultano le correlazioni esistenti tra caratteristiche qualitative e il contenuto di carne magra. Considerando gli orientamenti e gli obiettivi dei piani di selezione utilizzati attualmente è da attendersi un futuro peggioramento della qualità della carne.

Ripetibilità

Il Capitolo 2 è dedicato all'esame della ripetibilità e dei valori di correlazione dei principali caratteri relativi alla qualità della carne ottenuti in uno studio specifico. Particolare attenzione è stata posta ai metodi di determinazione della tenerezza vista l'importanza di questo carattere e la preferenza accordata nei piani di miglioramento genetico a metodi di determinazione di tipo oggettivo rispetto a valutazioni di tipo soggettivo.

Lo studio è stato condotto utilizzando 64 verri e scrofette di razza Duroc e Yorkshire olandese macellati nel corso di otto settimane. Ventiquattro ore dopo la macellazione, 14 fette di circa 2 cm di spessore sono state prelevate dal *M.longissimus* di entrambe le mezzene. Cinque fette sono state utilizzate per la determinazione della tenerezza della carne mediante taste panel condotto con 20 assaggiatori, quattro fette sono state destinate alla determinazione della forza di taglio mediante Warner-Batzler, mentre due fette sono state impiegate per la determinazione della tenerezza sulla base del contenuto totale di collagene. Inoltre sono stati determinati il colore, il pH finale, la capacità di ritenzione idrica e il tenore di grasso intramuscolare.

Il punteggio attribuito alla tenerezza da parte dei valutatori utilizzati nel taste panel e relativo a 12.4 assaggi ha evidenziato una ripetibilità pari a 0.53; due punteggi attribuiti da valutatori diversi alla carne di uno stesso animale hanno presentato una ripetibilità pari a 0.08 mentre, quando attribuiti dallo stesso valutatore, hanno evidenziato una ripetibilità pari a 0.50. La ripetibilità della massima forza di taglio è risultata pare a 0.41. La ripetibilità degli altri caratteri qualitativi della carne è risultata compresa tra 0.29 per le perdite di cottura e 0.76 per l'indice di luminosità L^* determinato mediante colorimetrico Minolta.

La correlazione fenotipica tra la tenerezza valutata taste panel e la massima forza di taglio è risultata pari a -.50. Il contenuto totale di collage, il tenore di grasso intramuscolare e il pH finale non sono risultati correlati in alcun modo alla tenerzza. Gli altri caratteri hanno evidenziato correlazioni con la tenerezza comprese tra zero (indice del rosso b^* Minolta) e -.44 (perdite di sgocciolamento).

Sulla base della correlazione con la tenerezza determinata tramite taste panel, la determinazione della massima forza di taglio può essere utilizzata quale carattere per migliorare la tenerezza della carne suina.

Parametri genetici

La conoscenza dell'ereditabilità e delle correlazioni relative sia ai caratteri qualitativi della carne che ai caratteri più propriamente produttivi è necessaria ai fini della valutazione delle potenzialità di miglioramento genetico della qualità della carne da un lato e della risposta correlata dei caratteri qualitativi derivante dalla selezione sui caratteri produttivi dall'altro.

Nel Capitolo 3 vengono riportate le stime dei parametri genetici e fenotipici ottenuti utilizzando i dati rilevati su 1113 verri e scrofette Duroc e Yorkshire olandesi macellati tra il gennaio 1988 e il giugno 1990. Sono stati presi in considerazione quattro caratteri produttivi (accrescimento giornaliero, spessore del grasso dorsale, contenuto di carne magra e valutazione morfo-funzionale) e cinque caratteristiche qualitative della carne (pH finale del *M. longissimus* e del *M. semimembranoso*, colore, capacità di ritenzione idrica e tasso di grasso intramuscolare nel *M. longissimus*). Ereditabilità e correlazioni sono state stimate tramite procedura REML bivariata animal model per dati rilevati su sets di animali diversi.

I valori di ereditabilità per i caratteri produttivi sono risultati compresi tra 0.27 per la valutazione morfofunzionale e 0.63 per il contenuto di carne magra. Le ereditabilità delle caratteristiche qualitive della carne sono risultate comprese tra 0.20 per il pH finale del *M. semimembranoso* e 0.63 per il tenore di grasso intramuscolare. Le correlazioni fenotipiche fra caratteri produttivi e qualitativi sono risultate diverse da zero ad eccezione delle correlazioni tra caratteri produttivi e tenore di grasso intramuscolare. Le caratteristiche qualitative della carne hanno evidenziato correlazioni genetiche positive con l'accrescimento medio giornaliero ma sfavorevoli con il contenuto di carne magra e lo spessore del grasso dorsale.

Sulla base di questi risultati e dei pesi economici attualmente utilizzati in Olanda è prevedibile un peggioramento delle caratteristiche qualitative della carne determinato dalla selezione sui caratteri produttivi. Una selezione meno intensa per la riduzione dello spessore del grasso dorsale o per l'aumento del contenuto di carne magra potrebbe tuttavia consentire un miglioramento delle caratteristiche qualitative della carne.

Valori economici

I valori economici utilizzati quali pesi relativi dei caratteri in un indice di selezione sono considerati indipendenti dalla media della popolazione. Tuttavia diversi caratteri presentano un intervallo ottimale che dà origine a una dipendenza tra il valore economico di una variazione della media della popolazione e il valore reale della media stessa. In tali casi alcuni degli approcci che possono essere seguiti sono rappresentati dall'indice di selezione ristretto e dal genotipo aggregato quadratico. Qualsiasi approccio venga utilizzato, è comunque necessario calcolare una funzione di profitto attendibile. Nel caso delle caratteristiche qualitative della carne è nota una funzione di profitto approssimativa e limitata alle soglie al di sotto o al di sopra delle quali il prodotto non è accettabile o accettabile solo a prezzi più ridotti.

Nel Capitolo 4 viene proposta una metodologia per determinare i valori economici di caratteri che presentano un intervallo ottimale quali sono i caratteri qualitativi della carne. La metodologia richiede la conoscenza di alcuni elementi quali il tipo di distribuzione, la media e deviazione standard della popolazione, l'intervallo ottimale e le differenze di prezzo tra prodotti all'interno e al di fuori dell'intervallo ottimale. L'intervallo ottimale dei caratteri qualitativi e le differenze di prezzo tra prodotti all'interno dell'intervallo devono essere determinati sulla base di indagini di mercato e di informazioni provenienti dall'industria di trasformazione.

La metodologia proposta è stata messa a confronto con altri metodi utilizzabili in piani di selezione per il miglioramento della qualità della carne quale l'indice di selezione ristretto, l'indice di miglioramento desiderato e gli indeci basati sul genotipo aggregato quadratico. La metodologia proposta si basa su una funzione di profitto non lineare ed è quindi valida solamente nel caso di variazioni limitate. Di conseguenza è necessario calcolare nuovi valori economici a ogni generazione. Un'altra possibilità è rappresentata dall'indice di selezione ristretto e dall'indice di miglioramento desiderato. Tuttavia, in tali casi i caratteri inseriti nel genotipo aggregato non sono ponderati sulla base del loro valore economico ma in base all'importanza economica implicitamente attribuita dall'allevatore ai diversi caratteri. L'impiego del genotipo è un ulteriore approccio utilizzato nella letteratura scientifica. In questo caso, sebbene l'obiettivo del piano di miglioramento è rappresentato dalla massimizzazione del profitto a livello di generazione filiale, si ottiene la massimizzazione del profitto a livello di generazione parentale.

Prospettive

Nel Capitolo 5 vengono discusse le conseguenze che piani di selezione finalizzati al miglioramento delle caratteristiche qualitative della carne suina hanno sulle diverse figure econimiche che pertecipano al processo produttivo. I maggiori costi derivanti da tali piani di selezione vengono sopportati da organizzazioni di selezione, svezzatori e ingrassatori. Tali costi derivano sia dall'esigenza di controlli funzionali specifici (costi diretti) che dalla riduzione del miglioramento genetico dei caratteri produttivi (costi indiretti).

Al contrario, sia l'industria di macellazione e di trasformazione che i consumatori trarranno vantaggio dall'inclusione dei caratteri qualitativi nel gruppo di caratteri oggetto di selezione in seguito al miglioramento delle caratteristiche tecnologiche e organolettiche della carne suina. Il rallentamento del processo genetico del contenuto di carne magra della carcassa comporterà una riduzione soprattutto del profitto ritraibilie dall'industria di macellazione. E' tuttavia da rilevare che non sono disponibili valutazioni economiche circa gli effetti prodotti dalla variazione del contenuto di carne magra o dei caratteri qualitativi.

Al fine di valutare l'effetto sul progresso genetico atteso indotto dall'introduzione delle caratteristiche qualitative della carne nel gruppo di caratteri da migliorare sono stati affrontati cinque studi specifici. I cinque casi presi in esame differivano nei riquadri del valore medio di uno dei caratteri qualitativi e quindi nei riguardi del relativo valore economico. Nel caso in cui nessuna importanza fosse attribuita alla qualità della carne (come avviene nei programmi di miglioramento genetico attuali) la superiorità econimica degli animali selezionati per i caratteri produttivi sarebbe pari a 5.21 fiorini olandesi dopo un turno di selezione ($\Delta G_{prod,1}$; i=1). Introducendo i valori economici dei 5 casi relativi alla qualità, la superiorità economico correlata per la qualità della carne ($\Delta G_{qual,1}$) è risultata compresa tra -3.5 e 21.9% di $\Delta G_{prod,1}$, a secondo del valore medio dei caratteri nella popolazione. La superiorità economica globale ($\Delta G_{tot,1}$) degli animali selazioni è risultata compresa tra 5.03 e 6.35 fiorini olandesi.

Quando i caratteri qualitivi sono stati introdotti nell'obiettivo di selezione, $\Delta G_{qual,1}$ è migliorato del 0-12,5% di $\Delta G_{prod,1}$ per i vari casi considerati, ΔG_{prod} è diminuito del 0-6% di $\Delta G_{prod,1}$ e sono corrisposti, in entrambi i casi, miglioramenti di ΔG_{tot} pari a 0-6% di $\Delta G_{tot,1}$. Quando i caratteri di qualità sono stati introdotti sia nel genotipo aggregato che nell'indice di selezione il miglioramento di ΔG_{qual} è risultato pari a 22.3-40.7%, la diminuzione di ΔG_{prod} è stata pari a 12.1-19.6% e ΔG_{tot} ha subito un miglioramento pari a 10.3-22.7% nei vari casi.

E' improbabile che le caratteristiche qualitative della carne verranno incluse nel gruppo di caratteri da migliorare se i costi sopportati da organizzazioni di selezione, svezzatori e ingrassatori non saranno restituiti dalle altre figure econimiche partecipanti al processo produttivo. Nel prossimo futuro non è possibile attendersi un pagamento della carne suina sulla base della qualità. Quindi l'introduzione della qualità nei piani di miglioramento genetico è prevedibile solo se esisteranno accordi tra i diversi componenti del processo produttivo in relazione a una ridistribuzione del profitto derivante dalla miglior qualità della carne suina.

Conclusioni

- i più importanti gruppi di caratteristiche qualitative sono i seguenti: 1. pH finale, capacità di ritenzione idrica e colore della carne; 2. tenerezza della carne; 3. tenore di grasso intramuscolare.
- la ripetibilità dei caratteri qualitivi appartenenti al primo gruppo è risultata compresa tra 0.29 (perdite di cottura) e 0.76 per l'indice di luminosità L^* determinata con colorimetro Minolta; la ripetibilità del tenore di grasso intramuscolare è risultato pari a 0.44, quelle della tenerezza al taste panel e

della massima forza di taglio pari a 0.08 e 0.41 rispettivamente.

- la massima forza di taglio può essere efficacemente utilizzata quale carattere indice per il miglioramento della tenerezza della carne.
- l'ereditabilità del primo gruppo di caratteri qualitativi è risultata compresa tra 0.20 e 0.40, quella del tenore di grasso intramuscolare pari a 0.61.
- le correlazioni genetiche tra caratteristiche qualitative della carne e accrescimento giornaliero sono positive e comprese tra 0.06 e 0.46 mentre quelle fenotipiche sono prossime a zero. Le correlazioni genetiche tra il tenore di grasso intramuscolare e lo spessore del grasso dorsale e il contenuto di carne magra sono risultate pari a 0.37 e -.44 rispettivamente mentre le correlazioni fenotipiche sono risultate pari a 0.30 e -.31 rispettivamente. Le correlazioni genetiche tra gli altri caratteri qualitativi, lo spessore del grasso dorsale e il contenuto di carne magra sons sfavorevoli variando tra 0.00 e -.25 mentre quelle fenotipiche sono quasi nulle.
- i valori economici dei caratteri di qualità della carne dipendono dalla media e dalla deviazione standard dei caratteri stessi, dall'intervallo di ottimo e dalle differenze di prezzo, tra il prodotto all'interno e all'esterno dell'intervallo di ottimo dei caratteri qualitativi.
- la risposta correlata dei caratteri qualitativi ottenibili con gli attuali piani di miglioramento genetico può essere sia positiva che negativa a seconda del valore medio dei caratteri qualitativi nella popolazione.
- tre diverse strategie possono essere utilizzate ai fini del miglioramento della qualità della carne suina: nessun cambiamento dei piani di selezione attuali e sfruttamento della risposta correlata delle caratteristiche qualitative, l'introduzione dei caratteri qualitativi solamente nel genotipo aggregato e l'introduzione dei caratteri qualitativi sia nel genotipo aggregato che nell'indice di selezione.
- l'introduzione della qualità nei piani di miglioramento genetico è prevedibile solo se esisteranno accordi tra i diversi componenti del processo produttivo in relazione a una ridistribuzione del profitto derivante dalla miglior qualità della carne suina.

CURRICULUM VITAE

Op 29 juli 1964 ben ik, Ronald Hovenier, geboren in Enkhuizen. Na het behalen van het diploma Gymnasium-ß aan de Rijksscholengemeenschap West-Friesland te Hoorn, ben ik in september 1982 begonnen met de studie Zoötechniek aan de toenmalige Landbouwhogeschool te Wageningen. Deze studie heb ik in januari 1988 afgerond met als eerste afstudeervak Veefokkerij en als tweede afstudeervak Pluimveeteelt. Direct daarna ben ik als A.I.O. bij de vakgroep Veefokkerij van de Landbouwuniversiteit begonnen, waar ik gedurende vier jaren heb gewerkt aan het in dit proefschrift beschreven onderzoek. Sinds mei 1992 ben ik als geneticus werkzaam bij Raggio di Sole Agricola S.p.A., Fiorenzuola d'Arda (PC) in Italië.