Relevance of exterior appraisal in pig breeding

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Proefschrift
ter verkrijging van de graad van
doctor in de landbouw- en milieuwetenschappen,
op gezag van de rector magnificus,
dr. H. C. van der Plas,
in het openbaar te verdedigen
op woensdag 6 juni 1990
des namiddags te vier uur in de aula
van de Landbouwuniversiteit te Wageningen

Cover design: W. J. A. Valen
Illustrations: W. J. A. Valen (cover), K. Boekhorst

Van Steenbergen, E. J., 1990. Relevance of exterior appraisal in pig breeding (De waarde van exterieur beoordelingen in de varkensfokkerij). Doctoral thesis, Department of Animal Breeding, Wageningen Agricultural University. P.O. Box 338, 6700 AH Wageningen, The Netherlands.

STELLINGEN

1. Een lineair beoordelingssysteem voor exterieurkenmerken bij varkens biedt goede mogelijkheden tot selectie op beenwerk.
   Dit proefschrift

2. De extra informatie van visueel beoordeelde lichaamsmaten en lichaamsbouw aan het eind van de toetsperiode is voor selectie op mesterijeigenschappen te verwaarlozen.
   Dit proefschrift

3. Om de functionaliteit van het beenwerk van op groei en spekdikte geselecteerde varkens op peil te houden dient de helft van de getoetste beren op beenwerk afgekeurd te worden.
   Dit proefschrift

4. Het beoordelen van de grootte en de evenredigheid van de achterpootklauwen van opfokgelten met het oog op verlenging van de levensduur, heeft geen zin.
   Dit proefschrift

5. Selectie tegen afwijkende beenstanden bij opfokgelten heeft een positief effect op de gemiddelde levensduur van de zeugenstapel.
   Dit proefschrift

6. Voor een effectief selectiebeleid ten aanzien van beenwerk is voor diverse beenstanden kennis van de positie van het populatie-gemiddelde ten opzichte van het optimum noodzakelijk.
   Dit proefschrift

7. De zin van selectie op exterieur in een zeugenlijn ter verhoging van de gemiddelde levensduur, zal met name afhangen van de beenwerkreputatie van betreffende lijn.

8. De opbrengst als gevolg van extra genetische vooruitgang in de varkensfokkerij door invoering van het 'animal-model', hangt af van de juistheid van zowel de dier- als de modelkeuze.

9. Voor een optimale valorisatie van het varkenskarkas verdient de benutting van de aanwezige variatie in vleeskwaliteit meer aandacht dan het terugdringen van die variatie.

10. Voorkeursbeleid jegens een bepaalde bevolkingsgroep maakt van het antidiscriminatiebeleid een lachertje.

11. De wetenschappelijke onderbouwing van de essentiële voorwaarde voor de mogelijkheid van het ontstaan van leven door evolutie, namelijk een ouderdom van de aarde van minstens 4.6 miljard jaar, is gebaseerd op drijfzand.
    Monthy White, A.J., 1985. Hoe oud is de aarde? Evangelical Press, Durham, Engeland.

12. Effectieve selectie op vleeskwaliteit is nog een taaie hap.

Proefschrift van Evert J. van Steenbergen
Relevance of exterior appraisal in pig breeding
Wageningen, 6 juni 1990.

Aan Tineke
Natasja, Michiel en Larissa
Aan mijn ouders

VOORWOORD

Het in dit proefschrift beschreven onderzoek is uitgevoerd bij de vakgroep Veefokkerij van de Landbouwuniversiteit te Wageningen. De uitvoering van het onderzoek werd mede mogelijk gemaakt door de financiële bijdrage van het Produktschap voor Vee en Vlees (P.V.V.) te Rijswijk. De varkensfokkerij-instellingen hebben een sleutelrol gespeeld door zorg te dragen voor alle exterieurbeoordelingen. De hulp van Hendrix' Voeders bij het vinden van de varkensbedrijven voor het praktijkonderzoek was van onschatbare waarde, evenals het jaarlijk verzamelen en op tape zetten van de zeuggegevens. Aan de twee jaar durende medewerking van de 24 varkenshouders en een tiental inspecteurs heb ik bijzonder goede herinneringen overgehouden. Zonder de bijdrage van alle hiervoor genoemde instellingen en personen zou het onderzoek niet plaats hebben kunnen vinden. Graag wil ik daarom een ieder bedanken die op enigerlei wijze een bijdrage heeft geleverd aan de totstandkoming van dit proefschrift. Een aantal van hen wil ik hier met name noemen.

Mijn promotor prof.dr.ir. R.D. Politiek ben ik zeer erkentelijk voor de geboden mogelijkheden, zijn geduld en stimulerende invloed bij dit onderzoek. Zijn vertrouwen in dit onderzoek en zijn inbreng in de discussies heb ik zeer gewaardeerd.

De aanzet tot dit onderzoek is gegeven door mijn directe begeleider en co-promotor dr.ir. E. Kanis. Hij is steeds nauw betrokken geweest bij de opzet, uitvoering en verslaggeving van het hier weergegeven onderzoek. Zijn kritische instelling heeft mede bijgedragen aan het tot stand komen van dit proefschrift. Egbert, hartelijk bedankt.

De discussies in de begeleidingscommissie waren vaak verhelderd en inspirerend. Wiebe Koops en Hein van der Steen, hartelijk bedankt voor alle waardevolle suggesties en commentaar. Alfred de Vries, hartelijk bedankt voor alle nuttige discussies en gezellige gesprekken gedurende al de jaren die we gezamelijk in 'onze' kamer op Zodiac hebben doorgebracht.

Verscheidene personen hebben een waardevolle bijdrage geleverd voor het verbeteren van de Engelse tekst: Mike Grossman, Karin Meyer, Gary Rogers en Olwen Southwood.

Tot slot wil ik het LEB-fonds bedanken voor de financiële ondersteuning bij de afronding van het proefschrift.

CONTENTS

Chapter 1

INTRODUCTION

General.

The characteristics pigs have today are the results of evolution and the selection that has taken place since their domestication. Foundation of pig herdbooks and start of central performance tests at the beginning of this century, have been important stimuli for breeders to a more systematic selection in their breeding stock. Selection was mainly based on visual appraisal of external characteristics and functions (exterior traits). Organized appraisal of living pigs can be traced back to livestock fairs or shows starting in the early 1800's in Europe and later in North America. The main objective in most of the shows was to emphasize the ideal type offered by leading breeders at that time. Little consideration was given either to pedigree or individual performance. Some descriptions of the ideal type are given by Anderson (1938): "The retention of good size with a higher degree of quality is the goal for which breeders are striving; trimness of the jowl, under line and hams is a definite indicator of quality; the hair coat is also an index of quality; a strong constitution is shown by a deep, wide chest, well-filled back of the shoulder, a body of good depth, a capacious middle, and a good appetite". However, despite severe limitations of the show ring in rating animals according to their breeding values, until about 1950 no suitable substitute was developed for the evaluation of the general merit of the animals.

Exterior traits can be characterized by measurements (e.g. width, height, circumference), photography (Calabotta et al., 1982) and visual appraisal of external characteristics and functions. From a viewpoint of objectivity and interpretation of the data, measurements and photography are attractive, whereas low measuring costs and quickness of measuring favour visual appraisal as means for characterization of exterior traits. Characterization of exterior is not a goal in itself but rather serves as an indicator of growth performance, reproductivity and constitution. This indication might be of interest when economically important traits (breeding goal traits) can not be measured on living animals (e.g.

slaughter and meat quality) or when traits can not be measured at an early age (e.g. reproduction, longevity).

Exterior traits in relation to reproductive and growth performance.

Main external characteristics for reproduction and maternal ability are number and quality of the teats. Relationships of body measurements (length, width and height) and weight at the age of about 230 days with reproduction are negligible (Drobig et al., 1983; Schlegel et al., 1983).

Until about 1950 estimation of slaughter quality on living animals was based only on visual appraisal of external characteristics. Since then, several measuring techniques for application on live animals were developed and enabled objective and more accurate estimates of backfat thickness and lean meat content (e.g. Price et al., 1960; Molenaar, 1985).

Exterior traits and constitution.

The term constitution refers to the general physical structure and condition of a body. This comprises for example locomotory ability and susceptibility to diseases and parasites. Constitution is considered to be important because it is seen as an indicator of longevity. Brody (1945) stated: "Function is intimately correlated with structure and form. The art of animal judging is crude because only the grosser aspects of form and structure are available for examination and comparison. The principle that function is an expression of structure is, however, unassailable". Large changes in housing systems, feeding and floor types during the last three decades were accompanied by a considerable increase of lean meat deposition efficiency. In the same period many reports dealing with constitutional problems, mainly due to foot and leg disorders, were published (e.g. Smith, 1966; Grøndalen, 1974a; Webb et al., 1983; Rothschild and Christian, 1988). Leg weakness is a well-established term to describe these disorders and is defined as a clinical syndrome characterized by anomalies of attitude and gait and difficulties to rise and mount (Goedegebuure et al., 1980a). It is concluded that the main motive for exterior appraisal is its presumed relationship with constitution, particularly with leg weakness. Economics and factors related to leg weakness are therefore discussed.

Economic loss due to leg weakness can arise in different ways at each level of the production pyramid: through (1) reduced genetic improvement in performance traits at nucleus level due to involuntary culling, (2) premature disposal of breeding stock at nucleus and multiplier levels, (3) loss of sales at nucleus and multiplier levels, and (4) reduced reproduction and production efficiency at all levels.

On central test stations 15 to 50% of tested boars are rejected for breeding because of leg weakness and/or insufficient exterior (Smith and Smith, 1965; Teuscher et al., 1972; Bereskin, 1979; Webb et al., 1983; C.B.V. Annual Report, 1985). Walters et al. (1982) reported that 10% of reared gilts of a pig breeding company are rejected for sale to commercial multiplier herds because of insufficient "legs/feet" and "conformation". On multiplier herds 10 to 20% of disposed sows are culled because of leg weakness/lameness (Dagorn and Aumaitre, 1979; Arthur et al., 1983; Te Brake, 1986; Dijkhuizen et al., 1989). A reduction of the leg weakness problem can increase average herd life of sows. The economic benefit of an increase of average herd life from four to five litters is calculated by Dijkhuizen et al. (1986) and De Vries (1989), and averaged Dfl. 45.- per sow per year. Dijkhuizen et al. (1989) calculated the economic losses of premature disposal of sows. The highest losses are found in cases of 'lameness/leg weakness', averaging Dfl. 183.- per culled sow.

Next to the economic consequences, leg weakness has a negative impact on animal welfare and emphasizes the negative image of intensive husbandry systems. Reduction of the leg weakness problem is therefore an important item.

In literature many factors are studied in relation to leg weakness. Those factors can be divided into environmental and internal (i.e. derived from or part of the animal) factors. The main factors will be reviewed here after.

Environmental factors. In the literature several factors concerning housing system (e.g. type of confinement, type of floors) are indicated to have a significant impact on leg weakness (Sather and Fredeen, 1982; Van der Wal et al., 1984). A direct relationship of annual culling rate with type of flooring during gestation, size of the herd and lactation length is shown by D'Allaire et al. (1989).

Several studies dealt with the effect of food supplements (biotin, sodium bicarbonate ($NaHCO_3$) and vitamin C) on leg weakness (Penny et al., 1980; Nakano et al., 1983; Bryant et al., 1985a,b; Van der Wal et al., 1986). Sodium bicarbonate and vitamin C are found to have a positive effect on locomotory ability while biotin showed an effect on severity of toe lesions.

A feeding level effect is described by Kornegay et al. (1983) reporting that structural soundness scores are at a more desirable level in ad libitum-fed than in restricted-fed boars. This is not supported by results of Grøndalen (1974a), Nakano et al. (1979) and Calabotta et al. (1982).

Internal factors. Osteochondrosis is considered to be the major component of the leg weakness syndrome (Goedegebuure et al., 1980a; Nakano et al., 1981). Grøndalen (1974a,b) found the degree of osteochondrosis of an animal to be related to leg weakness. He also suggested very broad hams, a long back, and a narrow lumbar region to be predisposing factors for leg weakness. Poor associations between the state of osteochondrosis of fattening pigs and the degree of leg weakness are presented by Fredeen and Sather (1978), Goedegebuure et al. (1980b), Van der Valk et al. (1982) and Nakano et al. (1983), while Reiland et al. (1978) stated that no correlation existed between presence of osteochondrosis and leg weakness. Goedegebuure et al. (1988) concluded that although osteochondrosis may play a role, it is not the primary cause of front-leg weakness in Duroc swine. Hilley et al. (1981) stated that visual scores for leg weakness do not relate to the degree of osteochondrosis.

Vaughan (1971) and Grøndalen (1974a) indicated that fast growing pigs appeared to be predisposed to structural soundness and locomotion problems. This is confirmed by Nakano et al. (1983) who found a significant correlation between average daily gain and locomotory ability scores. Those results do not agree with growth and leg problem figures from feeding level experiments, which indicate either nil or a positive effect of growth rate on locomotory ability. Conflicting results might partly be due to differences in weight and age at which animals were scored for locomotory ability. It is generally believed that a constant selection for rapid growth and muscle mass results in a severe unbalance between live weight and the immature skeletal frame (e.g. Goedegebuure et al. 1980a). That unbalance might decrease locomotory ability.

Heredity of exterior traits.

Hetzer and Miller (1972) reported heritabilities of measures on live animals (length, width and height) ranging from 0.36 to 0.48. Heritability estimates of total number of teats averaged about 0.30 (e.g. Pumfrey et al., 1980). Genetic background of a large number of individual leg traits is estimated by Smith (1966) and Webb et al. (1983). Heritabilities were low, but indicated that some leg traits might have a genetic predisposition. Genetic evaluations of combined scores of leg traits, generally reported as leg weakness or soundness scores, resulted in low to moderate heritabilities (Bereskin, 1979; Webb et al., 1983; Lundeheim, 1987). Rothschild and Christian (1988) showed a direct response to five generations of divergent selection on front-leg weakness in Duroc pigs. Landrace pigs are generally described to have poorer constitution than Yorkshire pigs (Smith, 1966; Goedegebuure et al, 1980a, Webb et al., 1983; Lundeheim, 1987). These breed differences indicate genetic variation. It can be concluded that response on selection for exterior traits in pigs is likely to occur.

Visual scoring of exterior traits.

In literature many reports on visual appraisal of exterior in swine deal with scoring to an ideal, while most traits are combinations of individual traits. Information on objectively and conclusively defined distinct exterior traits is lacking which also holds for relationships between exterior traits and measures of a good constitution, i.e. longevity. Because importance of external characteristics is mainly through their presumed relationship with constitution, attention for exterior traits should be focused on traits for which a relationship with constitution, particularly with leg weakness, is indicated by literature and/or pig breeders.

Many different methods for evaluation of exterior traits are in use. Thompson et al. (1981, 1983) mentioned several advantages of a linear scoring system over a descriptive coding system: (1) degree rather than desirability is recorded, (2) scores cover the biological range, (3) traits are scored individually rather than in combination, (4) a wide range of numerical scores can be used which allows analyses with continuous scale, (5) heritabilities for linearly scored traits are comparable to or slightly larger than corresponding traits scored in relation to an ideal and (6) linear scoring permits interpretation of biological relationships among exterior traits. In dairy cattle linear scoring systems are practiced widely. No literature reports, however, are found of linear scoring in pigs.

Investigations.

This thesis focuses on the consequences and relevance of selection on exterior traits that are presumed to be related to constitution. Results and conclusions are based on investigations of exterior traits of centrally tested boars and of gilts and sows on 24 commercial multiplier farms. Investigations were set up to:

- evaluate the use of a linear scoring system for exterior traits in pigs
- obtain heritability estimates of exterior traits
- estimate genetic and phenotypic correlations between exterior traits and growth performance
- estimate the relationships of exterior traits with reproductive performance, reasons for disposal and longevity
- indicate the importance of exterior traits for pig breeding.

Before investigations started, exterior traits to be investigated were chosen in deliberation with inspectors of the Dutch pig herdbook and three pig breeding companies. The choice of the traits to be evaluated was based on the expected economic value and the likelihood to have a relationship with constitution. For the present investigations 21 exterior traits are defined and scored on a linear scale which ranged from 0 to 9 with 0.5 intervals. Description and evaluation of the linear scoring method is reported in Chapter 2.

Heritability and genetic variance of a trait are main factors which determine amount of selection response for that trait. Depending on genetic (co)variances, selection on one group of traits might also change the phenotypic and genetic value of other traits. Possibilities of selection for exterior traits and impact of culling on exterior traits for performance traits are reported in Chapter 3.

Severity or degree of leg weakness is not linearly related with its economic relevance. The main economic losses only occur if the level of leg weakness is reached which necessitates premature disposal of the animal. Longevity in a breeding herd, which among other factors is the result of all known and unknown manifestations of leg weakness, might be a good indicator of leg weakness (Calabotta et al., 1982). In pig breeding, constitution is especially relevant in dam lines because these lines provide sows for commercial multiplier herds. Longevity of these sows is economically important (e.g. Dijkhuizen et al., 1986). Relationships of exterior traits, especially when judged at an early age, with longevity are therefore investigated on commercial multiplier herds. In Chapter 4, exterior scores in relation to age of sows, and association of exterior traits with reasons for disposal, are reported.

Relationships of exterior traits with reproductivity, as well as significance of exterior traits and quantification of their effect on longevity are described in Chapter 5.

Possibilities for incorporation of linearly scored exterior traits in pig breeding programs and effects on performance traits can be deduced from Chapters 2 and 3. The relative importance of exterior traits, derived from their relationships with leg weakness and longevity, is indicated in Chapters 4 and 5. Practical applications of the results of chapters 2 to 5 are discussed in Chapter 6.

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Chapter 2

DESCRIPTION AND EVALUATION OF A LINEAR SCORING SYSTEM FOR EXTERIOR TRAITS IN PIGS

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Published in Livestock Production Science 23 (1989): 163-181.

ABSTRACT

In pig breeding, much attention is paid to the animal's exterior, which is thought to have a predictive value for its constitution. The term constitution refers to the general physical structure and condition of a body. An important part of constitution failures consists of leg and claw disorders. A linear scoring system for exterior traits has been set up to study relationships of exterior traits with (re)production and longevity. A description of judged exterior traits is given and the linear scoring system has been evaluated in terms of: differences between inspectors, use of 19 (0 to 9 with 0.5 increments) categories, accuracy of the scoring method and relationships between traits. For that purpose 40 boars have been judged twice by each of 10 inspectors. Differences in mean and standard deviation occurred between inspectors, with most inspectors showing a marked preference for whole number categories. On average, repeatability was 0.60 and reproducibility, indicating the correlation between repeated measurements done by more than one person, was 0.30. Principal component analysis showed that 20 exterior traits could be summarized by five interpretable factors that explained 57% of the total variance. Those factors could be characterized as 1) side view of legs, 2) way of walking and lifetime expectation, 3) size, 4) harmony of the frame and 5) rear legs and claws.

In present form, usefulness of application of described linear scoring system for exterior traits for selection purposes higly depends on the persons who judge the animals. When selecting and training appropriate people satisfactory repeatabilities can be achieved for most traits.

INTRODUCTION

Selection on exterior traits has traditionally played an important role in pig breeding. Before introduction of ultrasonic measurement of backfat thickness, selection on exterior traits was used to improve slaughter characteristics and constitution, where constitution refers to the general physical structure and condition of a body. Afterwards more attention has been paid to exterior traits to improve constitution in particular. A major constitutional problem is leg weakness, which is thought to be correlated with the exterior of the animal. Leg weakness is a clinical syndrome characterized by anomalies of attitude and gait, and by difficulties to rise and mount (Goedegebuure et al., 1980). It is an evaluation of the pig's ability to move, usually based on visual impression (Grøndalen, 1976). Indirect selection on exterior traits is used to reduce forced culling of sows, boars and slaughter pigs for leg weakness.

Forced culling of sows can cause considerable economic losses. Kroes and Van Male (1979) reported a Dfl. 143 (≈ US$ 70) higher income per sow per year for farms with a low (31%) annual replacement compared to farms with a high (55%) replacement. Reasons for culling in sows, reviewed by Kunz (1986) indicated two important causes i.e. reproductive failure (45%) and leg weakness (15%). In central test stations, 15 to 50% of tested boars are rejected for breeding because of leg weakness (Smith and Smith, 1965; Teuscher et al., 1972; Bereskin, 1979; C.B.V. Annual report, 1985). Culling of test station boars for leg weakness can reduce selection intensity and, thus, selection response for production traits.

Some estimates of relationships between leg weakness and exterior traits are available from the literature (Webb et al., 1983; Lodde et al., 1985; Lundeheim, 1987; Rothschild et al., 1988). Grøndalen (1974) found the shapes of the lumbar region and of the hind quarters to significantly influence locomotory ability in slaughter pigs. He noticed a marked relationship of a narrow concave lumbar region and of broad hind quarters with poor locomotory ability. Although in literature leg weakness scores concern legs and gait of the pig, definition and scoring systems for leg weakness were not uniform. No clear conclusion can be drawn from the literature.

Many different methods for evaluation of leg weakness and exterior are in use. Thompson et al. (1981, 1983) mentioned several advantages of a linear scoring system over a descriptive coding system: (1) degree rather than desirability is recorded, (2) scores cover the biological range, (3) traits are scored individually rather than in combination, (4) a wide range of numerical scores can be used which allows analyses with continuous scale, (5) heritabilities for linearly scored traits are comparable to or slightly larger than corresponding traits scored in relation to an ideal and (6) linear scoring permits interpretation of biological relationships among exterior traits.

In animal breeding, ranking of animals is based on breeding values for traits which are of economic interest. When a large number of traits are to be considered, then information has to be combined. Information on two or more traits can be combined by a selection index procedure when phenotypic and genetic parameters and (economic) weighing values of those traits are known. However, calculation of weights for exterior traits is hard, if not impossible. Principal component analysis allows a large set of variables to be represented in a much smaller number of independent, hypothetical variables ("factors"). The technique has proved useful in studies on the phenotypic relationship between measures of size and shape of live animals (e.g. Carpenter et al., 1978; Arnason and Thorsteinsson, 1982; Zarnecki et al., 1987).

In the Netherlands, an experiment has been set up to evaluate the relevance of selection for exterior traits in pigs. In the experiment, exterior traits of pigs were described and defined on a linear scale. During two years, several thousand gilts and sows have been evaluated for exterior traits to investigate the relationship with leg weakness, longevity and sow productivity. In addition, test station boars have been evaluated to estimate heritabilities of exterior traits and correlations between exterior traits and production.

The goal of the present article is to describe linearly scored exterior traits in pigs and to evaluate the linear scoring method.

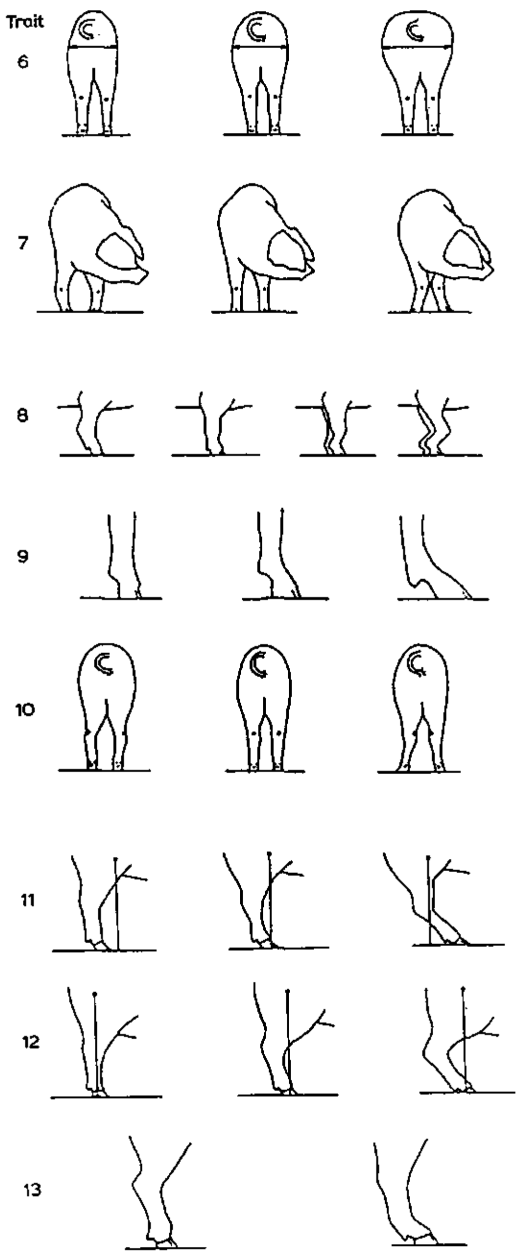
DESCRIPTION OF A LINEAR SCORING SYSTEM

The choice of the traits to be evaluated was determined by the expected economic value and the likelihood to have a relationship with leg weakness. In total, 19 singular and two composite traits (nipple quality and productive lifetime expectation) were described (Table 1). A further illustration of eight traits is in Figure 1. Traits were defined on a scale of 19 categories (0-9 with 0.5 intervals). In linear scoring systems in dairy cattle there is no uniformity about the scale and the number of categories to use, although most West European countries use a scale from 1 to 9 (De Graaf et al., 1987). It is important when using the "9-scale" that all variation in the traits between animals finds expression in the scores. A wide range of numerical scores is easier to handle to obtain this variation. De Graaf (personal communication, 1987) suggested 20 categories to be optimal.

Table 1. Description of 21 exterior traits.

	Score		
	0	4½	9
1. Connection of shoulder blade with body	loose		solid
Back and loin			
2. Length	short		long
3. Width	narrow		broad
4. Regularity	irregular		regular
Hams			
5. Length	short		long
6. Width	narrow		broad
Forelegs			
7. Front view legs	O-shaped		X-shaped
8. Side view legs	sickled	straight	buckled
9. Side view pastern	steep angle		low angle
Rear legs			
10. Rear view legs	O-shaped		X-shaped
11. Side view legs	straight		bow leg
12. Side view hock joint	steep		sickle hocked
13. Side view pastern	steep angle		low angle
14. Quantity subcut. liquid at hock joint	much		nil
15. Knottiness of legs; surface of tubercles	$\geq$ 12cm^2	6cm^2	0 cm^2
Claws rear leg			
16. Ratio size inner and outer claw	$\leq$ ½		$\geq$ 1
17. Toe size	small		large
18. Gait pattern; movements	slow (stiff)		easy, quick
19. Swinging of back	nil		much
20. Nipples	small		large
21. Lifetime expectation	short		long

At the start of the research project, inspectors were instructed to assume a population mean of 4.5, while emphasis has been put on use of the whole scale. In the description of the traits words such as "bad", "best", "satisfactory", "normal", etc. have not been used to avoid value judgement by the classifiers. Regularity of back and loin had to be appraised by the transition changes from shoulder to back and back to loin. Thus it will be an evaluation of the harmony of the body frame. Side view of the rear legs



<u>Figure 1.</u> Drawings to illustrate 8 exterior traits. (6) Width of hams, (7) front view forelegs, (8) side view forelegs, (9) side view pastern forelegs, (10) rear view rear legs, (11) side view rear legs, (12) side view hock joint, (13) side view pastern rear legs.

has been appraised based on the posture determined at the stifle joint. Teats were appraised by size and quality (e.g. presence of inverted nipples). Because exterior is expected to be related to sow life-productivity, lifetime expectation was defined as the expected number of litters to be produced in the future. This expectation was based only on the exterior of the sow. In present trial however, boars were scored for exterior. In order to get a score for lifetime expectation, boars had to be judged as if they were gilts.

MATERIAL AND METHOD

The scoring system was applied exclusively during the two years of the project by inspectors of herdbook and breeding companies. To avoid systematic changes in standard deviation and mean of inspectors during that two year period, no attempt was made to coach or standardize them.

At the end of the two year period, a trial was set up to evaluate the linear scoring system. Eleven Dutch Landrace (DL) and 29 Dutch Yorkshire (DY) boars were judged twice within one day by each of 10 inspectors from the herdbook and breeding organizations. Boars were shown to the inspectors one by one at a random order. To reduce the chance on recognition of boars, time between first and second judging was varied from boar to boar from .5 to 4 hours. Live weight of boars ranged from 97 to 111 kg and their ages varied from 151 to 171 days.

The following criteria were used to evaluate the scoring system:

(a) Mean and standard deviation for each trait.

(b) Use of categories.

(c) Repeatabilities and reproducibilities.

(d) Relationships between traits.

(a) Standard deviation per inspector was used as a measure for the use of the scale by the inspectors. Homogeneity of inspector variances was tested per trait with the Bartlett test (Snedecor and Cochran, 1977 p.296).

(b) The frequency distribution, summed over all traits and inspectors, was used to examine the use of the categories.

(c) To estimate the repeatability and reproducibility, variance components were estimated using the following linear model:

$$Y_{ijk} = \mu + R_i + I_j + B_{k:i} + I{*}R_{ij} + I{*}B_{jki} + e_{ijk} \quad \text{where,} \tag{1}$$

Y_{ijk} = exterior score on animal k, breed i done by inspector j

μ = overall mean

R_i = fixed effect of breed i (i=1,2)

I_j = fixed effect of inspector j (j=1,...,10)

$B_{k:i}$ = random effect of boar k within breed i

$I{*}R_{ij}$ = fixed effect of interaction between inspector j and breed i

$I{*}B_{jki}$ = random effect of interaction between inspector j and boar k within breed i

e_{ijk} = random error

Repeatability (r_1) is defined as the extent to which observations on the same animal, judged by the same inspector, correspond with each other, i.e., an intra-judge correlation. It is influenced only by measurement errors. The extent to which scores on the same animal, judged by different inspectors, correspond with each other is defined as the reproducibility (r_2), i.e., an inter-judge correlation. Differences between r_1 and r_2 are caused by the inspector*boar interaction. In formulae:

Repeatability (r_1) $= 1 - \sigma_e^2 / \sigma_{tot}^2$

Reproducibility (r_2) $= 1 - (\sigma_{I*B}^2 + \sigma_e^2) / \sigma_{tot}^2$ where,

σ_{I*B}^2 = inspector*boar interaction variance component

σ_e^2 = error variance component

$\sigma_{tot}^2 = \sigma_B^2 + \sigma_{I*B}^2 + \sigma_e^2$

σ_B^2 = boar variance component

In some publications with repeatability and reproducibility estimates (Hetzer et al., 1950; Evans, 1978; Jansen et al., 1985) the effect of inspectors was considered to be random. In those situations inspectors were trained to judge uniformly. In the present study, however, inspectors were from herdbook and three breeding companies, where each organization had its own system to judge and to evaluate the animal's exterior. In the two years that the inspectors used the linear scoring system, no meetings were organized to uniform scoring over inspectors. Therefore the differences between inspectors were partly due to their background and thus considered to be fixed. To make results more comparable with literature, the effect of inspectors was also considered to be random and 'variance' components were estimated for inspectors. The inspector 'variance' component was included in the total variance. In formulae:

Repeatability (r_1^*) $= 1 - \sigma_e^2 \;/\; (\sigma_{tot}^2 + \sigma_I^2 + \sigma_{I*R}^2)$

Reproducibility (r_2^*) $= \sigma_B^2 \;/\; (\sigma_{tot}^2 + \sigma_I^2 + \sigma_{I*R}^2)$ where,

σ_I^2 = inspector 'variance' component

σ_{I*R}^2 = inspector*breed interaction 'variance' component

Variance components have been estimated with the VARCOMP procedure (METHOD=TYPE1) of SAS (SAS Institute Inc., 1985).

(d) The correlation matrix was used to examine the observation structure, to see whether traits could be omitted or grouped together. When a high correlation between two traits exists, almost no new information will be added by judging the second trait. Omission of one of the traits may then be considered.

Principal component analysis was used to reduce the large set of exterior traits to a smaller number of independent factors, in which the exterior traits will be grouped. In principal component analysis three 'basic' steps are carried out: (1) the computation of the correlation matrix, (2) the extraction of the initial factors, and (3) the rotation to a terminal solution. The configuration of the factor structure is not unique; one factor solution can be transformed into another without violating the basic assumptions or the mathematical properties of a given solution. By factor rotation simple and interpretable factors are searched for by measuring how close correlation coefficients between traits and factor are to 0 or ±1. The number of factors to retain is chosen arbitrarily, but is mostly based on the eigenvalues of the correlation matrix. When eigenvalues of the correlation matrix are in descending order, the first eigenvalue represents the variance explained by the first factor. In this study factors were extracted with principal component analysis by the FACTOR procedure of SAS (SAS Institute Inc., 1985). Orthogonal rotation was by the VARIMAX option.

RESULTS AND DISCUSSION

Mean and standard deviation

Information about means, standard deviations (s.d.) and ranges is in Table 2. For most traits the range in inspector means was less than 2.5 points. For two traits (6 and 14), the overall mean deviated more than one point from the scale mean (4.5). This was partly due to the unequal number of boars per breed, because for those traits large breed differences existed.

The overall s.d. averaged 1.15. Three of 21 traits showed an overall s.d. smaller than 0.9. The standard deviation within inspectors was lower than the overall s.d. This was due to the large differences between inspector means. Posture of both fore- and rear legs (traits 7-13) showed little variation. Almost no variation was observed in nipple size and quality. The value of judging this trait is therefore nil, so it was excluded from further evaluation of the scoring method. A relatively large standard deviation was observed for knottiness, swinging of the back and lifetime expectation. A large standard deviation could be the result of a distribution with two peaks which could occur when inspectors interpret a trait as two different traits. However, no evidence of a distribution with more than one peak could be found.

Standard deviations per inspector (averaged over boars and traits) ranged from 0.62 to 1.16. For four inspectors a standard deviation lower than 0.9 was observed. From the test on homogeneity of variances it was concluded that differences between inspectors were significant (P<0.005) for all traits. Within some traits, inspectors differed mainly due to one or two outliers. However, the identity of the outliers (inspectors) was not consistent over traits. For each trait a regression of standard deviation and variance on means was carried out. All regression coefficients were found to be non-significant (P > 0.10), so it was concluded that no consistent relationship between variation and mean existed. A transformation will therefore not stabilize the variance.

Table 2. Distribution characteristics of linear scored traits.

Exterior traits[1]	MEAN		Standard deviation		
	overall	I-range[2]	overall	inspect[3]	I-range[2]
1. Shoulder blade	4.30	(2.4-5.2)	1.30	0.98	(0.6-1.5)
Back and loin					
2. Length	5.33	(4.2-6.2)	1.07	0.91	(0.7-1.1)
3. Width	5.23	(4.2-6.2)	1.05	0.93	(0.5-1.1)
4. Regularity	5.17	(4.2-6.0)	1.24	1.08	(0.4-1.5)
Hams					
5. Length	5.01	(4.1-5.8)	0.96	0.75	(0.6-1.6)
6. Width	5.65	(4.5-6.4)	1.29	1.13	(0.6-1.1)
Forelegs					
7. Front view legs	4.56	(4.3-5.3)	0.77	0.62	(0.1-1.1)
8. Side view legs	4.60	(3.7-5.4)	1.11	0.95	(0.6-1.6)
9. Side view pastern	4.31	(2.8-5.0)	1.14	0.94	(0.5-1.3)
Rear legs					
10. Rear view legs	4.67	(4.5-5.2)	0.65	0.53	(0.0-1.0)
11. Side view legs	4.67	(3.0-5.5)	0.98	0.70	(0.2-1.2)
12. Side view hock joint	4.58	(2.7-5.6)	1.05	0.73	(0.4-1.1)
13. Side view pastern	4.25	(2.0-4.9)	1.04	0.65	(0.3-1.0)
14. Liquid at hock joint	5.64	(4.6-7.3)	1.38	1.01	(0.4-1.4)
15. Knottiness of legs	5.43	(4.5-7.1)	1.43	1.21	(0.6-1.5)
Claws rear leg					
16. Ratio size of claws	4.95	(4.0-6.4)	1.36	1.06	(0.7-1.6)
17. Toe size	5.00	(3.9-6.7)	1.27	0.85	(0.6-1.2)
18. Gait; movements	5.24	(3.7-6.0)	1.37	1.15	(0.7-1.6)
19. Swinging of back	4.51	(2.6-5.9)	1.63	1.21	(0.8-1.7)
20. Nipples	4.51	(4.5-4.5)	0.08	0.06	(0.0-0.1)
21. Lifetime expectation	4.22	(2.9-6.0)	1.94	1.61	(0.9-2.0)

[1] : Traits are described in Table 1.
[2] : I-range = lowest and highest inspector mean.
[3] : inspect = average of 10 within-inspector standard deviations.

Use of the categories

From the frequency distribution in Figure 2, it can be seen that the 'half' categories were used less than would be expected, except for 4.5. The relatively high number of observations in category 4.5 can be explained by the instruction to the inspectors to assume a population mean of 4.5. In Table 3 are the percentage observations in the 'whole' categories, in 'half' categories except 4.5 and in category 4.5. Differences between inspectors can be noticed. Traits considering fore- and rear legs (traits 7-13) were scored frequently in category 4.5, which coincides with the relatively low standard deviation. Scoring in 'half' categories was avoided by a substantial number of inspectors, probably due to the coding of categories (0, .5, 1,...) and to the total number of categories. Changing the coding of categories might reduce the preference for certain groups of figures. No conclusion can be drawn on the optimal number of categories.

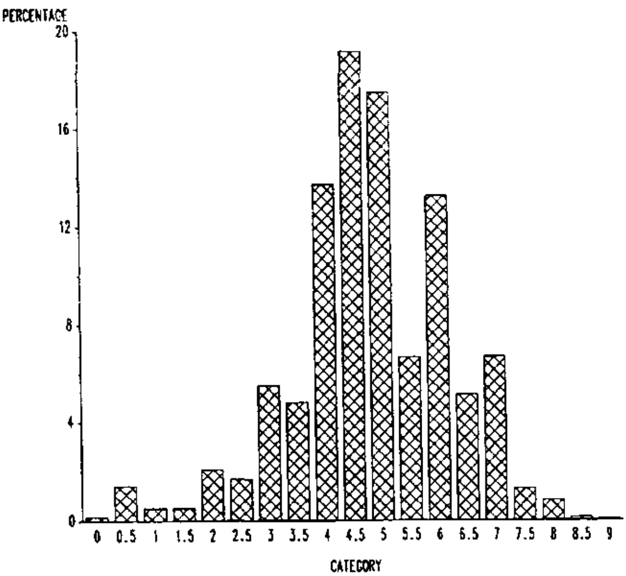


Figure 2. Distribution of observations summed over all traits and inspectors.

Table 3. Percentage observations in the 'whole' categories, 'half' excluding 4.5 and category 4.5, per trait and inspector.

	Category				Category		
Trait	'Whole'	'Half'	4.5	Inspect.	'Whole'	'Half'	4.5
1	62	26	12	1	59	16	25
2	66	20	14	2	86	12	2
3	64	25	11	3	67	15	17
4	64	25	11	4	51	26	23
5	54	16	19	5	58	31	11
6	59	32	9	6	56	16	28
7	44	12	44	7	51	20	29
8	54	21	25	8	52	35	13
9	61	17	22	9	50	26	24
10	37	10	53	10	74	8	18
11	55	20	25				
12	47	23	30				
13	50	15	35				
14	71	20	9				
15	70	25	5				
16	64	24	12				
17	67	19	14				
18	69	18	13				
19	70	18	12				
20	--	--	--				
21	70	24	6				

Repeatabilities and reproducibilities

Analysis of variance showed differences between DL and DY for several traits ($P<0.01$). For most traits, boar*inspector interaction was significant ($P<0.001$). In Table 4 variance analysis with degrees of freedom and expected mean squares is given, assuming inspectors to be random. Variance components, repeatability and reproducibility estimates of exterior traits are in Table 5. The boar*inspector interaction showed large variance components for shoulder blade, regularity of back and loin, dryness of hock joint and lifetime expectation. A large boar*inspector interaction variance component points to the possibility of different ranking of boars by inspectors. Regular coaching and discussions between them will probably reduce that interaction. The boar variance component was larger than the error component only for width of the hams and knottiness of the rear legs.

Table 4. Analysis of variance and expected mean squares.

Source	d.f.	Expected Mean Squares
Breed (R)	1	$\sigma_e^2 + 2\sigma_{I*B}^2 + 31.9\sigma_{I*R}^2 + 20\sigma_B^2 + Q(R)$
Inspector (I)	9	$\sigma_e^2 + 2\sigma_{I*B}^2 + 48.1\sigma_{I*R}^2 + 80\sigma_I^2$
Boar (B)	38	$\sigma_e^2 + 2\sigma_{I*B}^2 + 20\sigma_B^2$
Inspector*breed (I*R)	9	$\sigma_e^2 + 2\sigma_{I*B}^2 + 31.9\sigma_{I*R}^2$
Inspector*boar (I*B)	342	$\sigma_e^2 + 2\sigma_{I*B}^2$
Error (e)	400	σ_e^2

Repeatability (r_1) estimates ranged from 0.33 (swinging of the back) to 0.74 (width of the hams) and averaged 0.50. Reproducibility (r_2) estimates ranged from 0.12 (length of the hams) to 0.62 (width of the hams) and averaged 0.34. Lifetime expectation, which is defined as a composite trait, can be judged with a relatively high repeatability. Repeatability and reproducibility estimates including an inspector 'variance' component (r_1^* and r_2^*) averaged 0.66 and 0.25, which is 0.16 higher and 0.09 lower than their respective estimates without the inspector 'variance' component. Differences between r_1 and r_1^* are due to differences in total variance (σ_{tot}^2). When considering inspectors random, total variance increases and thus r_1^* is higher than r_1. Comparison of the formulae for r_2 and r_2^* indicates that r_2^* will always be lower or at most equal to r_2. When using the scoring system in practice, uniformity of scoring will be pursued, which probably could induce a smaller inspector and inspector*boar interaction variance component. In that situation, repeatability (r_1^*) and reproducibility (r_2^*) estimates would be between the estimates with and without an inspector 'variance' component.

No repeatability estimates of linear scored exterior traits were found in the literature. De Roo (1983) investigated several exterior scoring systems that were used by herdbook and breeding companies in The Netherlands. He found that r_1^* averaged 0.43 and r_2^* averaged 0.33. Hetzer et al. (1950) estimated reproducibilities (r_2^*) of eight body measurements on live

Table 5. Variance components, repeatabilities and reproducibilities of linear scored exterior traits.

Exterior traits.	Variance components.							
	boar	insp	insp* boar	error	r_1	r_2	r_1^*	r_2^*
1. Shoulder blade	.390	.746	.229	.400	.61	.38	.78	.22
Back and loin								
2. Length	.261	.292	.022	.432	.40	.37	.60	.24
3. Width	.237	.178	.125	.314	.54	.35	.68	.24
4. Regularity	.504	.311	.222	.513	.59	.41	.68	.32
Hams								
5. Length	.065	.305	.152	.325	.40	.12	.67	.07
6. Width	.697	.324	.137	.298	.74	.62	.80	.46
Forelegs								
7. Front view legs	.094	.786	.066	.301	.35	.20	.49	.16
8. Side view legs	.360	.266	.104	.473	.49	.38	.61	.30
9. Side view pastern	.389	.373	.122	.429	.54	.41	.68	.29
Rear legs								
10. Rear view legs	.100	.358	.071	.193	.47	.27	.54	.24
11. Side view legs	.164	.425	.114	.298	.48	.28	.71	.16
12. Side view hock joint	.119	.552	.150	.283	.49	.22	.75	.10
13. Side view pastern	.127	.703	.058	.276	.40	.28	.76	.11
14. Liquid at hock joint	.336	.875	.283	.432	.59	.32	.78	.17
15. Knottiness of legs	.708	.515	.194	.644	.58	.46	.70	.33
Claws rear leg								
16. Ratio size of claws	.485	.697	.177	.536	.55	.40	.72	.25
17. Toe size	.233	.928	.113	.422	.45	.30	.75	.14
18. Gait; movements	.559	.520	.055	.720	.46	.42	.62	.29
19. Swinging of back	.426	1.217	.076	1.012	.33	.28	.63	.15
20. Nipples	---	---	---	---	--	--	--	--
21. Lifetime expectation	1.150	1.111	.404	1.164	.57	.42	.70	.30

pigs of approximately 100 kg; estimates ranged from 0.56 to 0.77. Evans (1978) investigated the precision of body condition scoring on cows and ewes; r_1^* was 0.85 and r_2^* was 0.76. Jansen et al. (1985) presented repeatabilities and reproducibilities of body measurements, fleshiness and fat covering of 15-month old bulls; for body measurements r_1^* ranged from 0.60 to 0.78 and r_2^* ranged from 0.50 to 0.76, for fleshiness r_1^* was 0.76 and r_2^* 0.14, and for fat covering r_1^* was 0.80 and r_2^* 0.14.

Although inspectors practiced the linear scoring system only during two years for approximately two days per month, repeatability and reproducibility estimates for linear scored exterior traits were higher than results of De Roo (1983). Repeatability and reproducibility estimates were much lower than values based on body measurements and body condition scores (Hetzer et al. 1950; Evans 1978; Jansen et al. 1985).

Relationships between traits.

Pearson product-moment correlations for all exterior traits are in Table 6. Only nine of 210 correlations had an absolute value greater than 0.5. The highest correlation (0.74) was between size and evenness of the claws. Apparently proportional and large size claws coincide. The highest correlation with lifetime expectation was for gait (0.69) and for swinging of the back (-.69). Easy movements and a straight back while walking were associated with a long lifetime expectation. Level of correlations did not give a clear indication for omitting one or more traits without considerable loss of information.

Principal component analysis.

Table 7 presents the eigenvalues of the correlation matrix and the cumulative proportion of the total variance. Seven factors had an eigenvalue greater than unity. Together they explained 72% of the total variance. Thus a transformation of 20 traits to seven independent factors decreased the total variation by 28%. In Table 8, the factor pattern of seven factors and the variation explained by each factor after orthogonal transformation is presented. The first factor has high correlations with side view of the legs, about 0.82. The second factor can be seen as the way of walking and lifetime expectation. Size is mainly represented by factor three and harmony of the frame by four. Factor five provides some information about rear legs and claws. Factors 6 and 7 are more difficult to interpret. Therefore, it is concluded that 20 exterior traits can be transformed to five independent interpretable factors that explain 57% of the total variance. Variance components of the exterior factors are estimated using model (1) and are presented with repeatabilities and reproducibilities in Table 9. Estimates range from 0.52 to 0.67 for repeatability (r_1) and from 0.41 to 0.53 for reproducibility (r_2). Estimates of r_1, r_2, r_1^* and r_2^* for factor 1 and 5 (side view legs and rear legs/claws)

Table 6. Pearson correlations between exterior traits.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Shoulder blade	.04	.22	.68	.18	.09	−.01	−.13	−.03	.00	−.05	.07	−.05	.03	−.10	−.05	−.14	.09	−.30	--	.37
Back and loin																				
2. Length		−.12	.21	.34	−.17	.03	.29	−.16	.09	.05	.11	.11	.12	.11	.14	.17	.05	.13	--	−.06
3. Width			.24	.32	.62	.02	−.16	.18	−.12	.02	.00	.00	.00	−.09	−.14	−.08	.05	−.06	--	.16
4. Regularity				.34	.03	.09	−.14	−.05	.05	−.11	.02	−.07	.04	−.01	−.04	−.05	.15	−.19	--	.31
Hams																				
5. Length					.34	.13	−.01	−.06	−.04	−.15	−.08	−.05	.03	.00	.04	.13	−.01	.05	--	.04
6. Width						−.07	−.12	.22	−.27	.10	.06	.07	.04	−.19	−.08	.03	−.09	.08	--	.01
Forelegs																				
7. Front view legs							−.13	−.05	.13	−.27	−.17	−.18	−.10	.08	−.08	−.02	−.11	.04	--	−.02
8. Side view legs								.12	.03	.20	.19	.25	−.01	.05	.20	.23	−.10	.10	--	−.22
9. Side view pastern									−.14	.33	.31	.51	.16	.09	.19	.28	.08	−.05	--	.04
Rear legs																				
10. Rear view legs										−.08	−.16	−.23	−.11	.11	−.06	−.09	−.17	.16	--	−.22
11. Side view legs											.67	.55	.01	−.19	.02	.02	−.14	.13	--	−.17
12. Side view hock joint												.66	.09	−.05	.14	.17	.05	−.04	--	.08
13. Side view pastern													.25	.11	.33	.41	.14	−.13	--	.11
14. Liquid at hock joint														.49	.34	.32	.14	−.02	--	.10
15. Knottiness of legs															.28	.33	.15	−.10	--	.12
Claws rear leg																				
16. Ratio size of claws																.74	.27	−.09	--	.21
17. Toe size																	.30	−.12	--	.21
18. Gait; movements																		−.48	--	.69
19. Swinging of back																			--	−.69
20. Nipples																				--
21. Lifetime expectation																				1.00

are higher than estimates for its highly correlated exterior traits, while values of the remaining three factors are comparable. Evaluation of exterior can be made less complex by analyzing a small number of factor scores compared to analyzing all traits separately. However, biological interpretation of relationships between those factors and (re)production might be more complex. The final choice of traits or factors to be considered in animal breeding depends on their relative economic value.

Table 7. Eigenvalues of the correlation matrix and the cumulative proportion of the total variance.

factor nr.	eigen-value	cumulative proportion of variance
1	3.43	0.17
2	2.89	0.32
3	2.37	0.43
4	1.86	0.53
5	1.63	0.61
6	1.15	0.67
7	1.02	0.72
8	0.85	0.76
9	0.76	0.80
10	0.73	0.83
11	0.56	0.86
12	0.50	0.89
13	0.41	0.91
14	0.37	0.93
15	0.32	0.94
16	0.29	0.96
17	0.27	0.97
18	0.23	0.98
19	0.20	0.99
20	0.18	1.00

GENERAL DISCUSSION AND CONCLUSION

Scores of exterior traits were strongly influenced by inspector. Large differences between inspectors occurred for means and standard deviations of all traits. For most traits, inspector*boar interaction was significant. Interaction can be caused by differences in scale and ranking. Standardization of the scores, to remove scale differences, did not decrease the

Table 8. Factor pattern of seven factors and the variation explained by each of the factors after orthogonal transformation.

Exterior traits	Factors 1	2	3	4	5	6	7
1. Shoulder blade	.04	.22	.09	.83	-.04	-.05	-.01
Back and loin							
2. Length	-.02	-.11	-.12	.26	.08	.78	-.05
3. Width	.04	.03	.78	.23	-.04	-.15	.06
4. Regularity	-.04	.17	.13	.84	.03	.14	.12
Hams							
5. Length	-.20	-.04	.57	.27	.02	.53	.14
6. Width	.09	-.08	.88	-.02	-.04	-.09	-.10
Forelegs							
7. Front view legs	-.16	-.04	.03	.03	-.04	-.02	.83
8. Side view legs	.28	-.12	-.18	-.20	-.06	.57	-.06
9. Side view pastern	.66	.08	.27	-.15	.20	-.17	.22
Rear legs							
10. Rear view legs	-.12	-.32	-.39	.20	.06	.01	.43
11. Side view legs	.81	-.22	-.02	.02	-.15	.02	-.23
12. Side view hock joint	.83	.04	-.04	.12	-.04	.11	-.14
13. Side view pastern	.82	.17	.04	-.09	.19	.17	-.08
14. Liquid at hock joint	.09	.00	.07	.09	.85	.00	-.23
15. Knottiness of legs	-.06	.06	-.16	-.01	.80	.01	.14
Claws rear leg							
16. Ratio size of claws	.20	.35	-.03	-.26	.48	.43	.08
17. Toe size	.25	.37	.10	-.33	.47	.47	.17
18. Gait; movements	-.02	.81	-.02	.01	.13	.07	-.10
19. Swinging of back	-.04	-.79	.07	-.19	.03	.16	-.00
20. Nipples							
21. Lifetime expectation	-.01	.88	.07	.26	.07	-.08	-.02
Variation explained by each factor (eigenvalue)	2.74	2.62	2.06	2.00	1.97	1.77	1.19

interaction effect. Evans (1978) and Jansen et al. (1985) found animal*-person interactions for body condition, fleshiness and fat covering scores.

In practice, exterior scoring of pigs will generally be by more than one inspector. In the situation of no inspector training, reproducibility, in present study 0.30, is the best indicator for the usefulness of exterior scoring. When no inspector differences would occur, then repeatability estimates, which averaged 0.60, show a considerable increase in usefulness. Careful training of inspectors and periodic standardization exercises might

Table 9. Variance components, repeatabilities (r_1) and reproducibilities (r_2) of five factors.

	Variance components.							
Factor	boar	insp	insp* boar	error	r_1	r_2	r_1^*	r_2^*
1. Side view legs	.156	.668	.076	.149	.61	.41	.86	.15
2. Walking/lifetime	.276	.349	.051	.305	.52	.44	.69	.28
3. Size	.251	.192	.069	.156	.67	.53	.78	.35
4. Harmony frame	.193	.570	.078	.194	.58	.42	.81	.18
5. Rear legs/claws	.319	.329	.110	.209	.67	.50	.79	.32

Note: r_1^*, r_2^* are repeatability and reproducibility estimates including the inspector variance component.

decrease inspector differences and so increase the usefulness of a linear scoring system. The standard error of an animal's score can also be reduced by scoring the animal a second time, preferable by a different person (Evans, 1978). In the Netherlands, a linear scoring system for exterior traits in cows has been used for 10 years. For that scoring system De Graaf (personal communication, 1987) reported a correlation of 0.8 between exterior scores of the inspector who determines the standard and scores by other inspectors. This too gives an indication that accuracy of exterior scores in pigs might be increased to a satisfactory level.

Principal component analysis has been shown to be useful in grouping correlated traits into a small number of interpretable factors. Ranking of animals on exterior might be much easier when using those factors.

ACKNOWLEDGEMENT

Part of the costs of this study were covered by financial support from the Dutch Commodity Board for Livestock and Meat.

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Chapter 3

GENETIC PARAMETERS OF FATTENING PERFORMANCE AND EXTERIOR TRAITS OF BOARS TESTED IN CENTRAL STATIONS

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Published in Livestock Production Science 24 (1990): 67-85.

ABSTRACT

Genetic relationships among fattening performance and 20 linearly scored exterior traits were estimated from data of 2792 boars of several strains. Boars were tested with ad libitum feeding from approximately 25 to 105 kg at central test stations of the Dutch herdbook and three breeding companies. (Co)variances of fattening performance and exterior traits were estimated simultaneously in a multi-variate model with the Restricted Maximum Likelihood method.

Heritability estimates of performance traits ranged from 0.24 to 0.37 and of exterior traits from 0.01 to 0.38. High genetic correlations were found between daily gain and side view of the foreleg pastern, side view and dryness of the hock joint. Slower growing animals have steeper foreleg pastern, less liquid at the hock joint and more sickle hocked rear legs. The genetic correlation between feed conversion and rear view of the rear legs indicates that boars with better feed conversion have more O-shaped rear legs. Moderate heritabilities were found for five linear combinations of exterior traits (factors).

Index selection only on fattening performance will change the rear view of the rear legs to more O-shape, change the side view of the hock joint to more steep, increase the quantity of liquid at the hock joint and slow down the boar's gait. A two-stage selection with selection in the first stage on gait (movements) and on growth performance in the second stage, reduces genetic progress of performance traits. When assuming a nihil economic value for gait pattern and rejecting 50% of the boars in the first stage, then economic merit is reduced by 24%.

INTRODUCTION

In pig breeding, increasing attention has been paid to leg weakness during the last 20 years. Although not an exact diagnosis, leg weakness is a well-established term to describe the syndrome of locomotory disabilities commonly found in swine (Grøndalen, 1974). The leg weakness status of live animals is based on visual appraisal of exterior traits, such as legs and claws, which are related to the pigs locomotory ability. The severity of the leg weakness problem can be illustrated by the incidence of serious leg weakness which is generally reported in the range from 15 to 50% (Smith and Smith, 1965; Teuscher et al., 1972; Bereskin, 1979; C.B.V. Annual Report, 1985). Culling on leg weakness can have a considerable effect on the genetic change of performance traits and vice versa, depending on genetic (co)variances.

Numerous estimates of genetic and phenotypic parameters of performance traits in pigs have been reported in literature (e.g. Sönnichsen et al., 1984a,b; Johansson et al., 1985; Kennedy et al., 1985 and Merks, 1987). In contrast, relatively few estimates of such parameters have been reported for exterior traits. Heritability estimates of leg weakness have been reported in the range from 0.10 to 0.45 (Smith, 1966; Reiland et al., 1978; Bereskin, 1979; Webb et al., 1983; Lundeheim, 1987; Rothschild and Christian, 1988). Results of studies concerning the relationship between leg weakness and production traits are contradictory. An antagonistic genetic correlation between leg weakness and average daily gain (ADG) was found by Lundeheim (1987), while Bereskin (1979) and Sather and Fredeen (1982) found the association to be beneficial. Non significant genetic correlations between leg weakness and production traits were found by Smith (1966), Webb et al. (1983) and Rothschild et al. (1988). The genetic correlation between leg weakness and backfat thickness is generally unfavourable (Bereskin, 1979; Webb et al., 1983; Lundeheim, 1987; Rothschild et al., 1988). Webb et al. (1983) did not find a genetic association between feed conversion ratio and leg weakness.

Leg weakness can be scored by many different methods. Thompson et al. (1983) mentioned several advantages of a linear scoring system over a descriptive coding system. Relationships among linearly scored exterior traits and relationships between those traits and performance are easier to interpret, while heritability estimates are comparable to or slightly larger than corresponding descriptively coded traits (Thompson et al., 1981; 1983). In dairy cattle, linear type appraisal has become common practice (Thompson et al., 1983; Swanson and Bryan, 1984; Diers and Swalve, 1987). Concerning pigs, no applications of a linear scoring system for exterior traits were found in the literature.

The present study consists of an analysis of data on linearly scored exterior traits and fattening performance traits collected on boars of six strains. The objective of this study was to estimate genetic (co)variances of exterior and fattening performance and to evaluate the impact of some selection strategies on exterior traits and performance.

MATERIAL

Data were obtained from central test station boars of the Dutch herdbook and three breeding companies during 1986 and 1987. Inspectors of respective organizations judged boars at the end of the test at their own test station only. Each inspector judged a batch of 10 to 30 boars per day. A batch is defined as boars of one strain judged within one day by one inspector. During the two years 20 to 30 batches were scored per inspector. Performance tests were approximately from 25 to 105 kg live weight. The exterior traits considered are described in the Appendix.

Table 1. Number of boars, sires and dams, average live weight and standard deviation (between brackets) at end of the test and the distribution of inspectors over datasets.

Strain[1]	boars	sires	dams	weight (kg)	Inspector
DL	638	82	461	104 (2.3)	a,b + c,d,e[2]
DY	1043	124	831	104 (2.4)	a,b + c,d,e[2]
A	207	36	131	98 (2.6)	f,g
B1	366	59	197	109 (3.4)	f,g
B2	413	52	153	105 (5.3)	h
B3	367	54	160	118 (10.8)	i

[1] DL = Dutch Landrace; DY = Dutch Yorkshire; A is a dam line and B1 to B3 are sire lines. Strain B3 was group tested.

[2] DL and DY were tested at two different test stations. Inspector a and b judged animals at station 1; c,d and e at station 2.

Performance traits considered were weight divided by age at end of the test (W/A), average daily gain on test (ADG), average daily feed intake on test (DFI), average feed conversion (FC) expressed as total amount of feed consumed over total body weight gain on test and backfat thickness (UB) ultrasonically measured at the end of test. All boars were fed ad libitum. During the test boars were housed individually, except for one strain of which animals were group tested. As a consequence, FC and DFI could not be calculated in that strain. The structure of the data is shown in Table 1. About 8% of the dams had offspring in the data originating from subsequent litters and different sires. The number of boars with nil, one and two or more full sibs is 1394, 1058 and 582, respectively.

METHODS

Each animal was judged for 21 exterior traits on a linear scale of 0 to 9 with 0.5 increments. A detailed description of method of scoring is given by Van Steenbergen (1989). In that study, it was found that nipple quality scores showed almost no variation; therefore nipple quality was excluded from further analyses.

Evaluation of the exterior by a large number of traits is difficult. Principal component analysis can be used to combine information of all traits into one or more 'factors', given the relationships between the traits. Van Steenbergen (1989) used principal component analysis to summarize the set of 20 exterior traits to five uncorrelated factors. Based on the factor loadings the factors were described as 1) 'side view legs', 2) 'movements and lifetime expectation', 3) 'size', 4) 'harmony of the frame' and 5) 'rear legs'. Those five factors explained 57% of the variance of all exterior traits. Coefficients to calculate the five factor scores for the dataset described in the present paper, were adopted from Van Steenbergen (1989) and are given in the Appendix. In the present study both exterior factors and exterior traits are analyzed.

Variance components can be estimated by several methods (Kennedy, 1981). The choice of the method depends on structure of the dataset, computer facilities and desired properties of the estimates. Unbiasedness in variance component estimates, although a desirable property, is not of critical importance. Restricted Maximum Likelihood (REML), a biased procedure, has many other properties which are desirable, not the least of which is non-negativity of the variance component estimates (Kennedy, 1981). Increased computer capacity has enabled the use of REML on large datasets both with uni-variate and multi-variate models. The benefit of a

multi-variate model in comparison with a uni-variate model relates to the (co)variance matrix which is defined to be semi-positive definite, and to the gain in information through correlated traits. Because of the hierarchical structure of the data use of a multi-variate model implies exclusion of about 8% of the data. It was considered that the implied reduction in data did not offset the benefits of the multi-variate model. (Co)variance component estimation was therefore carried out by a multi-variate equal design REML procedure with the Expectation Maximization (EM) algorithm, as described by Meyer (1985, 1986, 1987). This procedure involves a transformation to canonical scale, changing a n-variate analysis to n uni-variate analyses, which makes calculations feasible. However, the multi-variate model could not handle a hierarchical genetic structure (e.g. full sibs nested within half sibs groups). Therefore the dataset of 3034 animals was split into two sets (I and II). Of each full sib group two animals were randomly chosen and then randomly divided over the two sets. Animals without a full sib were assigned to both sets. Each set consisted of 2093 animals of which 1394 were in both sets.
In the model, that was used to estimate (co)variances, genetic groups (sires) were based on sires and paternal grandsires. The total number of random levels was 443. The model:

$$Y_{ijkl} = \mu + ST_i + G_{j:i} + b_1(W_{ijkl} - \bar{W}) + b_2(W_{ijkl} - \bar{W})^2 + S_{k:i} + e_{ijkl}$$

included six strains (ST_i) and 179 groups nested within strains ($G_{j:i}$) as fixed effects, live weight at end of test (W_{ijkl}) linear and quadratic with regression coefficients b_1 and b_2 as covariable, sires within strain ($S_{k:i}$) as random factor and e_{ijkl} the residual error associated with Y_{ijkl}, the record of the l^{th} progeny of the k^{th} sire within strain i and judged in group j. The statistical model included weight at the end of the test to correct for the variation within strains, especially strain B3, as shown in Table 1.

Van Steenbergen (1989) found differences between inspectors for both the mean and standard deviation of exterior traits. The model used to analyze the data only accounts for differences in means, and the inspector effect is also only relevant for exterior traits. Therefore a correction for heterogeneous variances between inspectors and strains was carried out for all exterior traits as proposed by Hill (1984). Within inspector and strain, exterior scores were transformed by: $(x_{ijkl} - \bar{x}_{ijk.})/\sigma_{ijk.} + 4.5$, where x_{ijkl} is the l^{th} observation of the j^{th} inspector and the i^{th} trait within strain k, and $\sigma_{ijk.}$ and $\bar{x}_{ijk.}$ are the standard deviation and mean of the j^{th} inspector and the i^{th} trait within strain k. By this transformation exterior differences between strains are also corrected for. Because of strain differences in performance traits the strain effect was still included in the model.

(Co)variance component estimation was carried out in both dataset I and II and (co)variances were estimated simultaneously for exterior and performance traits. Starting values for variance components were obtained from uni-variate REML analyses using an EM-algorithm (Meyer, 1986, 1987) while covariances were set to zero. Iteration was stopped when the change in each of the (co)variance estimates between successive rounds was < 1%. (Co)variances of exterior factors were calculated from the (co)variances of exterior and performance traits, because factors are linear functions of the exterior traits, by the following formulae:

$$\text{var}(\Sigma_{i=1}^{n} \alpha_i \underline{x}_i) = \Sigma_{i=1}^{n} \alpha_i^2 \text{var}(\underline{x}_i) + 2\Sigma_{i=1}^{n-1}\Sigma_{j=i+1}^{n} \alpha_i\alpha_j \text{cov}(\underline{x}_i, \underline{x}_j) \quad (1)$$

$$\text{cov}(\Sigma_{i=1}^{n} \alpha_i \underline{x}_i, \Sigma_{j=1}^{n} \beta_j \underline{x}_j) = \Sigma_{i=1}^{n}\Sigma_{j=1}^{n} \alpha_i\beta_j \text{cov}(\underline{x}_i, \underline{x}_j) \quad (2)$$

$$\text{cov}(\Sigma_{i=1}^{n} \alpha_i \underline{x}_i, \underline{y}_j) = \Sigma_{i=1}^{n} \alpha_i \text{cov}(\underline{x}_i, \underline{y}_j) \quad (3)$$

where,

n = number of exterior traits (20)

$\underline{x}_i$, $\underline{x}_j$ = exterior traits i and j

$\underline{y}_j$ = exterior or performance trait j

α_i = loading of exterior trait i on a factor

β_j = loading of exterior trait j on an other factor.

Equation (1) denotes the factor variances, eqn. (2) the covariances between factors and eqn. (3) the covariances between factors and exterior/performance traits. Genetic parameters were based on (co)variance estimates averaged over both sets. Heritabilities (h^2), genetic and phenotypic correlations between traits x and y ($r_{g_{xy}}$ and $r_{p_{xy}}$ respectively) were estimated as:

$$h^2 = \frac{4\sigma_S^2}{\sigma_S^2 + \sigma_e^2}; \qquad r_{g_{xy}} = \frac{\sigma_{S_xS_y}}{\sigma_{S_x} * \sigma_{S_y}}; \qquad r_{p_{xy}} = \frac{\sigma_{p_xp_y}}{\sigma_{p_x} * \sigma_{p_y}}$$

Average standard errors of parameters for exterior and performance traits were approximated by the following formula:

$\sqrt{[(n/(2*n_{tot})) * (SE_I^2 + SE_{II}^2)]}$ where,

n is number of animals in each dataset; n_{tot} is total number of animals, and SE_I^2 and SE_{II}^2 are the squared standard errors of parameter estimates in dataset I and II. Because of common ancestry between the two datasets, the approximation is an under estimation. The standard errors calculated in each dataset are the lower bound estimates. Average standard errors of parameter estimates for exterior factors could not be approximated.

RESULTS

In Table 2, means and standard deviations for performance traits are presented. Average daily gain ranges from 852 to 992 g. The high standard deviation for ADG of strain B3 might be due to the high standard deviation of weight at end of test (Table 1) because of the group testing. Strain A has the thinnest backfat which may be related to the lowest weight at end of the test.

A significant effect of live weight (linear and quadratic) at end of test was found for the exterior traits length and width of back and loin and toe size and for the performance traits W/A, ADG and FC.

Estimates of heritability coefficients and of genetic and phenotypic correlations of performance traits are presented in Table 3. Heritability estimates range from 0.24 (DFI) to 0.37 (UB). Differences between genetic and phenotypic correlations are small.

For exterior factors parameter estimates are in Table 4. Heritability estimates range from 0.13 ('movements/longevity') to 0.39 ('size'). 'Rear legs' is genetically strongly related to 'movements/longevity'.

Heritability estimates of and correlations between exterior traits are in Table 5. The heritability estimates range from 0.01 (knottiness of rear legs) to 0.38 (width of back and loin) and all standard errors are < 0.07.

Table 2. Means and standard deviations (in parentheses) of performance traits[1] by strain.

Strain	W/A (g)	ADG (g)	DFI (kg)	FC	UB (mm)
DL	634 (39)	861 (91)	2.36 (0.20)	2.75 (0.24)	12.6 (1.7)
DY	643 (43)	878 (86)	2.25 (0.19)	2.57 (0.20)	11.1 (1.4)
A	657 (47)	915 (78)	2.17 (0.16)	2.38 (0.17)	10.4 (1.3)
B1	729 (41)	992 (65)	2.39 (0.18)	2.41 (0.15)	11.8 (1.6)
B2	679 (51)	925 (79)	2.19 (0.20)	2.33 (0.14)	13.9 (1.7)
B3[2]	651 (62)	852 (115)	---- ----	---- ----	14.0 (1.8)

[1] W/A : weight divided by age at the end of the test
ADG : average daily gain
DFI : average daily feed intake
FC : feed conversion (kg feed per kg body weight gain at the end of the test)
UB : ultrasonically measured backfat thickness
[2] No figures for DFI and FC because of group feeding.

Posture of the forelegs (traits 7-8) is less heritable than posture of the rear legs (traits 10-12). Claw characteristics have a low heritability. On average phenotypic correlations are much smaller than genetic correlations. Standard errors of phenotypic correlations are always < 0.02. Close genetic correlations are found between exterior traits referring to size (traits 2,3,5,6). Length and width are negatively correlated. Connection of shoulder blade with the body is highly correlated with regularity of back and loins (r_g=0.61 ±0.12; r_p=0.58). Body width shows negative genetic correlations with side view forelegs and positive with side view foreleg pastern; broader animals have less buckled forelegs and weaker pastern. Weak pastern forelegs are genetically related to X-shaped rear legs (r_g=-0.50 ±0.15). Bow rear legs genetically coincide with sickle hocked legs (r_g=0.60 ±0.12). Little liquid at the hock joint is genetically correlated with weak pastern of rear legs (r_g=0.53 ±0.15) and a smooth gait (r_g=0.65 ±0.17). A genetic association is found between large toes of rear legs and short hams (r_g=-0.47 ±0.19), less buckled forelegs (r_g=-0.43 ±0.24) and weak

Table 3. Heritabilities (on the diagonal) and genetic (below the diagonal) and phenotypic (above the diagonal) correlations of performance traits with standard error in parentheses.

	W/A (g)	ADG (g)	DFI (kg)	FC	UB (mm)
W/A	0.36 (0.06)	0.79 (0.01)	0.51 (0.02)	-.37 (0.02)	0.17 (0.02)
ADG	0.90 (0.04)	0.30 (0.06)	0.62 (0.01)	-.47 (0.02)	0.20 (0.02)
DFI	0.59 (0.12)	0.57 (0.12)	0.24 (0.06)	0.39 (0.02)	0.37 (0.02)
FC	-.42 (0.13)	-.58 (0.11)	0.33 (0.17)	0.31 (0.07)	0.14 (0.02)
UB	0.22 (0.13)	0.19 (0.13)	0.39 (0.15)	0.18 (0.15)	0.37 (0.07)

Table 4. Heritability estimates (diagonal) and genetic (lower triangle) and phenotypic (upper triangle) correlations of exterior factors.

	1	2	3	4	5
1. Side view legs	0.20	-.06	0.05	0.04	-.16
2. Movements/longevity	-.27	0.13	-.02	0.03	0.26
3. Size	0.16	0.11	0.39	-.20	-.03
4. Harmony of the frame	-.19	-.30	-.38	0.24	0.06
5. Rear legs	0.22	0.51	0.21	-.04	0.21

rear pastern (r_g=0.41 ±0.16). Uneven sized claws coincide with small toes (r_g=0.61 ±0.19; r_p=0.53). Much swinging of the back coincides with bow rear legs (r_g=0.54 ±0.16), sickle hocked rear legs (r_g=0.52 ±0.17) and a sluggish gait (r_g=-0.43 ±0.19; r_p=-0.40). A long lifetime expectation coincides with straight and steep rear legs (r_g=-0.56 ±0.15 and -0.49 ±0.17), weak rear pastern (r_g=0.57 ±0.15), large toe size (r_g=0.53 ±0.17; r_p=0.42), smooth gait (r_g=0.46 ±0.16; r_p=0.73) and little swinging of the back (r_g=-0.51 ±0.17; r_p=-0.50). Correlations between performance traits and exterior factors and traits are presented in Table 6.

Table 5. Heritability estimates (*100) on the diagonal and genetic (lower triangle) and phenotypic (upper triangle) correlations (*100) for exterior traits.

Exterior traits	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Shoulder blade	15	15	4	**58**	11	-9	-2	-6	1	4	-10	-1	8	13	9	10	12	**25**	-18	27
Back and loin																				
2. Length	8	28	**-22**	18	**27**	**-24**	4	9	-7	8	1	5	-2	4	-6	-1	-1	1	10	-2
3. Width	9	**-47**	38	13	13	**52**	1	-5	8	-11	3	0	3	-4	6	2	5	-3	-1	2
4. Regularity	**61**	21	14	30	16	-7	0	-5	-1	3	-12	-4	7	12	11	11	13	**22**	**-21**	**29**
Hams																				
5. Length	7	35	-32	11	6	11	1	2	2	-5	2	4	6	-2	2	5	7	2	1	4
6. Width	-11	**-56**	**84**	-15	-36	36	-5	1	12	-15	14	4	2	-15	-5	-1	2	-11	10	-13
Forelegs																				
7. Front view legs	29	-13	-13	3	37	-33	6	-13	1	15	-4	2	-1	3	3	1	-1	4	-4	4
8. Side view legs	29	39	-39	17	**61**	**-57**	**72**	6	-2	4	9	1	-7	-9	-7	-6	-3	-17	9	**-21**
9. Side view pastern	-7	-3	39	-25	7	**53**	-13	-20	31	-5	8	14	**23**	1	1	5	15	11	-2	8
Rear legs																				
10. Rear view legs	24	-15	-19	8	-30	-34	31	29	**-50**	22	2	7	-11	2	-6	-6	-5	-5	3	-7
11. Side view legs	-16	16	10	-18	-9	13	**-45**	-13	12	-9	23	**35**	6	-15	-18	-6	-2	**-26**	**26**	**-30**
12. Side view hock joint	-19	26	-23	-27	-5	-26	-32	1	-10	0	**60**	24	**21**	-9	-14	-6	7	0	13	-7
13. Side view pastern	-1	2	-25	-24	-5	5	-26	-32	24	-29	-8	14	30	9	6	7	**32**	**24**	-11	**31**
14. Liquid at hock joint	17	-25	-12	-7	-25	-5	1	-18	-10	14	-15	22	**53**	9	**33**	12	9	**32**	**-20**	**34**
15. Knottiness of legs	38	**-42**	28	10	-21	18	22	-28	-3	2	-39	-33	-4	14	1	14	9	**25**	**-22**	**29**
Claws rear leg																				
16. Ratio size of claws	-27	-4	-19	-20	1	-12	0	-2	25	6	-1	15	28	-15	-24	9	**53**	**24**	-16	**35**
17. Toe size	-13	-17	7	-18	**-47**	19	-23	**-43**	29	13	-9	-4	**41**	-3	16	**61**	15	**31**	-18	**42**
18. Gait; movements	7	-34	12	-5	-25	29	-16	-37	-12	-3	-39	-14	39	**65**	38	-39	-5	13	**-40**	**73**
19. Swinging of back	-4	11	21	-5	24	7	-19	3	16	-23	**54**	**52**	-10	-35	-12	30	1	**-43**	13	**-50**
20. Lifetime expectation	0	-27	3	-7	-25	21	10	-25	6	6	**-56**	**-49**	**57**	31	22	24	**53**	**46**	**-51**	16

Table 6. Genetic and phenotypic correlations (*100) between exterior and performance traits.

	Genetic correlations					Phenotypic correlations				
	W/A	ADG	DFI	FC	UB	W/A	ADG	DFI	FC	UB
Exterior factors										
1. Side view legs	-4	-10	4	11	-4	0	-1	1	3	4
2. Movements/longevity	-9	-13	-1	8	6	-5	-5	-3	3	10
3. Size	39	48	10	-55	12	17	17	12	-8	4
4. Harmony of the frame	7	9	30	25	49	-6	-4	0	6	8
5. Rear legs	-23	-24	0	28	33	-6	-6	-1	6	10
Exterior traits										
1. Shoulder blade	12	24	27	5	51	-7	-5	0	7	9
Back and loin										
2. Length	23	5	11	3	3	0	-3	-2	2	-18
3. Width	29	41	21	-29	26	18	18	15	-6	14
4. Regularity	28	29	37	6	47	-2	1	3	2	11
Hams										
5. Length	40	41	0	-55	5	1	1	0	-3	-6
6. Width	24	34	6	-39	5	16	16	11	-9	-1
Forelegs										
7. Front view legs	6	13	34	21	10	-1	-3	-1	1	-1
8. Side view legs	11	14	30	23	8	5	5	4	-3	-2
9. Side view pastern	44	41	39	-15	14	4	2	2	0	6
Rear legs										
10. Rear view legs	-29	-26	27	71	4	-3	-3	-3	2	-4
11. Side view legs	8	3	-3	-8	-16	4	3	1	-2	-5
12. Side view hock joint	-46	-53	-33	23	-23	-3	-2	-1	2	-1
13. Side view pastern	-13	-18	-11	3	6	-7	-7	-2	5	7
14. Liquid at hock joint	-46	-51	-15	37	38	-8	-8	-2	7	6
15. Knottiness of legs	-3	3	13	18	7	-2	-1	0	1	11
Claws rear leg										
16. Ratio size of claws	3	-6	-28	-21	-25	0	-1	1	3	-2
17. Toe size	-3	-6	5	6	-24	-3	-3	-2	2	-2
18. Gait; movements	-32	-35	-7	23	26	-8	-7	-5	4	8
19. Swinging of back	9	12	-13	-29	-11	0	1	0	-2	-10
20. Lifetime expectation	3	-2	6	5	11	-5	-4	-3	2	10

W/A and ADG have similar correlations with exterior, which is not surprising because of the high correlations between both performance traits (Table 3). Genetic correlations are found between daily gain (W/A and ADG) and exterior factor 'size' (r_g=0.39 and 0.48), FC and 'size' (r_g=-0.55), and between UB and 'harmony of frame' (r_g=0.49). Genetic correlations are also found between daily gain (W/A and ADG) and the exterior traits side view foreleg pastern (r_g=0.44 ±0.12 and r_g=0.41 ±0.13), side view of hock joint (r_g=-0.46 ±0.14 and r_g=-0.53 ±0.15) and dryness of hock joint (r_g=-0.46 ±0.16 and r_g=-0.51 ±0.16). Slower growing animals have steeper foreleg pastern, less liquid at the hock joint and more sickle hocked rear legs. Genetic correlations of length and width with daily gain indicate that faster growing animals are more likely to have a broad back and loins and broad and long hams at the same weight. A high genetic correlation is found between FC and rear view rear legs (r_g=0.71 ±0.15); boars with better FC have more O-shaped rear legs. Animals with loose shoulder blades and irregular back and loins have thinner backfat. Low correlations between performance traits and lifetime expectation were found.

Correlations between exterior factors and traits are presented in Table 7. Phenotypic correlations are in harmony with the regression coefficients for the exterior factors (Appendix). High genetic correlations are mostly associated with high phenotypic correlations. Exterior factor 'movements/-longevity' also has high genetic correlations with side view rear legs and side view hock joint. 'Size' is in addition to length and width, genetically also correlated with side view foreleg, side view foreleg pastern and rear view rear legs. The factor 'rear legs' has genetic correlations with length, rear legs, gait and lifetime expectation.

DISCUSSION

Heritability estimates of linearly scored exterior traits are in the same range as estimates of linearly scored exterior traits in dairy cattle (Thompson et al., 1983; Diers and Swalve, 1987). Effective selection on most of the linearly scored exterior traits will be possible.

Genetic parameters of performance traits are in good agreement with Sönnichsen et al. (1984a,b). Heritability estimates of performance traits are some higher than those reported by Johansson et al. (1985) and Merks (1987). Those literature estimates were based on data obtained under a restricted feeding regime which could be an explanation for the lower estimates. Genetic correlation between average daily gain and feed conversion (-0.58) is lower than that reported by Johansson et al. (1985) and Merks (1987), -0.98 and -1.0, respectively. This might also be caused by the difference in feeding regime.

High genetic correlations (Table 6) of some exterior factors and traits with performance traits indicate that selection on performance will also change the animal's exterior and vice versa. Low genetic correlations indicate that no linear genetic relationship exists between traits; however non-linear relationships might still be possible, especially for traits where both low and high scores are indications of pathological disorders. Most leg traits are defined such that both high and low scores are thought to be undesirable. Therefore if large genetic correlations between leg and performance traits exist, then the sign of the correlation and the population

Table 7. Genetic and phenotypic correlations (*100) between exterior traits and exterior factors[1].

	Genetic correlations					Phenotypic correlations				
Exterior traits	1	2	3	4	5	1	2	3	4	5
1. Shoulder blade	-7	-6	-10	78	26	5	24	-7	77	18
Back and loin										
2. Length	11	-29	-47	36	-49	-8	-11	-21	36	-5
3. Width	4	-6	87	-8	22	7	-1	74	4	4
4. Regularity	-33	-9	-7	83	1	0	24	1	78	19
Hams										
5. Length	-12	-24	-14	13	-45	-9	-1	42	21	-3
6. Width	18	18	94	-39	26	11	-13	81	-21	-10
Forelegs										
7. Front view legs	-41	5	-23	13	-7	6	4	-2	2	-2
8. Side view legs	-22	-31	-48	38	-48	9	-19	-9	-12	-23
9. Side view pastern	52	5	65	-42	22	53	10	24	-10	11
Rear legs										
10. Rear view legs	-23	-4	-51	30	12	7	-21	-38	25	3
11. Side view legs	68	-70	7	0	-30	61	-38	5	-1	-26
12. Side view hock	67	-52	-29	2	-6	70	-10	-4	12	-20
13. Side view pastern	51	55	2	-23	52	55	31	8	2	13
14. Liquid in hock	21	37	-15	13	71	-12	17	-10	25	80
15. Knottiness of legs	-30	29	20	7	50	-16	19	-4	14	75
Claws rear leg										
16. Ratio size of claws	33	11	-5	-39	19	1	45	8	-14	33
17. Toe size	31	42	16	-39	50	22	52	14	-15	26
18. Gait; movements	-17	63	15	-3	51	-4	79	-6	15	33
19. Swinging of back	46	-68	20	-3	-18	9	-69	11	-16	-19
20. Lifetime expectation	-16	91	15	-25	51	-4	86	-2	19	40

[1] 1– Side view legs; 2– Movements/longevity; 3– Size
4– Harmony of the frame; 5– Rear legs

mean of the leg trait determine whether the short term response will result in a desirable or an undesirable change of the leg trait. On the long term, when correlations will continue to be stable, the correlated response will always be undesirable and therefore attention has to be paid to that trait (e.g. independent culling or restricted selection index).

When selection is based on an own performance index with average daily gain, daily feed intake and backfat thickness as index and breeding goal traits (genetic and phenotypic parameters from this study and economic values for average daily gain, daily feed intake and backfat thickness from Knap et al. (1985)), then several exterior traits will change considerably as can be seen in Table 8. Boars will grow broader at 105 kg, the rear view rear legs will change to more O-shape, the side view of the hock joint will become more steep, more liquid will be present at the joint and the gait pattern will slow down.

In the material analyzed in this study no overall leg weakness score as such was given. Relationships of leg weakness with exterior traits and performance therefore could not be estimated. In literature, however, gait pattern usually is a major element in the determination of the leg weakness score (Grøndalen, 1974; Lundeheim, 1987). When considering leg weakness and gait (movements) score to be analogous, it can be concluded (Table 6) that selection against leg weakness will influence growth, feed conversion and backfat thickness in an undesirable direction. The antagonistic relationship between leg weakness and growth is in agreement with Lundeheim (1987). However, Bereskin (1979) and Sather and Fredeen (1982) found the association to be beneficial. The genetic correlation between leg weakness and UB agrees with literature (e.g. Webb et al., 1983; Lundeheim, 1987; Rothschild et al., 1988).

Total genetic response and genetic change in gait (movements) have been calculated in a situation with two-stage index selection. In the first stage boars are selected on gait pattern only. In the second stage boars are selected on an index with ADG, DFI, UB and gait pattern as index and breeding goal traits. Calculations are based on parameters from this study while economic values of performance traits are adopted from Knap et al. (1985). Economic value of gait (movements) is set to zero. Genetic change in gait pattern and total genetic response is calculated for varying fractions of boars selected in the first stage while total selected fraction after two stages was kept constant at 0.05 and is presented in Figure 1. In the present Dutch herdbook situation approximately 50% of all tested boars are rejected for breeding because of leg weakness. It can be seen from Figure 1 that in that situation gait pattern will change in an undesired direction and total genetic response will be 76% of what will be achieved when selection occurs only in the second stage. When rejecting 63% of the boars in the first stage then gait pattern will not change and total genetic response will be 64% of what will be achieved when selection occurs only in the second stage. When boars are selected only in the first stage then total response will be negative.

Table 8. Genetic change in exterior traits when selecting for performance.

Exterior traits	$b_{Y_i,index}$[1]	δG_{Yi}[2]
1. Shoulder blade	.0038	.0140
Back and loin		
2. Length	-.0014	-.0052
3. Width	.0316	.1168
4. Regularity	.0049	.0181
Hams		
5. Length	.0187	.0691
6. Width	.0341	.1260
Forelegs		
7. Front view legs	-.0032	-.0118
8. Side view legs	-.0017	-.0063
9. Side view pastern	.0187	.0691
Rear legs		
10. Rear view legs	-.0366	-.1352
11. Side view legs	.0052	.0192
12. Side view hock joint	-.0301	-.1112
13. Side view pastern	-.0125	-.0462
14. Liquid at hock joint	-.0254	-.0938
15. Knottiness of legs	-.0009	-.0033
Claws rear leg		
16. Ratio size of claws	.0065	.0240
17. Toe size	-.0053	-.0196
18. Gait; movements	-.0222	-.0820
19. Swinging of back	.0136	.0502
20. Lifetime expectation	-.0046	-.0170

[1] regression of exterior trait Y_i on index

[2] change in exterior trait Y_i as a result of one round of selection (selection intensity: 1) on the index

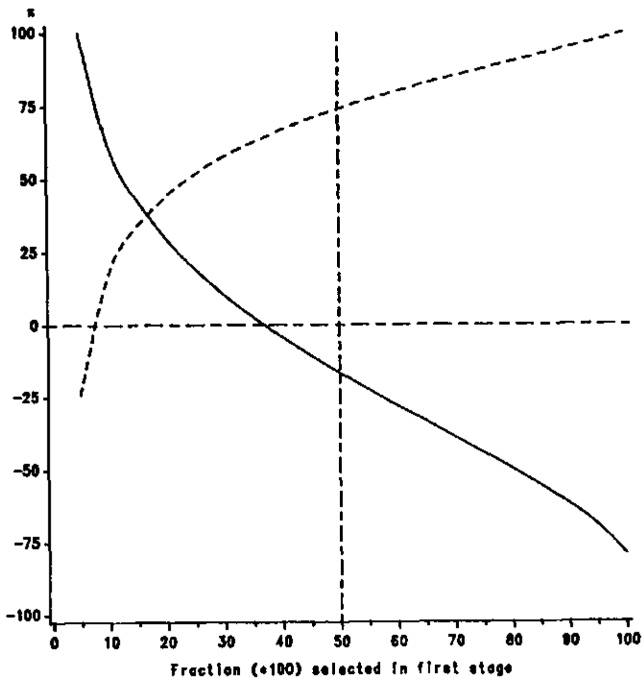

Figure 1. Genetic change in gait (——) and total response (----) from a two stage selection index with varying fractions selected in the first stage and a total selected fraction of 0.05.

When selection decisions have to be made, it is difficult to use information of a large number of separate exterior traits. Combining information on all judged exterior traits into a few factors can be an aid in handling that problem. In this study moderate heritability estimates were found for five analyzed exterior factors, which indicates the possibility of effective selection for exterior by those factors. However, relationships between exterior factors and performance traits are more difficult to interpret. Reduction of the number of exterior traits on which a selection decision has to be based can also be achieved by judging just a few relevant exterior traits. The choice which exterior traits have to be judged must be based on their economic value and heritability. However, no information is available in literature about the economic values of exterior traits. The economic values depend among others on the relationship with sow productivity and longevity, which is subject of study in two subsequent chapters.

ACKNOWLEDGEMENT

Part of the costs of this study were covered by financial support from the Dutch Commodity Board for Livestock and Meat.

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Appendix. Description of 20 linearly scored exterior traits and standardized regression coefficients for five factors[1].

	Score 0	4½	9	Factors[1] 1	2	3	4	5
1. Shoulder blade	loose		solid	0.06	0.01	-.04	0.43	0.03
Back and loin								
2. Length	short		long	-.05	-.06	-.06	0.15	-.02
3. Width	narrow		broad	0.02	-.02	0.37	0.05	0.01
4. Regularity	irregular		regular	0.03	-.01	-.01	0.43	0.04
Hams								
5. Length	short		long	-.11	-.03	0.29	0.07	-.04
6. Width	narrow		broad	-.01	-.05	0.45	-.08	0.00
Forelegs								
7. Front view legs	O-shaped		X-shaped	0.06	0.02	0.02	-.03	-.07
8. Side view legs	sickled	straight	buckled	0.07	-.01	-.07	-.09	-.14
9. Side view pastern	steep angle		low angle	0.28	0.00	0.11	-.06	0.08
Rear legs								
10. Rear view legs	O-shaped		X-shaped	0.05	-.15	-.20	0.16	0.07
11. Side view legs	straight		bow leg	0.32	-.11	-.05	0.09	-.08
12. Side view hock joint	steep		sickle hocked	0.33	-.01	-.07	0.12	-.06
13. Side view pastern	steep angle		low angle	0.30	0.03	-.01	-.00	0.03
14. Liquid at hock joint	much		little	-.03	-.15	0.03	0.14	0.54
15. Knottiness of legs	≥ 12 cm^2	6 cm^2	0 cm^2	-.04	-.08	-.07	0.07	0.47
Claws rear leg								
16. Ratio size of claws	≤ 1/2	3/4	≥ 1	0.02	0.12	0.01	-.14	0.13
17. Toe size	small		large	0.03	0.14	0.08	-.20	0.11
18. Gait; movements	slow (stiff)		easy, quick	-.06	0.33	-.02	-.06	-.04
19. Swinging of back	nil		much	-.03	-.32	0.08	-.04	0.09
20. Lifetime expectation	short		long	-.01	0.34	-.01	0.05	-.05

[1] See text for description

Chapter 4

EXTERIOR IN SOWS: 1. EFFECT OF PARITY NUMBER AND ASSOCIATION WITH REASONS FOR DISPOSAL

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Submitted for publication in Livestock Production Science.

ABSTRACT

Over a two-year period, several thousand gilts between 7 and 9 months of age and sows from weaning till about 30 days post weaning, were repeatedly judged for exterior on 24 commercial multiplier herds. A total of 20 linearly scored exterior traits (especially those concerning legs) were considered. Exterior traits of gilts and sows were described and association of exterior with reasons for disposal was investigated.

Length of the animals increased until 6th parity whereas width increased over the 10 parities. Pasterns of fore- and rear legs became weaker after 5th parity. The development of size traits, length of back, loins and hams, and toe size indicated that maturity was probably reached at 6th parity.

Principal component analysis was used to indicate relationships between exterior traits and to mark the relevant exterior variables in relation to reasons for disposal. Some exterior traits of gilts, showed a significant relationship with reasons for disposal, especially leg weakness. Sows culled because of leg weakness before 4th parity were longer and broader as gilts, had less straight rear legs and more tubercles at the rear legs, they walked slower and twisted more with the hind quarters compared to sows that had produced at least four litters. Sows culled before fourth parity because of leg weakness, had a lower score for lifetime expectation (number of litters expected still to be produced) at a age of 7-9 months than sows that produced $\geq$ 4 litters.

INTRODUCTION

In the literature, studies on exterior in pigs have been concentrated on body size and bone characteristics of fore- and rear legs (e.g., Hetzer and Miller, 1972; Grøndalen, 1974; Van der Wal et al., 1987). The relevance of exterior traits in pigs depends on their relationship with involuntary culling and on their predictive value for other economically important traits. Involuntary culling reflects problems, e.g., leg weakness, diseases, and infertility, that are manifested in premature disposal. Advantages of decreased involuntary culling are: (1) reduction in annual cost of replacement, (2) increase of average number of piglets per litter because of decreasing number of first parity sows, (3) reduction in number of non-productive days, and (4) increased opportunities for selection on other traits. In commercial herds, exterior of sows is mainly used to predict the risk for involuntary culling. Relationships between exterior traits in pigs and involuntary culling were not found in literature. In dairy cattle, Rogers and McDaniel (1989) mentioned consistent relationships of the type traits, udder depth, teat placement, and foot angle, with culling.

The objective of this study was, to characterize exterior of an animal, to describe the change in exterior traits with parity number, and to estimate relationships between exterior and reasons for disposal.

MATERIAL

In 1985 and 1986, gilts and sows were judged for exterior at 24 commercial multiplier herds with 100-200 sows. Farms participating in the project obtained feed from the same company, and sow information was registered by a computer Sow Management System, supplied by this feed company. Farms were visited regularly by the extension service of the feed company. Therefore differences between farms due to feed and/or feeding regime were assumed not to be relevant.

A total of eleven inspectors of the Dutch herdbook and three breeding companies rotated over the farms to score exterior of the animals. In total, 20 exterior traits (Appendix) were scored on a linear scale (Van Steenbergen, 1989). Farms were visited monthly by an inspector who judged all gilts of about 7-9 months of age and all sows from weaning (on average 28 days after farrowing) till about 30 days post weaning. So most of the gilts were judged twice by different inspectors and most of the sows were judged once after each weaning of the piglets. Over a period of two years 6333 animals were judged once or more. Combining exterior information with sow productivity information reduced the number of animals with both exterior and production records to 5804. Data were further checked for following criteria: i. gilts had to be judged between 150 and 300 days of age and ii. sows had to be judged between weaning and 40 days post weaning, while the parity number was restricted to a maximum of 10. After this screening, data included 5660 animals on which 16456 judgements were made.

The distribution of number of judgements per animal in relation to parity number of first judgement is shown in Table 1. Of all judgements, 91% was before parity 6; approximately 2% of the judgements made after weaning were repeated appraisals in the same parity; 50% of the animals (2906) were judged between 150 and 300 days of age.

Table 1. Distribution of animals over number of judgements per animal and the parity number when first judged.

Parity number	Number of judgements per animal					
when first judged	1	2	3	4	≥5	Total
0	183	697	918	620	488	2906
1	165	110	124	171	132	702
2	134	136	141	148	89	648
3	95	96	128	75	20	414
4	96	138	87	36	25	382
≥5	259	235	71	35	8	608

The distribution over strains is in Table 2. One third of the sows were crossbred from Dutch Yorkshire boar and Dutch Landrace sow. On most farms, animals were mainly from one strain.

Table 2. Distribution of animals over strains.

Strain	%
Dutch Landrace (DL)	10
Dutch Yorkshire (DY)	3
DL * DY	10
DY * DL	32
Duroc * DL	11
Hypor[1]	15
Other	19

[1] :Commercial crossbred sow.

During the experiment over 70% of the animals were culled for various reasons. Farmers could record only the main culling reason out of eight reasons indicated by the sow management system. During one and a half year a form was send to the farmers on which they could record: (1) culling reasons in more detail and (2) a second and third culling reason in order of relevance.

METHODS

Exterior scores were transformed to a logit scale (Bliss, 1970) to overcome two undesired aspects of the scoring system:

(1) Exterior traits have been scored on a linear scale from zero to nine with 0.5 intervals. When scoring has not taken place at all parities, extrapolation might result in the undesirable situation that scores on the scale of 0 to 9 can fall outside the limits.

(2) Although the scale is defined linearly, it is expected, because of limiting the scale within the range of 0 to 9, that inspectors will not use equidistant steps over the whole scale. For example steps in exterior scores from 1 to 0 and from 8 to 9 are expected to be larger than a step from 4 to 5.

The general logit definition is: Logit $Y = y' = \ln [Y / (Y_u - Y)]$ with lower limit of zero and upper limit Y_u. When changing the formula to: $y' = \ln [(Y + b) / (Y_u + b - Y)]$ where b is a constant (b>0), all scores including 0 and 9 can be transformed to logit scale. The logit transformation was performed on all exterior scores with b arbitrary set to 0.1. Back transformation to original scale can be done by:

$$Y = \frac{Y_u}{1 + e^{-y'}} - b\frac{1 - e^{y'}}{1 + e^{y'}}$$

Effect of parity on exterior traits was analyzed with the following model, using the LSML76 program of Harvey (1977):

$$y'_{ijkmn} = \mu + HS_i + \underline{A}_{ij} + I_k + P_m + \underline{e}_{ijkmn} \qquad (1)$$

where,

y'_{ijkmn} = logit of the score for an exterior trait

μ = mean logit score

HS_i = fixed effect of herd-strain group i (i=1,...,74)

$\underline{A}_{ij}$ = random effect of animal j within herd-strain i

I_k = fixed effect of inspector k (k=1,...,11)

P_m = fixed effect of parity m (m=0,...,10)

$\underline{e}_{ijkmn}$ = random error term

Least squares means for parity number were used to evaluate relationships between exterior traits and parity number.

In order to simplify analysis and interpretation of exterior traits from different parities, an attempt was made to combine all information per animal. Information from gilts (judged at 150-300 days of age), however, was not combined with information obtained on the same animals as sows (judged from 0 to ~30 days post weaning) because of differences in housing, feeding and condition. Because of the significant effect of inspectors and herd-strain groups on logit scores, all scores were corrected for inspector and herd-strain by least squares constants estimated with model 1. For gilts with two or more records, corrected scores were averaged per trait.

Preliminary analyses showed a significant effect of parity number on scores of most exterior traits. Exterior scores were corrected for the effect of parity number and expressed as deviation from the parity mean (DM). Parity means for the exterior traits were estimated per exterior trait by a second degree polynomial fitted to the parity least squares means (model 1), weighted by their effective numbers. When two or more judgements were made on a sow, DM was averaged per trait. For sows with repeated judgements, the deviation of the linear regression on parity number (DLR) of each of the exterior traits, from the average linear regression was estimated. Orthogonal polynomials (OP) were used to estimated both DM and DLR. OP's were fitted to the corrected logit scores with the IMSL routine RLFOTW (IMSL, 1984), with weighing coefficient 1 for parities with an observation and 0 for parities with no observations. DLR was estimated when a sow had been judged more than two times and otherwise set to zero.

This resulted in a total of 60 exterior variables divided into 3 groups of 20 exterior traits each. The first group consisted of traits that referred to exterior judged at gilt stage (GE), whereas the second (DM) and third (DLR) group referred to exterior traits judged on sows. DM manifested the deviation from the overall average level and DLR indicated the deviation from the overall linear regression of the exterior least squares means on parity number.

The derivation of the 60 exterior variables from the original exterior scores is summarized in Figure 1.

Principal component analysis was used to reduce the large number of variables to a smaller set of independent factors in which the variables were grouped, and to study the relationships between the 60 variables. Principal component analysis is a three step procedure: (1) the computation of the correlation matrix, (2) the extraction of the initial orthogonal factors, and (3) the rotation to a terminal solution. Initial orthogonal factors composed of combinations of traits, based on the correlation structure between those traits. The contribution of a trait to a factor can be changed by factor rotation. When rotating factors, a discrimination between traits is sought, where only a few highly correlated traits make a large contribution to the factor, and the remaining traits contribute only marginally. This simplifies the interpretation of a factor. The number of factors to retain is arbitrary, but is based mostly on their eigenvalue, i.e., the variance explained by each factor. For GE traits, 2754 animals had missing values because they were not judged at age of 7-9 months. To analyze data of all 5660 animals together, least squares means for the animal's herd-strain group were allotted to missing values. In this study factors were extracted with principal component analysis by the FACTOR procedure of SAS (SAS Institute Inc., 1985). Orthogonal rotation was done by the VARIMAX option.

Resulting factors were related to culling reasons. By combining some culling reasons mentioned in Table 3, the following five reasons were considered: (1) leg weakness, (2) udder problems, (3) productivity, (4) reproduction failures and (5) unknown. It was assumed that sows that had produced at least four litters could be classified as animals that had a satisfactory constitution. Factor scores of these animals were compared with scores of animals culled (for various reasons) before 4th parity. Linear contrasts between non-culled animals and those culled for various reasons were estimated by the GLM procedure of SAS (SAS Institute Inc., 1985) with the following model:

$$Y_{ijk} = \mu + HS_i + CR_j + \underline{e}_{ijk} \qquad (2)$$

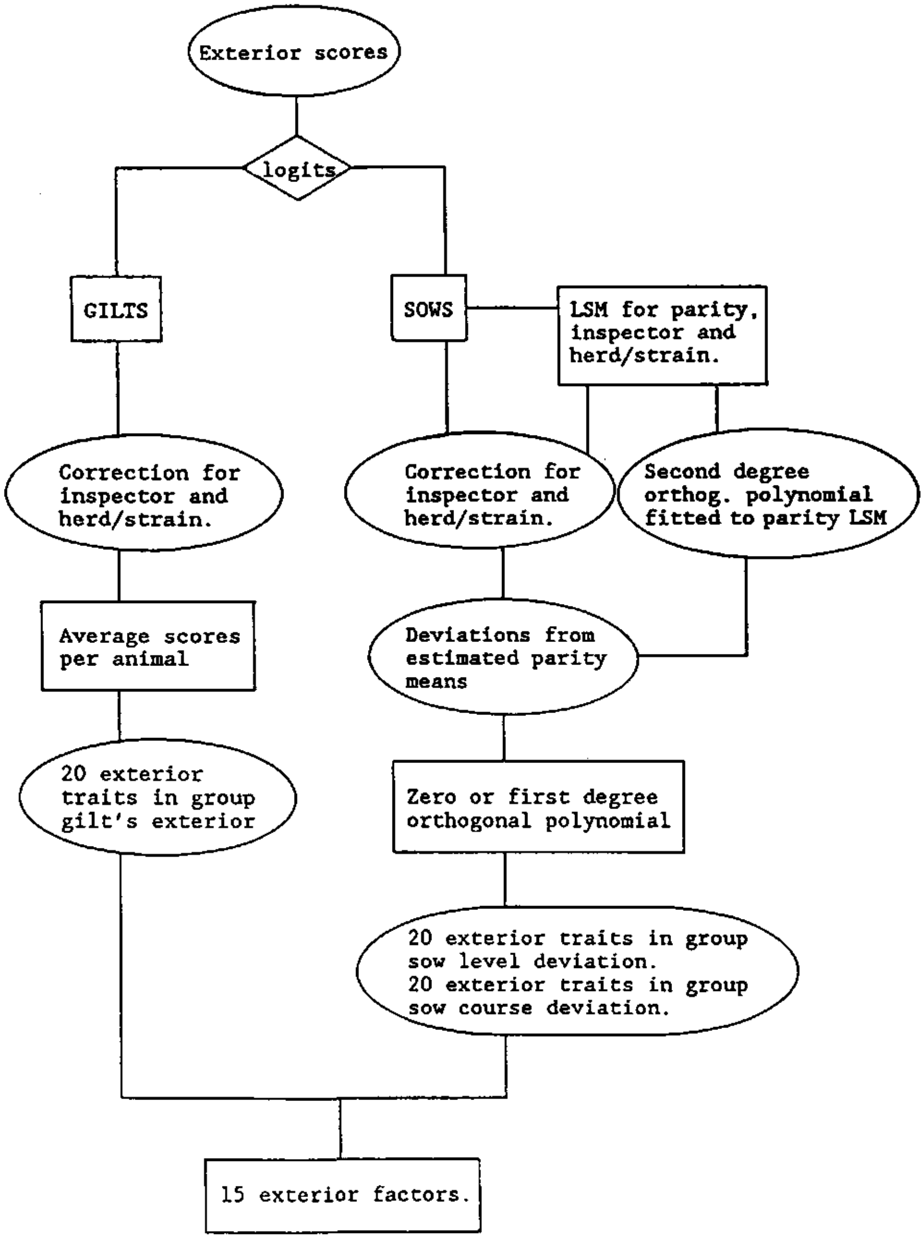

Figure 1. Scheme of transformation of exterior scores to final exterior variables (see text for explanation).

where, Y_{ijk} is an exterior factor score, μ the overall mean, HS_i the herd-strain group i (i=1,..,74), CR_j the culling reason j (j=1,...,6; not culled or culled for various reasons), and $\underline{e}_{ijk}$ the random error term. An exterior indication for risk on premature disposal, obtained at an early age, can be an interesting tool to decrease premature disposal. Exterior traits judged at gilt stage were therefore also studied with model 2.

RESULTS

Distribution of animals over culling reasons as reported in the sow management system is given in Table 3. Almost one third of the animals was culled because of unsatisfactory production results (litter size) and 23% because of fertility problems. Leg weakness was the culling reason for 11% of the disposed sows, which is in close agreement with figures reviewed by Pattison (1980). Detailed reasons for disposal were available for 898 sows. A major and a minor culling reason were given for 25% of the sows and three culling reasons were given for 3%. In Table 3 frequency distribution over the first mentioned culling reasons is given. When leg weakness could be recorded in more detail, a larger portion of the animals (8% more) were culled because of that reason, compared to a similar reason in the sow management system. Twenty five of the 131 animals (19%) disposed because of leg and claw disorders had a second culling reason which referred to productivity or reproduction failure. A detailed recording of culling reasons does not seem to increase the reliability of the information.

Combined distribution of all exterior scores is in Figure 2. There was preference for 'whole' scores, which was found also in another experiment by Van Steenbergen (1989). Standard deviations of the 20 exterior traits are similar with results found in boars (Van Steenbergen et al., 1990).

With model (1), 47 to 64% of the total variance in logit exterior scores was explained, whereas the variance explained by parity number ranged from 0 to 5%. An effect of parity number was found for all traits ($P<0.01$), except side view rear legs. Of all exterior traits, the second degree polynomial, fitted to the parity least squares means of parity 1 to 10 is presented graphically in Figure 3. The average gilt scores are also indicated in that figure. Back, loin, and hams of gilts are broader than those of sows after the first weaning. There is also an increase in both

Table 3. Distribution of disposed animals over culling reasons.

Reasons reported by the Sow Management System.

Number	%	Reason
311	8	Anoestrus
613	15	Failure to conceive or to maintain pregnancy
452	11	Leg weakness
229	6	Udder problems
192	5	Vitality
1193	30	Productivity (mainly litter size)
323	8	Disease
677	17	Unknown

First (main) culling reasons of detailed reporting.

Number	%	Reason
14	2	Forelegs
131	15	Rear legs
17	2	Claws
65	7	Udder
72	8	Old age
198	22	Productivity (mainly litter size)
40	4	Abortion
81	9	Anoestrus
157	17	Failure to breed after two matings
50	6	Disease / inflammation
83	9	Other reasons

length and width after first weaning. Front view forelegs and side view pastern of both fore- and rear legs showed a curvilinear trend with parity. From side view forelegs, an increase in buckled knees after third parity can be noticed. After 5th parity, rear legs showed a tendency to be less sickle hocked. Quantity of liquid at the hock joint (swelling) decreased with age whereas knottiness of rear legs increased with age. Size ratio of claws and toe size showed an increase till 5th parity, and stabilized thereafter. After a stable gait pattern from first to fifth parity, gait slowed down. Lifetime expectation scores show a linear decrease with parity number, as expected, because of the definition of the trait (expected number of litters still to be produced).

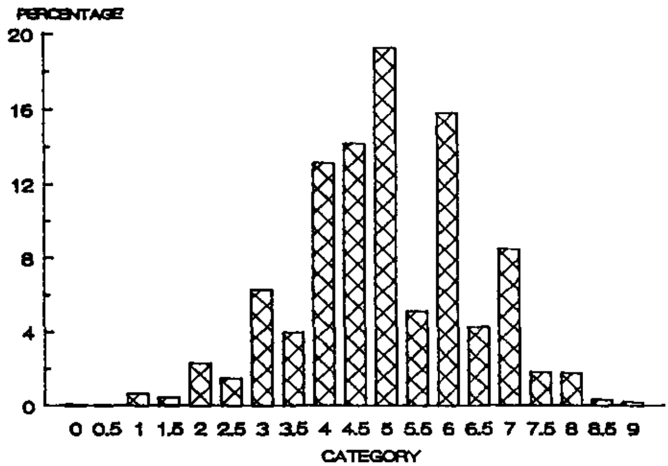

Figure 2. Overall distribution of exterior scores.

A factor analysis was performed on the 60 exterior variables. Twenty factors had an eigenvalue >1, which jointly explained 61% of the total exterior variance. After rotation of those 20 factors, eigenvalues of the factors and correlation with the exterior variables were examined. After a gradual decrease of the eigenvalues of factor 1 to 15, a markedly stronger decrease was noticed from factor 15 to factor 16. This was the main reason to restrict further analyses to factor 1 to 15. Those 15 factors explained 51% of the total variance. For each factor, the variables with a correlation with the factor greater than 0.50, are in Table 4.

Deviation between exterior factor scores of non-culled animals and animals culled for various reasons (contrast estimates) are in Table 5. A significant effect of exterior on culling for leg weakness is found for factors 1, 2, 4, and 13. Those factors refer to exterior of gilts, particularly their width, rear legs and claws, locomotion and lifetime expectation score; and to exterior of sows, the deviation of the average (DM group) for side view rear legs, gait, swinging of the back and lifetime expectation score. Exterior of animals culled for reproduction failures

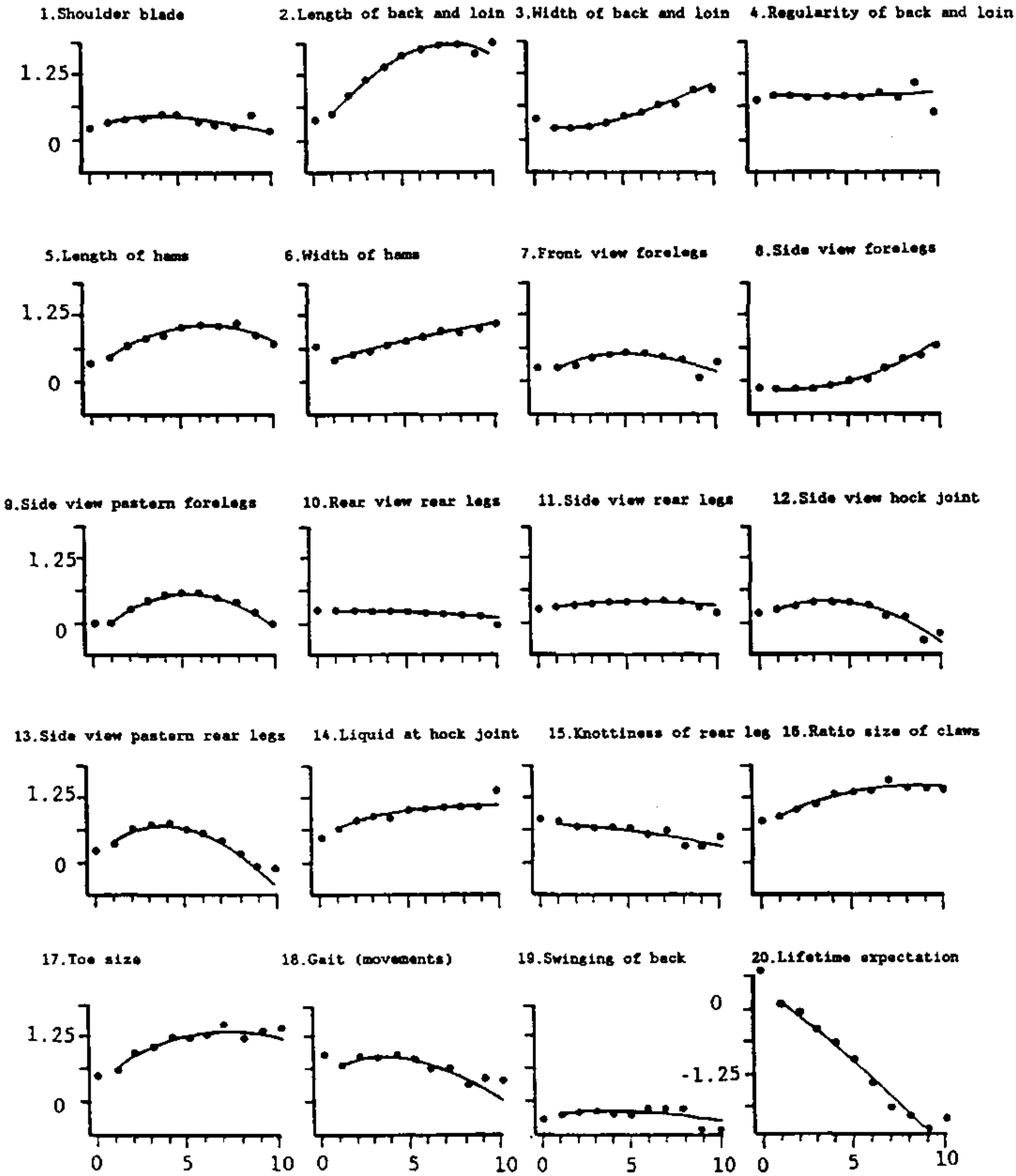

Figure 3. Least squares means of exterior traits by parity number and the fit of a 2nd degree polynomial (logit exterior score on the vertical axis and parity number on the horizontal axis).

Table 4. Traits with an absolute loading on the factors greater than 0.50.

	Exterior traits[1]		
Factor	Exterior of gilts	Level deviation	Course deviation
1	14 to 20	....	....
2	....	11, 18 to 20	....
3	....	....	18 to 20
4	3 and 6	....	....
5	1, 2, 4 and 5	....	....
6	....	....	1, 2, 4 and 5
7	....	9, 11 to 13	....
8	....	....	16 and 17
9	....	3 and 6	....
10	....	16 and 17	....
11	....	1 and 4	....
12	....	....	11 to 13
13	11 and 12	....	....
14	....	....	3 and 6
15	9 and 13	....	....

[1] :See Appendix for explanation of the trait numbers.

before 4th parity and animals that had produced at least four litters did not show differences. An association between exterior and disposal because of udder problems is indicated by the first factor e.g. hind quarter characteristics at gilt stage. Analysis of exterior traits judged at gilt stage was based only on data of animals that were judged as gilts (Table 6). Most interesting traits are: length of back and loins (2), width of hams (6), side view rear legs (11), knottiness of rear legs (15), gait (movements) (18), swinging of the back (19) and the lifetime expectation score (20). For those traits, differences between culled for leg weakness and non-culled animals vary from 0.15 to 0.35, which is about 35% of the standard deviation of the logit exterior scores. Sows that had produced at least four litters possessed, as gilts, smaller hams, more straight legs and fewer tubercles at the rear legs. They could walk easier and quicker, twisted less with the back, and were expected to produce more litters in comparison to sows that had been culled because of leg weakness before 4th parity.

Table 5. Linear contrasts[1] of exterior factors, of animals that produced ≥ 4 litters (H) and animals culled before 4th parity for various reasons (L).

	Culling reasons				
Factors	Leg weakness	Udder problems	Piglet production	Reproduct. failures	Unknown
1	0.28***	0.32***	0.22***	0.05	0.16***
2	0.41***	-.09	-.01	0.06	0.01
3	0.07	0.11	0.00	0.06	0.07
4	-.30***	0.04	0.03	-.05	-.05
5	-.01	0.24	0.09	0.08	0.09
6	-.09	-.14	-.07	-.02	-.04
7	-.06	-.10	-.10	0.02	-.13**
8	0.01	0.00	-.07	-.02	0.02
9	0.03	0.07	-.11*	-.08	0.00
10	0.06	0.21	0.12**	0.02	0.13**
11	-.02	-.02	0.05	-.02	0.04
12	-.07	-.06	-.06	0.00	0.02
13	-.17*	0.11	0.06	0.09	-.01
14	0.00	-.09	-.05	0.01	0.01
15	0.08	0.06	-.01	0.06	-.03

* : $P < 0.05$;
** : $P < 0.01$;
*** : $P < 0.001$
[1] : Contrast estimated as H minus L.

DISCUSSION

Many components of exterior may be expected to change with increasing age, especially during growth to maturity. In dairy cattle, several type traits, e.g., rear legs, pasterns and udder traits, are affected by age (Bowden, 1982). When culling is due to exterior traits, then this might

Table 6. Linear contrasts[1] of gilt exterior traits, of animals that produced ≥ 4 litters (H) and animals culled before 4th parity for various reasons (L).

Exterior traits	Culling reasons				
	Leg weakness	Udder problems	Piglet production	Reproduction failures	Unknown
1. Shoulder blade	0.03	0.11	0.02	0.05	0.03
Back and loin					
2. Length	-.15***	0.15	0.01	0.00	-.02
3. Width	-.10*	0.06	-.05	-.01	-.05
4. Regularity	0.02	0.05	-.02	0.02	0.01
Hams					
5. Length	-.03	-.01	-.01	0.00	-.01
6. Width	-.20***	-.08	-.06	-.07	-.11***
Forelegs					
7. Front view legs	0.02	0.14*	0.01	0.01	0.01
8. Side view legs	-.04	0.25**	-.03	-.01	-.02
9. Side view pastern	0.04	0.10	0.05	0.01	0.02
Rear legs					
10. Rear view legs	0.02	0.00	-.01	0.00	0.00
11. Side view legs	-.15***	-.08	0.00	0.01	-.05
12. Side view hock joint	-.03	0.05	-.01	0.05	-.03
13. Side view pastern	0.01	0.05	-.04	0.04	-.05
14. Liquid at hock joint	0.12	0.12	0.01	-.03	0.06
15. Knottiness of legs	0.18**	0.11	0.07	0.00	0.00
Claws rear leg					
16. Ratio size of claws	-.10	0.05	0.01	0.02	-.04
17. Toe size	0.06	0.00	0.01	-.02	-.02
18. Gait; movements	0.32***	0.29	0.10	0.03	0.08
19. Swinging of back	-.19***	-.16	-.09	-.01	-.05
20. Lifetime expectation	0.35***	0.40	0.13	0.01	0.12
Number of animals	154	31	262	315	315

[1] : Contrast estimated as H minus L.

have introduced a bias in parity estimates of exterior traits. This bias might be more relevant with increasing parity number. Development of exterior traits in time (Figure 3) might therefore be different for animals that are culled at an early stage. Increase of length of sows till 6th parity (Figure 3) might be an indication for maturity at that time. For non-producing sows, Walstra (1980) found a mature age of approximately 750 days, which is about 1.5 years earlier.

With principal component analysis the number of exterior traits for further analysis was reduced from 60 to a more feasible number of 15. The main traits in a factor related to one group (GE, DM or DLR). Relationships between exterior traits within a group were stronger than relationships between the same traits across groups. This might be due partly to the structure of the dataset, where missing values or values that could not be estimated were replaced by herd-strain least squares means. Correlations between traits within a group were similar for all three groups.

Only a few factors showed significant relationships with reasons for disposal. Disposal because of leg weakness was related to three closely correlated traits e.g. gait, swinging of the back and the lifetime expectation score. Interpretation of relationships between factors and reasons for disposal, however, is difficult because all exterior traits were more or less included in a factor.

Several exterior traits judged at gilt stage showed a relationship with reason for disposal. This is an indication that those traits have a predictive value for the gilt's chance to produce more than four litters. Results, however, could be biased by the prejudice of farmers and of inspectors, although exterior scores were not supplied to the farmers. This bias will decrease with increasing time interval between moment of judgement and culling. Analysis of gilt's exterior, in a subset of data where all animals had produced at least one litter, showed only minor changes in contrast estimates. This bias is therefore assumed to be absent. The larger gilts (longer and broader) are more susceptible to leg problems. This might be due to their higher weight, making higher demands upon the strength of the legs. Predisposition to bowed legs in gilts is unfavourable. A slow gait and much swinging of the back has an undesirable correlation with leg weakness. The last two traits and lifetime expectation score are closely correlated. Those traits might be helpful to reduce early involuntary culling. Combination of those three traits might yield to an acceptable indicator for risk of culling because of leg weakness.

ACKNOWLEDGEMENT

Part of the costs of this study were covered by financial support from the Dutch Commodity Board for Livestock and Meat. The essential contribution of the Dutch Pig Herdbook, the breeding organizations Cofok b.v., Euribrid b.v. and Nieuw Dalland b.v. in obtaining the exterior judgements was greatly appreciated. Hendrix' Voeders b.v. was helpful in gathering sow productivity data. We gratefully acknowledge the contribution and co-operation of the herdsmen whose sow herds have been judged during two years.

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APPENDIX

Description of 20 exterior traits.

Exterior traits	Score 0	4½	9
1.Connection of shoulder blade with body	loose		solid
Back and loin			
2.Length	short		long
3.Width	narrow		broad
4.Regularity	irregular		regular
Hams			
5.Length	short		long
6.Width	narrow		broad
Forelegs			
7.Front view legs	O-shaped		X-shaped
8.Side view legs	sickled	straight	buckled
9.Side view pastern	steep angle		low angle
Rear legs			
10.Rear view legs	O-shaped		X-shaped
11.Side view legs	straight		bow leg
12.Side view hock joint	steep		sickle hocked
13.Side view pastern	steep angle		low angle
14.Quantity subcut. liquid at hock joint	much		nil
15.Knottiness of legs; surface of tubercles	$\geq$ 12cm^2	6cm^2	0 cm^2
Claws rear leg			
16.Ratio size inner and outer claw	$\leq$ ½	3/4	$\geq$ 1
17.Toe size	small		large
18.Gait pattern; movements	slow (stiff)		easy, quick
19.Swinging of back	nil		much
20.Lifetime expectation	short		long

Chapter 5

EXTERIOR IN SOWS: 2. RELATIONSHIPS WITH REPRODUCTIVE PERFORMANCE AND LONGEVITY

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Submitted for publication in Livestock Production Science.

ABSTRACT

Over a two-year period, exterior of over 5000 sows on 24 commercial multiplier herds was appraised. Twenty exterior traits were judged after each weaning and were scored linearly. Relationships of exterior traits with reproductive performance were investigated and found to be of marginal importance.

For 2809 animals, of which most were purchased at 6 months of age, survival analysis was used to investigate the relationship between exterior traits judged at gilt stage and longevity. A Weibull model was found adequately in describing the survival distribution. For most traits concerning the posture of the legs, both low and high scores were negatively correlated with longevity.

The effect of a change of one standard deviation unit (s.d.) from the average exterior score on the median length of productive life (LPL) was estimated. Broader hindquarters were unfavourably related to LPL (-53 days per s.d.) while with one s.d. smaller hindquarters LPL was increased by 44 days. LPL increased with decreased swelling at the hock joint. A more flexible gait, less swinging of the back and a higher lifetime expectation score coincided with a higher median LPL (67, 44 and 42 days per s.d. respectively). Selection on exterior traits judged at gilt stage, with main attention for gait, can increase average length of productive life and so decrease the annual culling rate.

INTRODUCTION

Exterior of animals has been and still is a topic which draws attention of farmers, breeders and scientists. Main attention is focused on the predictive value of exterior traits for involuntary culling (e.g. in the case of health and fertility problems and leg weakness). A decrease of involuntary culling increases selection possibilities and might also result in a smaller portion of first litter sows, which results in a positive effect on number of pigs per sow per year. Economic impact of premature disposal was calculated by Dijkhuizen et al. (1989) and turned out to average Dfl. 124 per culled sow and Dfl. 183 when the sow was culled because of leg weakness/lameness.

Sow's exterior may be used to predict her longevity and future reproductivity. This prediction influences the decision whether or not to cull the sow. The relevance of exterior in that decision depends on availability of additional information especially concerning the animals reproductive ability. For gilts little additional information is available and future expectation of longevity and reproductivity might largely be based on the animals exterior. Economic relevance of exterior traits can be derived from the relationships of those traits with longevity and reproductivity.

Reviews of studies concerning relationships of exterior traits with production and longevity in dairy cattle are given by Bowden (1982) and Burnside et al. (1984). The latter authors concluded that there is still no definite answer on whether or not exterior judgements are useful to predict longevity. They concluded that the relative economic weights for sire breeding values of milk production per lactation and stayability (as simple indicator of longevity) are about 2:1. Rogers and McDaniel (1989) concluded that production in first lactation should receive about two to three times as much emphasis as the combination of three exterior traits that were associated with involuntary culling.

Drobig et al. (1983) and Schlegel et al. (1983) studied relationships of body measurements of gilts with reproductive performance. They showed phenotypic associations between body size parameters and reproduction. King (1989) concluded that reproductive efficiency of gilts after parturition was not significantly affected by body weight or body composition at about 170 days of age. Rothschild et al. (1988) reported correlated responses in reproduction after 5 generations of divergent selection for front-leg weakness in Duroc pigs. Although no obvious trends could be observed, results suggested, in general, that culling for front-leg weakness would make some improvement in reproduction productivity.

In a previous study of linearly scored exterior traits of gilts, Van Steenbergen et al. (1990) studied associations between exterior traits judged at gilt stage and culling reasons. Significant differences existed for a number of traits between the group of animals that produced at least four litters and the group of animals that were disposed because of leg weakness before the 4th parity. In the present study, associations of exterior of gilts and sows with reproductive performance and of exterior traits judged at gilt stage with longevity are analyzed.

MATERIAL

In 1985 and 1986, gilts and sows from different strains were judged for exterior at 24 commercial multiplier herds of size 100-200 sows. Eleven inspectors of the Dutch herdbook and of three breeding companies rotated over the farms to score exterior of the animals. In total 20 exterior traits (Van Steenbergen, 1989) were scored on a linear scale. Farms were monthly visited by an inspector who judged all gilts of approximately 7-9 months of age (gilt stage) and all sows from weaning (on average 28 days after farrowing) till 40 days post weaning. Most gilts were judged twice by different inspectors and most sows once after each weaning of the piglets. Data enclosed 5564 animals, born from 1979 to 1985, of which exterior scores and reproductive performance of at least one litter were available. Over 50% (2812) of the animals had been judged at the gilt stage. Reproduction productivity data were obtained in 1988. At that time over 70% of all animals were culled for various reasons. A more detailed description of the material is given by Van Steenbergen et al. (1990). Information on reproduction traits were per litter:

- total number of piglets born (TNB),
- number of still-born piglets (NSB),
- piglet mortality in the suckling period (PMS) (number of piglets) and
- interval weaning-oestrus (IWO) (number of days); the intervals weaning-oestrus concerned the periods after first to ninth litter.

Three measures for sow longevity were used:

- length of productive life (LPL) as difference between date of first service and date of disposal (number of days),
- number of litters produced (NLP) and
- total number of piglets produced (NPP).

METHOD

Exterior of each animal was characterized by the exterior scores as gilt (GE) and, at older ages by the average deviation of the exterior scores from the parity least squares means (DM) and the deviation of the linear regression of the exterior scores on parity number, from the average linear regression (DLR) was estimated. This was done for all 20 traits. The original exterior scores were transformed by a logit transformation which changed the range of scores of 0 to 9 into -4.5 to 4.5. Principal component analysis was used to reduce the 60 exterior variables (20 traits for GE, 20 traits for DM and 20 traits for DLR) to a more feasible number of 15 factors (Van Steenbergen et al., 1990).

An effect of culling on parity estimates of reproduction traits is likely to exist but is not accounted for with ordinary Least Squares analyses. Reproduction traits were analyzed by the LSML76 program of Harvey (1977) with the model:

$$y_{ijkmn} = \mu + HS_i + \underline{A}_{ij} + YS_k + P_m + \underline{e}_{ijkmn} \quad (1)$$

where,

y_{ijkmn} = a reproduction trait

μ = mean

HS_i = fixed effect of herd-strain group i (i=1,...,74)

$\underline{A}_{ij}$ = random effect of animal j within herd-strain i

YS_k = fixed effect of year-season k (k=1,...,16)

P_m = fixed effect of parity m (m=1,...,10)

$\underline{e}_{ijkmn}$ = random error term

Seasons were based on month of conception and included the periods April to September and October to March. For TNB the number of matings per oestrus (1 or 2) which resulted in pregnancy was included in the model as an extra factor.

Reproductive performance of each animal was characterized in a similar way as was done for exterior (Van Steenbergen et al., 1990). For each of the four reproduction traits the average of the deviations from the parity least squares means (TNB_1, NSB_1, PMS_1 and IWO_1) and the linear regression of that deviations on parity number (TNB_2, NSB_2, PMS_2 and IWO_2) were estimated per animal using orthogonal polynomials. Positive values for TNB_2, i.e. a more than average increase of number of piglets born, with parity number, and negative values for NSB_2, PMS_2, and IWO_2 can be considered as desirable and indicate that the functionality of biological processes which determine reproductive performance, increases with parity number.

The association between the eight reproduction variables and the exterior variables was based on all 5564 animals and was analyzed by the GLM procedure of SAS (SAS Institute Inc., 1985). The model to analyze variance in the reproduction variables included herd-strain group and all 15 exterior factors as covariables (model 2). Relationships of exterior traits judged as gilts with reproduction were studied with stepwise regression. Reproduction variables were analyzed with a regression model which included scores and squared scores of exterior traits and the herd-strain variable (model 3). The definite regression model was searched by stepwise regression performed by the STEPWISE procedure (method=stepwise) of SAS (SAS Institute Inc., 1985). The herd-strain variable was forced into the model while the criterion for exterior variables to be added to or deleted from the model was based on a F statistic level of 0.15.

Survival analysis.

At the moment that sow reproduction productivity data became available for analysis, about 30% of the animals with exterior judgements were still in production. Complete longevity measures could only be computed for animals that were culled. Information on animals still alive, however, is useful. The statistical technique of survival analysis utilizes both the complete and incomplete (censored) observations (Kalbfleisch and Prentice, 1980). A first step in survival analysis is the estimation of the distribution of the longevity measures. When this distribution is specified by a function, the following model can be assumed for analyzing the longevity measures:

$$Y = I + \Sigma \beta_i X_i + \Sigma \alpha_j Z_j + \sigma W \qquad (4)$$

where Y is the natural logarithm of a longevity measure, I is the intercept, β_j are unknown coefficients of covariates X_i, α_j are the constants of the j levels of factor Z, σ is a scale parameter and W is a vector of errors from the assumed distribution. The covariables in the model were: i) average number of piglets born, calculated as deviate from the herd-strain mean, and ii) one exterior trait (linear and quadratic). Herd was considered as a variable.

Ducrocq (1987) showed the Weibull function adequately describing the distribution of length of productive life in dairy cattle. The Weibull function [$S(t) = \exp[-(\lambda t)^\rho]$ where, S(t) was the fraction of animals still alive at t, with t being a longevity measure, and λ, ρ parameters] used for the description of the survival distribution, was empirically validated by plotting $\ln(-\ln[S(t)])$ versus $\ln(t)$. If the assumed distribution is correct, then the plot should give approximately a straight line. Parameters of the Weibull model can be derived from that line; the slope provides an estimate of ρ and the intercept an estimate of $\rho\ln(\lambda)$.

The effect of exterior traits on longevity measures was quantified by estimation of the median of the longevity measures for the average exterior scores (AES) and for the AES ± one unit standard deviation (s.d.). Survival analyses were performed with the LIFEREG procedure of SAS (SAS Institute Inc., 1985).

RESULTS

Least squares means (model 1) of the reproduction traits for parity 1 to 10 are graphically presented in Figure 1. An increase of 2.5 piglets born can be noticed from first to sixth parity. Number of still-born piglets increases from 0.5 in parity 1 to 2.3 in parity 10. Piglet mortality in the suckling period increases until seventh parity from 1.2 to over 3 piglets per litter. Interval weaning-oestrus shows a rapid decline after first parity and stabilizes after third parity at a level of approximately 7 days. A second mating during the same oestrus results in 0.2 extra piglets born ($P<0.001$).

Exterior factors which have a significant effect on the reproduction variables (model 2) are summarized in Table 1. Gilt's exterior, especially the rear legs (traits 14-20; see Appendices), and sow's exterior traits side view rear legs (11), gait (18), swinging of the back (19) and lifetime expectation (20) are associated with most reproduction variables. Regression coefficients of the regression of reproduction variables on exterior traits judged at gilt stage, that remained in the final stepwise regression model (model 3), are in Table 2. Average 'total number of piglets born' (TNB_1) increases with length of the gilt (2) and decreases with higher scores for regularity of back and loin (4). Both average number of still-born piglets (NSB_1) and the regression of NSB on parity number (NSB_2) show a negative relation with the linear and quadratic component of side view rear legs (11). Referring to the number of still-born piglets, bow legs are favourable. Piglet mortality during the suckling period (PMS_1)

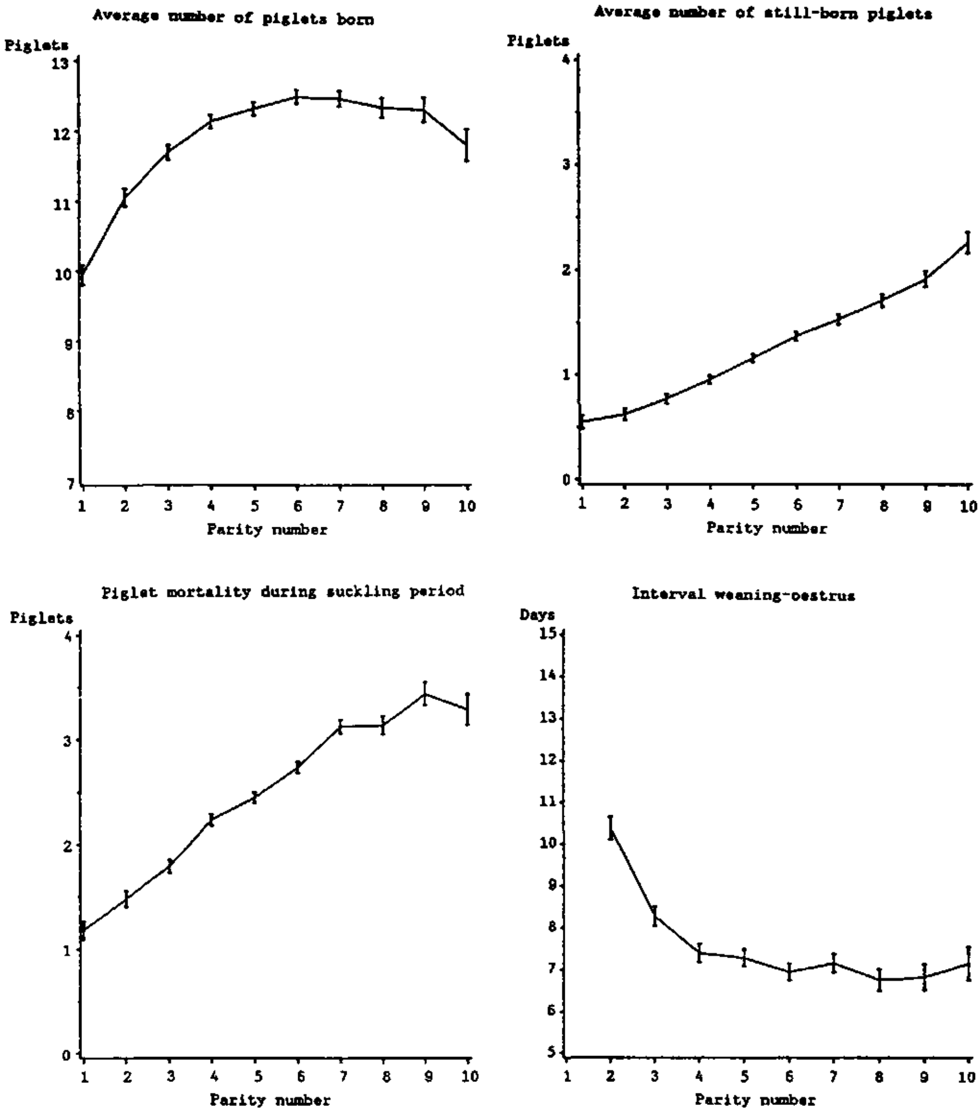

Figure 1. Least squares means (± S.E.) of reproduction traits by parity number.

is influenced by the quadratic component of knottiness (15), and by the linear component of claw ratio (16), and gait (18). The exterior characteristics at gilt stage, even sized claws and a slow gait are unfavourably correlated with piglet mortality during the suckling period.

Table 1. Factors with a significant effect on reproduction parameters.

Reprod. param[1].	Factor number[2] and significance level
TNB_1	1^*, 2^*, 9^{***}
TNB_2	5^*
NSB_1	1^{**}, 2^{***}, 4^*, 5^{**}
NSB_2	
PMS_1	1^{***}, 2^{***}, 4^{***}, 5^*, 7^{**}, 10^{***}, 13^{***}
PMS_2	1^{**}, 4^{***}, 5^*, 7^{**}
IWO_1	1^*, 2^{**}
IWO_2	2^{**}, 10^{**}

[1] TNB - Total number of piglets born
NSB - Number of still-born piglets
PMS - Piglet mortality in the suckling period
IWO - Interval weaning-oestrus
Subscript 1 : deviation from the mean (DM)
Subscript 2 : regression of DM on parity number

[2] See Appendix 2.

Survival analysis.

A graphical validation of the Weibull model for LPL, NLP and NPP, based on 5660 sows, is in Figure 2. The regression of estimates of $\ln(-\ln[S(t)])$ on $\ln(t)$ showed that estimates of $S(t)$ can be well approximated by a Weibull function: Coefficients of determination (R^2) for LPL, NLP and NPP of over 0.97 were obtained.

Regression coefficient (r.c.) estimates (model 4) for lnY, where Y is a longevity measure, on exterior traits (linear and quadratic) are in Table 3. When |r.c.| is small (e.g. ≤ 0.20), then r.c. can be interpreted as a proportion; i.e. a r.c. of -0.10 stands for 10% decrease of Y. A linear

Table 2. Regression coefficients of reproduction variables on gilt's exterior traits that were in the final stepwise regression model. Underlined coefficients concern squared exterior scores.

	Reproduction variables							
Gilt's exterior traits	TNB_1	TNB_2	NSB_1	NSB_2	PMS_1	PMS_2	IWO_1	IWO_2
1. Shoulder blade				.05		-.06		
Back and loin								
2. Length	.38***					.09		-.24
3. Width					-.09			
4. Regularity	-.25**	-.14**						0.30
Hams								
5. Length			.10					
6. Width	-.07		-.04					
Forelegs								
7. Front view legs			-.14					
8. Side view legs	.16*							
9. Side view pastern	-.15		.10*				-.30	
Rear legs								
10. Rear view legs	-.26	-.26*						-.60*
11. Side view legs			-.25***	-.09*			-.49	.34
			.18***	.15***			.48**	
12. Side view hock joint					-.12	-.13		
14. Liquid at hock joint		.09			-.05			
15. Knottiness of legs					-.07			
					.10***			
Claws rear leg								
16. Ratio size of claws				.04	.12*	.09		
17. Toe size				-.08**				
18. Gait; movements			-.07		-.10*	-.07*		
20. Lifetime expectation	.12*							

effect of exterior as gilt on ln(LPL) is shown for connection of shoulder blade (1), side view hock joint (12), swelling at the hock joint (14), knottiness of the rear legs (15), gait (18), swinging of the back (19) and lifetime expectation score (20). Linear regression coefficients (a) of ln(NLP) and ln(NPP) on the three last mentioned exterior traits are also

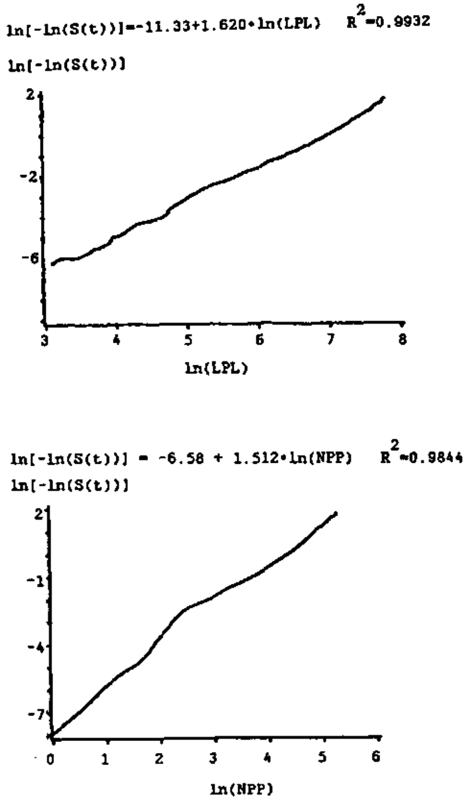

Figure 2. Check of the Weibull model assumption for the survival distribution of length of productive life (LPL), number of litters produced (NLP) and number of piglets produced (NPP) by regression of ln[-ln(S(t))] on ln(LPL), ln(NLP) and ln(NPP).

highly significant. A negative association of longevity measures with the quadratic component of width of back and loin (3), foreleg stature (7,8,9), side view rear legs (11) and hock joint (12) is found, which indicate that low and high scores for those traits are unfavourable related to longevity. Effects of exterior on NLP and NPP are similar to LPL, which is not surprising because of the high correlation (> 0.90) between those three longevity measures. Further results will therefore only be presented for LPL. For most exterior traits a negative regression coefficient b is found which points to reduced possibilities of selection on those exterior traits to increase LPL. Effect of exterior traits on LPL is demonstrated in Figure 3. Calculation is based on regression coefficients a and b in Table 3.

Table 3. Regression coefficient estimates and significance levels of lifetime measures on gilt's exterior traits (linear (a) and quadratic (b)).

	Length prod. life		Number of litters		Number of piglets	
Gilt's exterior traits	a	b	a	b	a	b
1. Shoulder blade	.122**	-.063	.084*	-.041	.097*	-.048
Back and loin						
2. Length	-.001	-.073	-.040	-.056	-.042	-.064
3. Width	-.031	-.109**	-.009	-.096**	-.010	-.109***
4. Regularity	.067	-.057	.034	-.038	.043	-.045
Hams						
5. Length	-.043	.001	-.061	.018	-.072	.021
6. Width	-.094	-.029	-.076	-.025	-.088	-.027
Forelegs						
7. Front view legs	.046	-.078*	.024	-.097***	.026	-.104***
8. Side view legs	-.064	-.077**	-.057	-.057*	-.063	-.065*
9. Side view pastern	-.007	-.075**	-.018	-.074**	-.020	-.081**
Rear legs						
10. Rear view legs	.024	-.079	-.004	-.010	-.007	-.010
11. Side view legs	-.017	-.088***	-.005	-.060**	-.014	-.065**
12. Side view hock joint	.096*	-.153**	.075	-.100*	.075	-.118*
13. Side view pastern	.043	-.066	.042	-.042	.040	-.047
14. Liquid at hock joint	.071*	.006	.037	.008	.045	.008
15. Knottiness of legs	.064*	-.012	.051	-.006	.055	-.006
Claws rear leg						
16. Ratio size of claws	-.041	.002	-.072	.024	-.082	.028
17. Toe size	.019	.037	-.038	.051	-.044	.058
18. Gait; movements	.179***	-.031	.142***	-.019	.163***	-.023
19. Swinging of back	-.143***	-.047	-.094**	-.028	-.109***	-.032
20. Lifetime expectation	.065***	-.010	.055***	-.001	.062***	-.002

A low score for width of the hams results in a higher median LPL (44 days per s.d.) while a higher score has an even stronger opposite effect (-53 days per s.d.). Both a lower and higher than average score for side view pastern forelegs result in a small decrease of the median LPL (12 and 9 days respectively). It can be seen that a change of the average scores of exterior traits 7 to 13 (fore- and rear legs) mostly results in a considerable decrease of the median LPL while only marginal increases can be noticed. When the average exterior score changes one unit s.d., an increase (> 30 days) of the median LPL is noticed: 44 days for smaller hams

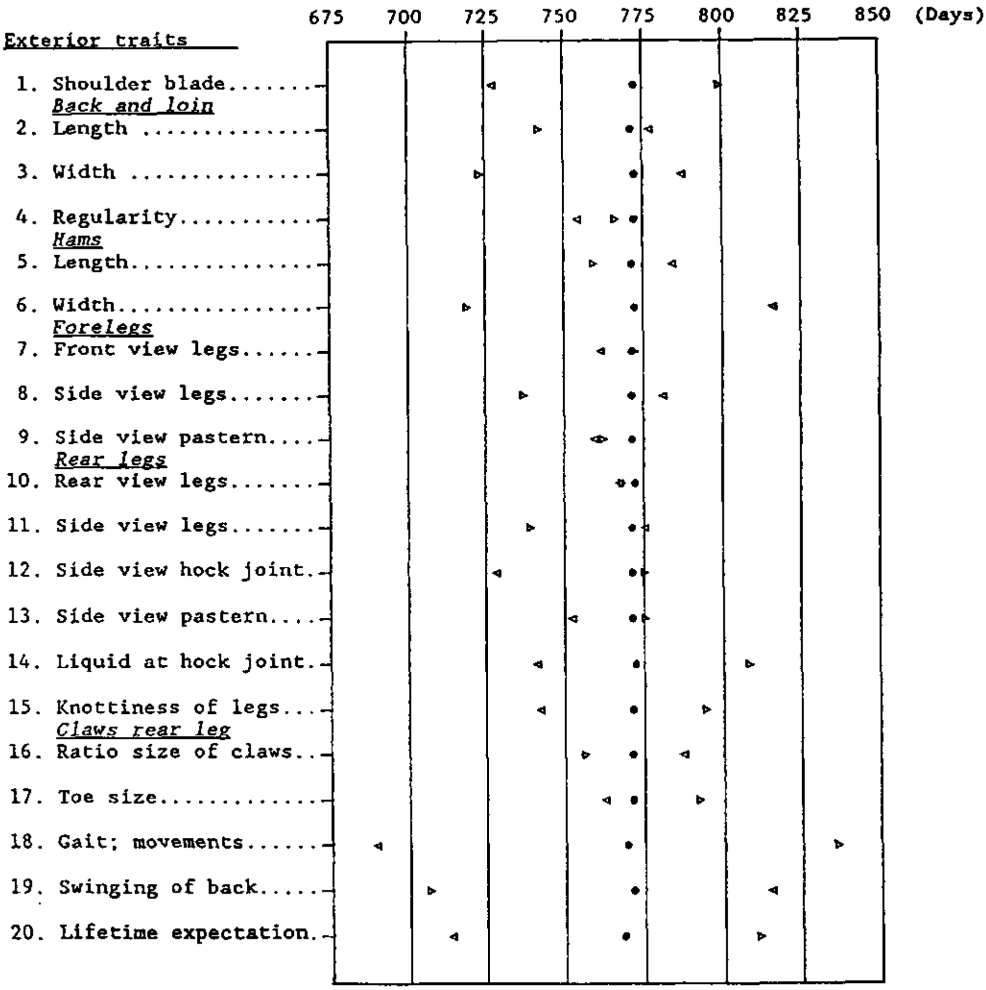

Figure 3. Estimates of the median of length of productive life for average exterior scores (•) and the average plus or minus one unit s.d. denoted by ▷ and ◁, respectively.

(6), 36 days for less swelling at the hock joint (14), 67 days for easier movements/gait (18), 44 days for less swinging of the back (19), and 42 days for a higher lifetime expectation score (20).

DISCUSSION

Parity effect of the reproduction traits as demonstrated in Figure 1 is biased because of culling. This bias increases with parity number while the severity of the bias depends on the correlation of reproductivity with the risk to be culled. For total number of piglets born it is likely that differences between first and higher parity numbers are over-estimated.

From Table 1 it was concluded that a linear combination of exterior traits concerning the rear legs at gilt stage (factor 1; traits 14-20) is associated with reproductivity. Results of the analysis of GE traits (Table 2) show only minor associations of gilts rear legs with reproductivity, and therefore do not confirm the conclusion based on Table 1. A possible explanation for this discrepancy might be that results of Table 1 were based on all (5564) animals, while analysis of exterior traits judged at gilt stage were based only on animals that had been judged when gilt (2812 animals). From Table 2 it can be concluded that exterior traits judged at gilt stage and reproductivity have just small associations. This is in accordance with results of Drobig et al. (1983) and Schlegel et al. (1983).

The distribution of the longevity measures could adequately be described by the Weibull model, which is in agreement with findings for length of productive life of dairy cattle (Ducrocq, 1987). Culling rates for sows per parity are often required in model calculations (e.g. Dijkhuizen et al., 1986; De Vries, 1989). Those culling rates (CR) can be derived from the survival distribution as: $-d \ln(S(t))/dt$. For the Weibull function this leads to $CR(t) = \rho\lambda^{\rho}(t)^{\rho-1}$. Parameters of the Weibull function can be derived from the equation $\ln[-\ln(S(t))] = \rho\ln(\lambda) + \rho\ln(t)$ and were: $\rho=1.481$ and $\lambda=0.1541$ (Fig. 2). Risk for a sow to be disposed after parity t can then be calculated as $CR(t)=0.09t^{0.481}$.

Median LPL (Fig. 3) averaged 770 days, so 50% of the sows reached an age of at least 1000 days which stands for a production of 4.8 litters on average. This is almost one litter above the figure presented by Dijkhuizen et al. (1989), who found 51% of the sows to produce at least 4 litters.

That lower figure might be due to the large portion of removed first parity sows in the data of last mentioned authors.

In most of the 24 commercial multiplier herds, gilts were purchased at 6 months age. A considerable selection on exterior might have occurred before delivery. In spite of the reduced variation in exterior, significant associations of exterior with longevity measures are observed. The following exterior traits, judged at gilt stage, have an important effect on longevity: width of the hams (6), swelling at the hock joint (15), gait (18), swinging of the back (19) and lifetime expectation score (20). Of those five traits, lifetime expectation (20) was scored most subjectively because it implied an overall impression. This trait might therefore be less attractive for selection purposes. Longevity shows a negative relationship with broad size and with extreme scores for side view of most leg traits. Little swelling at the hock joint, a quick and flexible gait, and little twisting of the hind quarters are favourably correlated with longevity. Those five traits were also indicated by Van Steenbergen et al. (1989) to be relevant in relation to disposal for leg weakness. It is therefore likely that increased longevity through selection on exterior traits, will be achieved mainly by a reduced culling because of leg weakness.

An increased herd life was found to be economically beneficial by Kroes and Van Male (1979) and Dijkhuizen et al. (1986). The latter author calculated 10 litters to be the economic optimum herd life for average producing sows. Dijkhuizen et al. (1989) calculated economic losses for sows culled because of leg weakness, averaging Dfl. 183 per culled sow. A strong selection in gilts on the three closely correlated exterior traits gait (18), twisting of hind quarters (19) and lifetime expectation (20) will reduce involuntary culling because of leg weakness and increases median length of productive life by approximately 75 days which is equivalent to 0.5 parity. Selection on exterior might therefore expected to yield substantial economic benefits.

ACKNOWLEDGEMENT

Part of the costs of this study were covered by financial support from the Dutch Commodity Board for Livestock and Meat. The essential contribution of the Dutch Pig Herdbook, the breeding organizations Cofok b.v., Euribrid b.v. and Nieuw Dalland b.v. in obtaining the exterior judgements was greatly appreciated. Hendrix' Voeders b.v. was helpful in gathering sow productivity data. We gratefully acknowledge the contribution and co-operation of the herdsmen whose sow herds have been judged during two years.

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APPENDICES

Appendix 1. Description of 20 exterior traits

Exterior traits	Score: 0	4½	9
1. Connection of shoulder blade with body	loose		solid
Back and loin			
2. Length	short		long
3. Width	narrow		broad
4. Regularity	irregular		regular
Hams			
5. Length	short		long
6. Width	narrow		broad
Forelegs			
7. Front view legs	O-shaped		X-shaped
8. Side view legs	sickled	straight	buckled
9. Side view pastern	steep angle		low angle
Rear legs			
10. Rear view legs	O-shaped		X-shaped
11. Side view legs	straight		bow leg
12. Side view hock joint	steep		sickle hocked
13. Side view pastern	steep angle		low angle
14. Quantity subcut. liquid at hock joint	much		nil
15. Knottiness of legs; surface of tubercles	≥ 12cm²	6cm²	0 cm²
Claws rear leg			
16. Ratio size inner and outer claw	≤ ½		≥ 1
17. Toe size	small		large
18. Gait pattern; movements	slow (stiff)		easy, quick
19. Swinging of back	nil		much
20. Constitution	short		long

Appendix 2. Traits with an absolute loading on the factors greater than 0.50

Factor	Exterior traits[1]: Exterior of gilts	Level deviation	Course deviation
1	14 to 20	....	....
2	....	11, 18 to 20	....
3	....	....	18 to 20
4	3 and 6	....	....
5	1, 2, 4 and 5	....	....
6	....	....	1, 2, 4 and 5
7	....	9, 11 to 13	....
8	....	....	16 and 17
9	....	3 and 6	....
10	....	16 and 17	....
11	....	1 and 4	....
12	....	....	11 to 13
13	11 and 12	....	....
14	....	....	3 and 6
15	9 and 13	....	....

[1] :See Appendix 1 for explanation of the trait numbers.

Chapter 6

GENERAL DISCUSSION

The relevance of selection for exterior traits depends on the purpose for which animals are domesticated. For small pets, fancy poultry and pigeons which are bred for exhibition purposes, benefit is directly and mainly related to exterior traits and character. The main purpose of most livestock species, however, is production of food for human consumption, e.g. milk, meat and eggs. Economic benefit of those species can directly be related to amount and quality of their products. The importance of exterior traits should therefore depend on the relationship of these traits with economic merit. Selection on exterior traits should only be done when short or longer term economic merit is expected.

In this thesis the relevance of exterior traits for a pig breeding programme has been studied. Selection on exterior traits can influence selection response for growth performance and reproduction traits, depending on heritabilities and genetic and phenotypic interrelationships. Nowadays attention is mainly focused on those exterior traits which are expected to be related to constitution, especially locomotory ability. In this chapter results of chapters 2 to 5 are discussed in view of their practical application. Most relevant parameters for this discussion are: repeatability, reproducibility, standard deviation, heritability, correlations with growth performance and relationship with constitution and longevity. These parameters, which are presented in foregoing chapters, are summarized in Table 1.

Scoring system.

A first and main step when considering exterior traits is to establish a clear and conclusive definition of the characteristics one wants to describe and investigate. In dairy cattle, linear scoring systems for evaluation of exterior traits are considered to be favourable over descriptively scored traits (Thompson et al., 1981) and are widely used now. The number of categories used to score the traits, however, varies over countries and ranges from 9 to 60 (Diers and Swalve, 1987; Thompson

Table 1. Relevant parameters for the discussion of the practical application of exterior appraisal in pigs.

Exterior traits	Measuring accuracy[1] r_1	r_2	s.d.	h^2	Relation with performance[2] ADG	UB	Relation with longevity[3] a	b
1. Shoulder blade	0.61	0.38	1.30	0.15	0.24	0.51	0.12	-.06
Back and loin								
2. Length	0.40	0.37	1.07	0.28	0.05	0.03	-.00	-.07
3. Width	0.54	0.35	1.05	0.38	0.41	0.26	-.03	-.11
4. Regularity	0.59	0.41	1.24	0.30	0.29	0.47	0.07	-.06
Hams								
5. Length	0.40	0.12	0.96	0.06	0.41	0.05	-.04	.00
6. Width	0.74	0.62	1.29	0.36	0.34	0.05	-.09	-.03
Forelegs								
7. Front view legs	0.35	0.20	0.77	0.06	0.13	0.10	0.05	-.08
8. Side view legs	0.49	0.38	1.11	0.06	0.14	0.08	-.06	-.08
9. Side view pastern	0.54	0.41	1.14	0.31	0.41	0.14	-.02	-.08
Rear legs								
10. Rear view legs	0.47	0.27	0.65	0.22	-.26	0.04	0.02	-.08
11. Side view legs	0.48	0.28	0.98	0.23	0.03	-.16	-.02	-.09
12. Side view hock joint	0.49	0.22	1.05	0.24	-.53	-.23	0.10	-.15
13. Side view pastern	0.40	0.28	1.04	0.30	-.18	0.06	0.04	-.07
14. Liquid at hock joint	0.59	0.32	1.38	0.09	-.51	0.38	0.07	.01
15. Knottiness of legs	0.58	0.46	1.43	0.01	0.03	0.07	0.06	-.01
Claws rear leg								
16. Ratio size of claws	0.55	0.40	1.36	0.09	-.06	-.25	-.04	.00
17. Toe size	0.45	0.30	1.27	0.15	-.06	-.24	0.02	.04
18. Gait; movements	0.46	0.42	1.37	0.13	-.35	0.26	0.18	-.03
19. Swinging of back	0.33	0.28	1.63	0.13	0.12	-.11	-.14	-.05
20. Nipples	--	--	0.08	--	--	--	--	--
21. Lifetime expectation	0.57	0.42	1.94	0.16	-.02	0.11	0.07	-.01

[1] : repeatability (r_1) and reproducibility (r_2) estimates (Chapter 2; Table 5)
[2] : genetic correlations for average daily gain (ADG) and ultrasonically measured backfat thickness (UB). (Chapter 3; Table 6)
[3] : Linear (a) and quadratic (b) regression coefficient estimates of the natural logarithm of longevity (ln(days)) on exterior traits in the gilt. (Chapter 5; Table 3)

et al, 1981; De Graaf et al, 1986; Murphy and Sinnott, 1989). Historical factors and personal preferences were important in the choice of the number of categories for linear scoring systems in dairy cattle. No conclusive rules are available to determine the number of categories to be used. The range of scores, however, should supply sufficient opportunity to express the visual variation which can be detected. Both a very small and a very large number of categories are supposed to reduce the reliability of the scores, and so negatively influence further use of the scores (e.g. for breeding value estimation).

In chapter 2, 21 exterior traits were defined and described on a linear scale from 0 to 9 with 0.5 intervals (19 categories). In consultation with inspectors who used the scoring system, and taking possible scoring forms into account, 19 categories were considered to be a good choice. For all exterior traits large differences in mean and standard deviation between inspectors were found. These differences hinder application of linear scoring of exterior traits in pig breeding. An intensive and regular training of the classifiers in order to get uniform means (4.5) and standard deviations, is therefore necessary. Several inspectors made minor use of the 'half' scores. Training or change to another scale might dissolve this preference for specific categories. Because the 'half' categories are proportionally distributed on the scale of 0 to 9, disproportionate use of categories for statistical analysis or for breeding value estimation is expected to be of minor importance.

Repeatabilities were used to determine the accuracy of visual exterior appraisal. No visible variation was observed in nipple quality. That trait was therefore excluded from further analysis. Front view forelegs and rear view rear legs showed little variation, while accuracy of appraisal was relatively small. These traits should therefore be considered of minor importance for selection purposes. A low accuracy for traits showing average variation (s.d. 1) might be caused by an incomplete and indistinct definition and description of the trait. This holds especially for length of back and loin, length of hams, and swinging of the back. A more distinct and comprehensive definition of these traits is therefore recommended. In view of the present level of the repeatabilities and reproducibilities (Table 1), and experience in dairy cattle, it is concluded that accuracy of exterior scoring can achieve a satisfactory level ($r_1>0.6$) for most traits if inspectors are intensively and regularly trained.

Principal component analysis was used to determine whether exterior traits could be grouped together into a few new and 'interpretable' traits (factors). The advantage of principal component analysis refers to the less comprehensive analysis of the data (e.g. in the case of breeding value estimation) due to the reduced number of new traits which are uncorrelated with each other, while using information on all traits. It was shown that 20 exterior traits could be summarized by five interpretable factors that explained 57% of the total variance. A reduction of the number of variables from 20 to 5, involved discarding 43% of the total variance. A total of thirteen factors were needed to utilize at least 90% of the total variance. For pig breeding companies which are involved in collecting the data, costs play an important role in the final decision as to which traits should be scored for exterior breeding value estimation. Calculation of the factor scores implies that all traits should be scored. It is therefore concluded that the merit of using exterior factor scores for selection purposes is questionable.

Heritabilities of exterior traits and relationships with growth performance.

An excellent growth performance is only profitable if time of delivery of the animal is achieved without (severe) constitutional problems manifested in deviant behavior or malfunction of legs and body. Because of the continuous selection for growth performance in pig breeding, correlated responses for exterior traits might become relevant. Those responses depend on genetic correlations and standard deviations. In chapter 3, the genetic background of exterior traits and their correlations with growth performance were reported. Exterior traits describing body size and structure (trait 1 to 6) are moderately heritable except for length of the hams (h^2=0.06). That trait is also found to have a relatively low repeatability and reproducibility (Table 1). It is therefore likely that the low heritability is due to inaccurate appraisal, probably because of shortcomings in the definition and description of the trait. Heritabilities of size (objectively measured) are generally reported in the range of 0.4 to 0.5 (e.g. Falconer, 1981). Selection for size should therefore not be based on visual appraisal but on objective measurements.

Of the forelegs, only side view of the pastern shows a significant heritability estimate. Heritability estimates of the posture of rear legs range from 0.22 to 0.30, and are larger than estimates of individual rear leg traits reported by Webb et al. (1983). Difference in size between inner and outer claw is considered to be a predisposing cause of lameness (Penny, 1979). The low heritability found in our own investigations and by Webb et al. (1983) indicate that selection on size ratio of inner and outer claw will not give much response and is therefore irrelevant in nucleus breeding.

In practice, the breeding value of growth performance of nucleus pigs of sire and dam lines is generally estimated by the traits: daily growth (ADG), backfat thickness (UB), and daily feed intake (DFI), using a selection index. Depending on correlations and heritabilities, visual appraisal of exterior traits can increase accuracy of the estimation. Relative to a performance index including ADG, UB and DFI as index and breeding goal traits using economic values 0.178, -0.415 and -0.05 (Knap et al., 1985), respectively, the correlation between index and breeding goal increases 7% (from 0.49 to 0.52) when six exterior traits describing size and structure of the body (traits 1 to 6) are added to the index. The exterior traits, regularity of back and loin, length and width of the hams account for 88% of this increase. The increase in accuracy of growth performance estimation by including information on exterior traits, however, declines when performance information of relatives is included in the breeding value estimation. Schaeffer and Kennedy (1986) showed that the application of an animal model for breeding value estimation in pigs was possible on a Personal Computer. It is, therefore, likely that pig breeding companies will include information of all relatives of a pig for breeding value estimation. It is concluded that contribution of exterior traits for growth performance estimation is small and is expected to decrease in the near future, so exterior traits should be considered of minor importance for growth performance estimation.

In the breeding goal, however, no attention is paid to type (shape of the hams) of the carcass, whereas classification of carcasses according to EEC regulations is on the basis of lean meat percentage and 'type'. Type therefore represents an economic value. No type measuring technique is developed yet for practical application, so classification of type is still by visual appraisal. Scoring the shape of the hams of live animals by visual appraisal might therefore be relevant in selection programmes. Further research is needed to determine the relevance of visual appraisal of type of living animals for prediction of carcass type classes.

Exterior traits and longevity.

Many factors affect the decision of a herdsman whether or not to cull a sow and so affect the animal's longevity. Some of these factors are reproductive performance, constitution, diseases, age, character, and the price of gilts and sows. It is obvious that the disposal decision is mainly based on characteristics of the sow that are directly related to the animal's functioning and performance. As stated by Brody (1945), function is intimately correlated with structure and form. Exterior traits, which describe structure and form of an animal are therefore of interest.

The mean annual culling rate for sows from different studies varies between 39 and 55%, with the main reasons for disposal being: fertility problems (40%), low number of piglets (30%) and leg weakness (15%) (Dagorn and Aumaitre, 1979; Pattison, 1980; Te Brake, 1986; Van Steenbergen et al, 1990). Disposal because of leg and foot disorders causes the largest economic loss (Dijkhuizen et al., 1989). When leg and foot disorders can be timely foreseen, then this loss can be reduced through more flexibility in the choice of time to cull the animal. Reduction of disposals because of leg weakness will increase reproductive lifetime and might be achieved by early selection on exterior traits which are related to leg weakness.

The economic relevance of reproductive lifetime of sows is described by Kroes and Van Male (1979), Dijkhuizen et al. (1986) and De Vries (1989). An increase of average longevity from four to five litters has an economic benefit of approximately Dfl. 45.- per sow per year (Dijkhuizen et al., 1986; De Vries, 1989).

Constitution of sows is of interest for nucleus dam lines and commercial multiplier herds. In chapter 4, eight exterior traits judged at gilt stage were found to be significantly related to disposal because of leg weakness. Those traits are: length and width of back and loin, width of the hams, side view of the rear legs, knottiness of the rear legs, gait (movements), swinging of the back and the lifetime expectation score. Selection in dam lines is for a combination of growth and reproductive (fertility and longevity of sows) performance. In view of the genetic correlations between exterior traits and growth performance, and relationships between exterior traits and disposal because of leg weakness, it can be concluded that selection for growth performance negatively influences leg weakness by increasing width of back, loin and hams, slowing down the gait (locomotory ability) and increased swinging of the back. These exterior traits therefore deserve attention in pig breeding.

Calabotta et al. (1982) stated that longevity in a breeding herd, which among other factors is the result of all known and unknown manifestations of leg weakness, might be a good indicator of leg weakness. In chapter 5 relationships between exterior traits judged at gilt stage and longevity were analyzed. Significant linear regression coefficients of four exterior traits on the natural logarithm of longevity are found: shoulder blade, gait (movements), swinging of the back and the lifetime expectation score. Significant quadratic regression coefficients of longevity on exterior traits are found for: width of back and loin, front and side view of the forelegs, side view pastern of the forelegs, side view rear legs and side view of the hock joint. Extremes of these traits are unfavourably related to longevity. The effect of modification of exterior traits on longevity is found to be relevant for the connection of the shoulder blade with the body, width of the back, loin, and hams, side view of the hock joint, quantity of liquid (swelling) at the hock joint, gait (movements), swinging of the back and lifetime expectation. For multiplier farms these traits can be used to estimate the gilt's future profitability. Based on accuracy of the measurements and the effect of the traits on longevity (Table 1), the five most interesting exterior traits for multiplier farms, in order of decreasing relevance are: (1) width of hams, (2) gait (movements), (3) lifetime expectation, (4) connection of the shoulder blade with the body and (5) swelling at the hock joint.

The effect of selection for longevity in dam lines of pig breeding companies depends on genetic correlations between exterior traits and longevity. These correlations could not be estimated in the present study and were also not found in the literature. Values of phenotypic correlations might however, be useful estimates for the genetic correlations. Inclusion in a selection index implies a known economic value and linearity of this value. Several leg traits showed an optimum for longevity and are therefore troublesome to include into a selection index. Because the economic value of exterior traits is as yet not quantified and linearity of the economic value of several traits is doubtful, independent culling on exterior traits that are related to longevity, might be an attractive alternative for index selection.

Main conclusions.

From the investigations presented in this thesis, the following main conclusions can be draw:

- A satisfactory accuracy of linear scoring of exterior traits in pigs can be achieved. When judgements are made by several persons, regular deliberation and training are recommendable.
- Exterior traits describing size and structure of the body are not relevant for growth performance estimation.
- Selection only on growth performance has an unfavourable effect on locomotory ability of boars.
- Broad back, loin and hams at gilt stage are unfavourably related with sow lifetime. An increased herd life, which is of interest for multiplier farms, might be achieved by an increased exterior selection in gilts. A broad body, slow gait (movements) and extreme leg postures are the main exterior criteria on which gilts should be selected out.
- Selection for constitution in dam lines should be concentrated on the exterior traits: gait (movements) and body width, whereas animals with extreme posture of the legs, especially buckled knees, bowed and steep rear legs, should be discarded for breeding purposes. For a long lifetime, pigs with an easy and quick gait, and a relatively narrow sized body are desirable.

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SUMMARY

In farm animals characterization of exterior is not a goal in itself but rather serves as an indicator of economically important traits, i.e. for pigs: growth performance, reproductivity and constitution. This indication might be of interest when these traits can not be measured on living animals (e.g. slaughter and meat quality) or when traits can only be measured on one sex or at later age (e.g. piglet production, longevity). Several methods are available to characterize exterior: direct measurements (e.g. width, height, circumference), photography and visual appraisal. Disadvantages of the last method are subjectivity and the relatively low accuracy of the characterization. Despite of those disadvantages visual appraisal is frequently used mainly because of the low costs and quickness of measuring.

Since introduction of ultrasonic measuring equipment, prediction of slaughter characteristics of living pigs can be done more accurately by ultrasonic backfat measurement then by visual appraisal. Since then, the main relevance for appraisal of exterior traits is due to presumed relationships with constitution and reproduction. Leg and foot disorders are a main constitutional problem in pigs. These disorders are generally described by the term leg weakness. The proportion of tested nucleus boars culled for leg weakness varies from 15 to 50%. In sow herds 15 to 20% of the disposed sows are culled because of leg weakness. Economic loss due to leg weakness can arise in different ways: (1) reduced genetic improvement in performance traits at nucleus level due to involuntary culling, (2) premature disposal of breeding stock at nucleus and multiplier levels, (3) loss of sales at nucleus and multiplier levels, and (4) reduced reproduction and production efficiency at all levels. Next to the economic consequences, leg weakness has a negative impact on animal welfare and emphasizes the negative image of intensive husbandry systems.

In pig breeding programmes emphasis is given to exterior traits mainly as a method to select for a better constitution. Very little, however, is known about the effectiveness of that selection. Responses to selection depend on heritabilities of exterior traits and on correlations between exterior traits and constitution, whereas application of modern techniques

for breeding values estimation necessitates an appropriate way for exterior scoring.

The aim of this study was to evaluate the importance of exterior appraisal in pig breeding. In the first chapter the function of exterior judgement in pig breeding and husbandry is reviewed. Special attention is given to relationships between exterior and the problem of foot and leg disorders.

Investigations were set up to obtain the parameters that are relevant for the evaluation of the importance of exterior appraisal in pig breeding. Before investigations started, exterior traits to be investigated were chosen in deliberation with inspectors of the Dutch pig herdbook and three pig breeding companies. The choice of the traits to be evaluated was based on the expected economic value and the likelihood to have a relationship with constitution. Results and conclusions are based on appraisal of exterior traits of centrally tested boars and of gilts and sows on 24 commercial multiplier farms.

Methods of exterior appraisal.

A large number of exterior appraisals is needed for a sufficient reliability of heritability and correlation estimates. Ease, and time necessary for a judgement are therefore important criteria for the choice of the method for exterior characterization. Visual appraisal meets those criteria. In literature several advantages are mentioned for linear scoring of visually appraised exterior traits. For present investigations 19 distinct and two composite exterior traits are defined and described on a linear scale which ranged from 0 to 9 with 0.5 intervals. Traits considered refer to size and structure of the body (6), forelegs (3), rear legs and claws (8), movements (2), and a lifetime expectation score which should be an estimate of the animal's life time as interval between time of judgement and expected disposal. The evaluation of the linear scoring is described in chapter 2.

The linear scoring system is evaluated in terms of: differences between inspectors, use of the 19 (0 to 9 with 0.5 increments) categories, accuracy of scoring and relationships between traits. For that purpose 40 boars were judged twice by each of 10 inspectors. Differences in mean and standard deviation for linearly scored exterior traits occurred between inspectors, with most inspectors showing a marked preference for whole number categories. On average, repeatability was 0.60 and reproducibility, indicating the correlation between repeated measurements done by different inspectors, was 0.30. Exterior traits could be summarized by principal component analysis to five new independent exterior variables, that are characterized as 1) side view of legs, 2) way of walking and lifetime expectation, 3) size, 4) harmony of the frame and 5) rear legs and claws.

In present form, usefulness of application of described linear scoring system for exterior traits for selection purposes highly depends on the persons who judge the animals. When selecting and training appropriate people, a satisfactory scoring accuracy can be achieved for most traits.

<u>Heritabilities of exterior traits and relationships with growing performance.</u>

In chapter 3 genetic relationships between growth performance and 20 linearly scored exterior traits are estimated from data of 2792 boars of several strains. Boars are tested with ad libitum feeding from approximately 25 to 105 kg at central test stations of the Dutch herdbook and three breeding companies. Heritability estimates of exterior traits ranged from 0.01 to 0.38. Traits describing body size and harmony (trait 1 to 6) are moderately heritable (h^2=0.15-0.3) except length of the hams (h^2=0.06). Of the forelegs, only side view of the pastern shows a significant heritability estimate. Heritability estimates of posture of rear legs ranged from 0.22 to 0.30. Movements and constitution score have a small genetic component (h^2~0.15). Close genetic correlations (r_g=0.4-0.5) are found between daily gain and side view of foreleg pastern, side view and dryness of the hock joint. Slower growing animals have steeper foreleg pastern, less liquid at the hock joint and more sickle hocked rear legs. The genetic correlation between feed conversion and rear view of the rear legs indicates that boars with better feed conversion have more O-shaped rear legs.

A two-stage selection strategy with selection in the first stage on gait pattern (movements) only and on growth performance in the second stage, reduces genetic improvement of performance traits. When assuming a nihil economic value for gait pattern and rejecting 25 or 50% of the boars in the first stage, then economic merit is reduced by 13 or 24%, respectively.

The accuracy of the estimated breeding value for growth performance, based on an own performance index with the index traits: daily growth, backfat thickness, and daily feed intake, shows a minor increase when exterior traits describing size and structure of the body are included in the index.

Exterior traits and constitution.

In practice most interest for exterior traits is because of the expected correlations between exterior traits and longevity as determined by the animals constitution. Over a two-year period, several thousand gilts between 7 and 9 months of age and sows from weaning till about 30 days post weaning, were repeatedly judged for exterior on 24 commercial multiplier herds. In chapters 4 and 5 relationships of linearly scored exterior traits with reasons for disposal and longevity are studied. Some exterior traits judged at gilt stage, showed to be relevant for disposal for leg weakness. Sows culled for leg weakness before 4th parity were longer and broader at gilt stage, had less straight rear legs and more tubercles at the rear legs, they walked slower and twisted more with the hind quarters compared to animals that had produced at least 4 litters. Sows culled before fourth parity because of leg weakness, had a lower score for constitution at gilt stage than sows that produced ≥ 4 litters.

For most traits concerning the posture of the legs, both low and high scores were negatively correlated with longevity. The effect of a change of one standard deviation unit (s.d.) from the average exterior score on length of productive life (LPL), as a measure for longevity, is considerable for a number of exterior traits. Broader hindquarters are unfavourably related to LPL (-53 days per s.d.) while with one s.d. thinner hindquarters LPL increases 44 days. LPL increases with decreasing swelling at the hock joint. A more flexible gait pattern, less twisting of the hindquarters and a higher lifetime expectation score coincide with a higher LPL (67, 44 and 42 days per s.d. respectively). Selection on exterior traits with main attention for gait (movements) and body width can increase average length of productive life and so decrease the annual involuntary disposal of sows.

Main conclusions.

From the investigations presented in this thesis, the following main conclusions can be draw:

- A satisfactory accuracy of linear scoring of exterior traits in pigs can be achieved. When judgements are made by several persons, regular deliberation and training are recommendable.
- Exterior traits describing size and structure of the body are not relevant for growth performance estimation.
- Selection only on growth performance has an unfavourable effect on locomotory ability of boars.
- Broad back, loin and hams at gilt stage are unfavourably related with sow lifetime. An increased herd life, which is of interest for multiplier farms, might be achieved by an increased exterior selection in gilts. A broad body, slow gait (movements) and extreme leg postures are the main exterior criteria on which gilts should be culled.
- Selection for constitution in dam lines should be concentrated on the exterior traits: gait (movements) and body width, whereas animals with extreme posture of the legs, especially buckled knees, bowed and steep rear legs, should be discarded for breeding purposes. For a long lifetime, pigs with an easy and quick gait, and a relatively narrow sized body are desirable.

SAMENVATTING

Exterieur beoordelen bij landbouwhuisdieren is geen doel op zichzelf, maar wordt gebruikt ter voorspelling van economisch belangrijke kenmerken. Bij varkens zijn produktiekenmerken zoals groei en spekdikte, reproduktiekenmerken en constitutie economisch gezien belangrijk. Onder constitutie wordt de algehele lichamelijke gesteldheid van het dier verstaan. De voorspellende waarde van het exterieur wordt met name dan van belang wanneer de kenmerken waar het in feite omgaat niet direct aan het levende dier gemeten kunnen worden (b.v. slacht- en vleeskwaliteit) of wanneer de kenmerken pas op latere leeftijd gemeten kunnen worden (b.v. levensduur of -produktie).

Voor het karakteriseren van het exterieur zijn diverse methoden beschikbaar: direct meten (b.v. lengte), fotograferen of filmen, en visueel beoordelen. Op het oog beoordelen is een subjectieve methode waarvan de nauwkeurigheid vaak matig is. Desondanks wordt het visueel karakteriseren van exterieurkenmerken veelvuldig toegepast. De voordelen van de methode zijn de lage kosten en de snelheid waarmee de waarnemingen verkregen worden alsmede de praktische toepasbaarheid.

Sinds de ontdekking dat ultrasone geluidstechnieken gebruikt kunnen worden om de spekdikte bij levende varkens nauwkeurig te meten, kan de slachtkwaliteit nauwkeuriger aan het levende dier worden gemeten door ultrasone spekdikte-metingen dan door visuele beoordelingen van het exterieur. Sindsdien concentreert exterieurbeoordeling zich met name op de veronderstelde relaties met constitutie en reproduktie. Een belangrijk constitutie-probleem bij varkens heeft betrekking op beengebreken. Zowel in de varkensfokkerij als de -houderij wordt een aanzienlijk deel van de dieren voortijdig afgevoerd vanwege onvoldoende functionerend beenwerk. Het economisch verlies wordt veroorzaakt door: (1) verminderde genetische vooruitgang in produktiekenmerken op topfokniveau, (2) voortijdige afvoer van zeugen op vermeerderings- en topfokbedrijven, (3) minder fokmateriaal beschikbaar voor verkoop aan zeugenbedrijven, en (4) verminderde (re)produktie-efficiëntie van zeugen, beren en slachtvarkens. Naast de economische gevolgen van beengebreken zijn ook de welzijnsaspecten van belang. Veel beenwerkproblemen zijn ongezond voor zowel de varkens als de varkenssector.

In de huidige varkensfokkerijprogramma's wordt het exterieur voornamelijk gebruikt als voorspeller van constitutie. De genetische vooruitgang voor constitutie hangt af van de erfelijkheid van exterieurkenmerken en van de correlaties tussen exterieur en constitutie. Voor het schatten van fokwaardes voor exterieur kenmerken is een geschikt beoordelingssysteem nodig.

Het doel van dit onderzoek is de bepaling van het belang van exterieurbeoordeling in de varkensfokkerij. In het eerste hoofdstuk wordt een literatuuroverzicht gegeven van de relaties van exterieur met (re)produktiekenmerken en constitutie. Daarbij wordt vooral aandacht geschonken aan de relatie tussen exterieur en beenwerkproblematiek.

Een aantal praktijkonderzoeken zijn opgezet om de voor dit onderzoek relevante kengetallen boven water te krijgen. Op 24 zeugenbedrijven zijn gedurende twee jaar gelten en zeugen op exterieur beoordeeld, terwijl op selectiemesterijen en toetsstallen van varkensfokkerij-instellingen gedurende een jaar enkele duizenden getoetste beren op exterieur zijn beoordeeld. Voorafgaand aan het exterieurbeoordelen, zijn in overleg met de betrokken beoordelaars de te beoordelen kenmerken vastgesteld. De keuze van de kenmerken werd voornamelijk bepaald door de verwachte relatie met constitutie.

Beoordelingsmethodieken

Voor het verkrijgen van voldoende nauwkeurige kengetallen zijn een groot aantal exterieurbeoordelingen noodzakelijk. Gemak en snelheid van beoordelen zijn dan belangrijke criteria voor de keuze van de beoordelingsmethode. Visuele beoordeling voldoet aan die criteria. Uit statistisch oogpunt en voor de interpretatie van de resultaten biedt het beoordelen van enkelvoudige kenmerken welke gescoord worden op een lineaire schaal, duidelijke voordelen boven andere visuele beoordelingssystemen. Daarom zijn voor dit onderzoek exterieurkenmerken zoveel mogelijk enkelvoudig gedefinieerd en beschreven op een lineaire schaal welke loopt van 0 tot 9 met ½ intervallen. Zes kenmerken hebben betrekking op de lichaamsbouw en -omvang, drie kenmerken beschrijven de stand van de voorpoten, terwijl achterpoten en klauwen worden gekarakteriseerd door acht kenmerken. Verder worden beoordeeld: mate van zijwaarts bewegen van de achterhand tijdens het lopen, de soepelheid van het lopen (gangen), kwaliteit en grootte van de spenen en verwachte levensduur, te noteren als het aantal verwachte nog te produceren worpen.

De bruikbaarheid van het lineaire beoordelingssysteem is beoordeeld op grond van: persoonsverschillen, gebruik van de 19 schaalklassen, nauwkeurigheid van beoordelen (herhaalbaarheid) en de correlaties tussen de beoordeelde kenmerken. Daartoe zijn 40 beren van ongeveer 100 kg op één dag twee keer beoordeeld door 10 beoordelaars. Er werden duidelijke persoonsverschillen in gemiddelde en spreiding gevonden. Ook werd bij de meeste personen een duidelijke voorkeur voor het gebruik van gehele getallen geconstateerd. De gemiddelde herhaalbaarheid binnen personen is 0.60 en tussen personen 0.30. Het met behulp van factor analyse reduceren van het aantal kenmerken door kenmerken samen te voegen tot een nieuw kenmerk, resulteerde in de volgende onderling onafhankelijke nieuwe kenmerken: 1) zijaanzicht van de poten, 2) bewegingen/levensduur, 3) grootte en omvang, 4) lichaamsbouw, en 5) achterpoten en klauwen.

De praktische bruikbaarheid van het lineaire beoordelingssysteem voor exterieur is duidelijk afhankelijk van de beoordelaar. Wanneer de juiste mensen worden gekozen en wanneer zij regelmatig worden getraind en begeleid, dan kan de bruikbaarheid van het systeem als goed geclassificeerd worden.

Erfelijkheid van exterieur kenmerken en relaties met produktie

In hoofdstuk 3 zijn de erfelijke achtergrond van exterieur en de relaties met produktiekenmerken geanalyseerd in materiaal dat afkomstig was van toetsstallen van diverse fokkerij-instellingen. De resultaten zijn gebaseerd op gegevens van 2792 onbeperkt gevoerde en voor het merendeel individueel gehuisveste beren uit diverse lijnen. Lichaamsgrootte is middelmatig erfelijk (h^2=0.15-0.30). De erfelijkheidsgraad van individuele achterpoot-kenmerken varieert van 0.22 tot 0.30. Gangen en algehele gesteldheid zijn matig erfelijk (h^2~0.15). Duidelijk genetische correlaties tussen groei en enkele exterieurkenmerken (r_g=0.4-0.5) geven aan dat trager groeiende dieren aanleg hebben voor steiler voorpootkoten, droger hakken en sabelbenige achterpoten. Dieren met een hoge voederefficiëntie hebben aanleg voor O-benige achterpoten.

Het meenemen van exterieurbeoordelingen voor lichaamsmaten in de fokwaardeschatting voor produktieaanleg geeft slechts een geringe verhoging van de nauwkeurigheid van die schatting. Het beoordelen van die exterieurkenmerken voor het hiervoor genoemde doel lijkt daarom niet zinvol.

Beenwerkproblemen zullen zich het eerst manifesteren in het kenmerk gangen. Een selectie op het kenmerk gangen met als doel het verminderen van de beenwerkproblemen blijkt gevolgen te hebben voor de genetische vooruitgang in de produktiekenmerken. Een voorselectie van toetsberen waarbij 50% van de dieren afgekeurd wordt op gangen vermindert de genetische vooruitgang voor de produktiekenmerken met 24%.

Exterieurkenmerken en constitutie

In de praktijk is de belangstelling voor het varkensexterieur voornamelijk het gevolg van de veronderstelde relaties tussen exterieur en de door de constitutie bepaalde levensduur. Het onderzoek naar deze relaties is gebaseerd op exterieurbeoordelingen aan enkele duizenden gelten op 24 zeugenbedrijven. Het overgrote deel van de beoordeelde gelten is aangekocht op een leeftijd van zes maanden. Een aanzienlijke voorselectie op exterieur heeft dan waarschijnlijk reeds plaats gevonden. In het vierde en vijfde hoofdstuk zijn de gevonden relaties van exterieur met redenen van uitval en levensduur beschreven. Enkele exterieurkenmerken beoordeeld aan gelten vertonen een verband met uitval op grond van beengebreken. Zeugen uitgevallen vóór de vierde worp vanwege beengebreken, waren als gelt ten opzichte van de gelten die later bewezen hebben minimaal vier worpen te kunnen produceren, langer en breder, hadden minder steile achterpoten, en hadden een groter deel van de achterpoten bedekt met knobbels. Hun gangen waren trager terwijl de achterhand meer heen en weer bewoog, en de beoordeling van de algehele gesteldheid was minder.

Bij de meeste beenwerkkenmerken waren zowel hoge als lage scores (extremen) ongunstig gerelateerd met levensduur. Afwijking van het gemiddelde exterieur met 1 eenheid spreiding (s.d.), heeft bij diverse exterieurkenmerken een duidelijk effect op de levensduur. Een matig aangesloten schouder is negatief gerelateerd aan levensduur. Brede hammen zijn negatief gecorreleerd met levensduur (-53 dagen per s.d.), terwijl bij 1 s.d. smallere hammen de levensduur gemiddeld 44 dagen langer is. De levensduur neemt toe met het droger worden van de hakken. Soepele gangen, weinig zijwaarts bewegende achterhand en een hogere score voor de algehele gesteldheid zijn gunstig voor een hoge levensduur (respectievelijk 67, 44 en 42 dagen per s.d.). Ondanks de vermoedelijke voorselectie op exterieur op zes maanden leeftijd, blijkt de bij diverse kenmerken nog aanwezige variatie voldoende te zijn om duidelijke verschillen in levensduur aan te kunnen tonen.

Belangrijkste conclusies

Uit dit proefschrift kunnen de volgende conclusies getrokken worden:

- Lineaire beoordeling van het exterieur is praktisch goed uitvoerbaar. Wanneer de juiste mensen worden ingeschakeld voor de exterieurbeoordelingen en wanneer zij regelmatig worden getraind en begeleid, dan is de nauwkeurigheid van de beoordelingen acceptabel. De correlatiestructuur tussen de exterieurkenmerken is zodanig dat het samenvoegen van kenmerken tot een kleiner aantal nieuwe kenmerken niet is aan te bevelen.
- Beoordeling van de lichaamsbouw en -omvang ten behoeve van de fokwaardeschatting voor produktiekenmerken is niet relevant.
- Een brede midden- en achterhand als gelt zijn ongunstig gerelateerd aan levensduur. Een verhoging van de gemiddelde levensduur van zeugen kan bereikt worden door selectie op exterieur bij gelten. Brede dieren met trage gangen komen als eerste in aanmerking om afgevoerd te worden.
- Selectie op levensduur in zeugenlijnen dient zich te concentreren op de kenmerken: gangen en lichaamsbreedte, terwijl dieren met extreme pootstanden, in het bijzonder bokbenige voorpoten, onderstandige en steile achterpoten, niet voor de fokkerij moeten worden ingezet. Voor een hoge levensduur zijn niet te brede dieren met soepele gangen gewenst.

Curriculum vitae

Evert Jan van Steenbergen werd op 26 januari 1959 geboren te Bennekom (gemeente Ede), waar hij op een veehouderijbedrijf opgroeide. In 1977 behaalde hij het VWO diploma aan het Chr. Streeklyceum te Ede. In datzelfde jaar begon hij met zijn studie Zoötechniek aan de toenmalige Landbouwhogeschool te Wageningen. Het doctoraal examen werd afgelegd in januari 1984 met als hoofdvakken de Veeteelt en de Gezondheids- en Ziekteleer der Huisdieren en als bijvak Agrarische Bedrijfseconomie. Van augustus 1983 tot januari 1984 was hij werkzaam als docent aan de Chr. Middelbare Agrarische School te Barneveld. Vanaf 9 januari 1984 was hij aangesteld als wetenschappelijk medewerker in tijdelijke dienst bij de vakgroep Veefokkerij. Sinds 5 maart 1990 is hij werkzaam als geneticus bij de varkensfokkerijgroepering Cofok te Oosterhout (Gld).