CHAPTER V

STRUCTURING OF DESIRED BREEDING OBJECTIVES FOR THE PIG INDUSTRY

(TAKING COGNIZANCE OF THE MARKET, CONSUMER, SUPPLY CHAIN AND GENETIC COMPONENTS)

"Animal products of the future (including pork) will have to consider a strategy of value adding and effective advertising to establish a brand identity which is tailormade to the tastes of the consumers"

- J.H. Hofmeyr, 1997

5.1 INTRODUCTION

A fundamental question that needs to be addressed in the modern era of breeding and more specifically the modern era of breeding objectives, is the following: *"Which genetic traits can be selected for (or altered) at the genome level to satisfy the consumer's sensory and/organoleptic requirements without impairing efficiency in the livestock production chain?"*. According to Dirinck, De Winne, Casteels & Frigg (1996) the sensory attributes/traits of meat (appearance, colour, tenderness, juiciness and flavour) are conductive to the purchasing behaviour of consumers. These sensory attributes of pork are also known as the primary acceptance criteria of pork. It is therefore of utmost importance that the studbreeder and producer knows exactly what these primary acceptance criteria of pork are (Vide Fig 5.1).

Meat quality today, is not only about improving the organoleptic traits (tenderness, juiciness, flavour & marbling) but also about increasing uniformity (De Vries *et al*., 1999). Consistency of performance (from the point of view of meat quality) will become increasingly important in future.

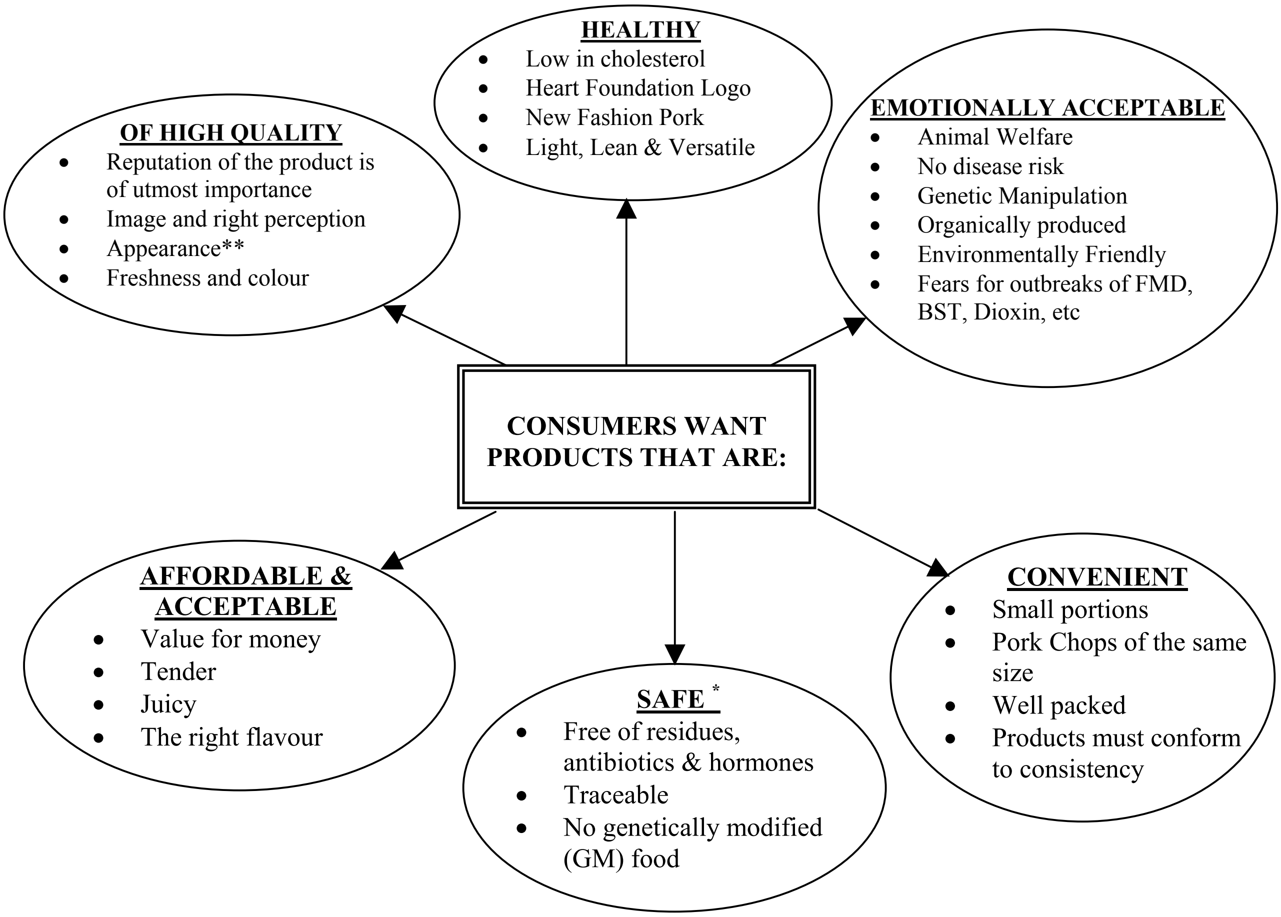

Fig 5.1 Attributes that a product should have, as perceived by the consumer

* Venter (2001) indicated that food safety has emerged as the single most important demand driver of red meat.

** Appearance is not an indicative guide to meat quality, but is foremost the first impression the consumer gets when buying pork.

Consumer surveys world-wide have proven that tenderness, followed by juiciness, flavour and colour are the most important sensory quality attributes of meat, irrespective of animal species (Schönfeld, 2001).

The rationale behind this study is the philosophy that breeding objectives of the future must reconcile meat quality, genetics and the consumer. If meat quality is affected at the genetic level, the farm level, during transportation and at the slaughterhouse level (Van Oeckel, 1999 - Vide 1.2.3), then it must be addressed as an integrated approach (Vide Fig 5.2). A further question that needs to be answered is the following: *Which one (or how many) of the following six dimensions, should the breeding objective actually address?*

i) Structuring of breeding objectives to satisfy the present consumer or the consumer of the future

ii) Structuring of breeding objectives to satisfy the seedstock producer and/or the commercial producer

iii) Structuring of breeding objectives to satisfy the slaughterhouses and processors

iv) Structuring of breeding objectives whilst including or excluding genetic correlations (Vide 2.4.3.2 and Fig 5.6)

v) Structuring of breeding objectives to be in tandem with the maturity of the supply chains in the industry

vi) Structuring of breeding objectives to satisfy all the links in the supply chain.

According to Grunert *et al.* (1998), the information on the end user's needs and trends is crucial. The value of a product (as perceived by the end user) sets the limit for the price of a product and therefore the returns (earnings) for the entire value chain. Van Trijp, Steenkamp & Candel (1998) indicated a positive ambivalence between perceive quality[20] and economic returns. The higher the perceived quality of a product, the higher is the selling price resulting in an increased market share and profitability.

According to Steenkamp (1998), an investigation was conducted in 1992 by AGB/Euro panel in seven EU countries pertaining to a set of fourteen (N=14) major evaluation criteria *when it comes to the general choice of a product* (including food products). The **five most importantly ranked criteria** (accounting for no less than 75 % of the variation) were:

- product quality (25,2 %)
- price (16,5 %)
- reputation (brand name) (14,4 %)
- freshness (9,4 %)
- guarantee (9,4 %)

( ) Brackets indicating the % contribution to total variation

[20] Perceived product quality can be defined as the consumer's perception of the fitness for use of the product with respect to its intended purpose, relative to alternatives.

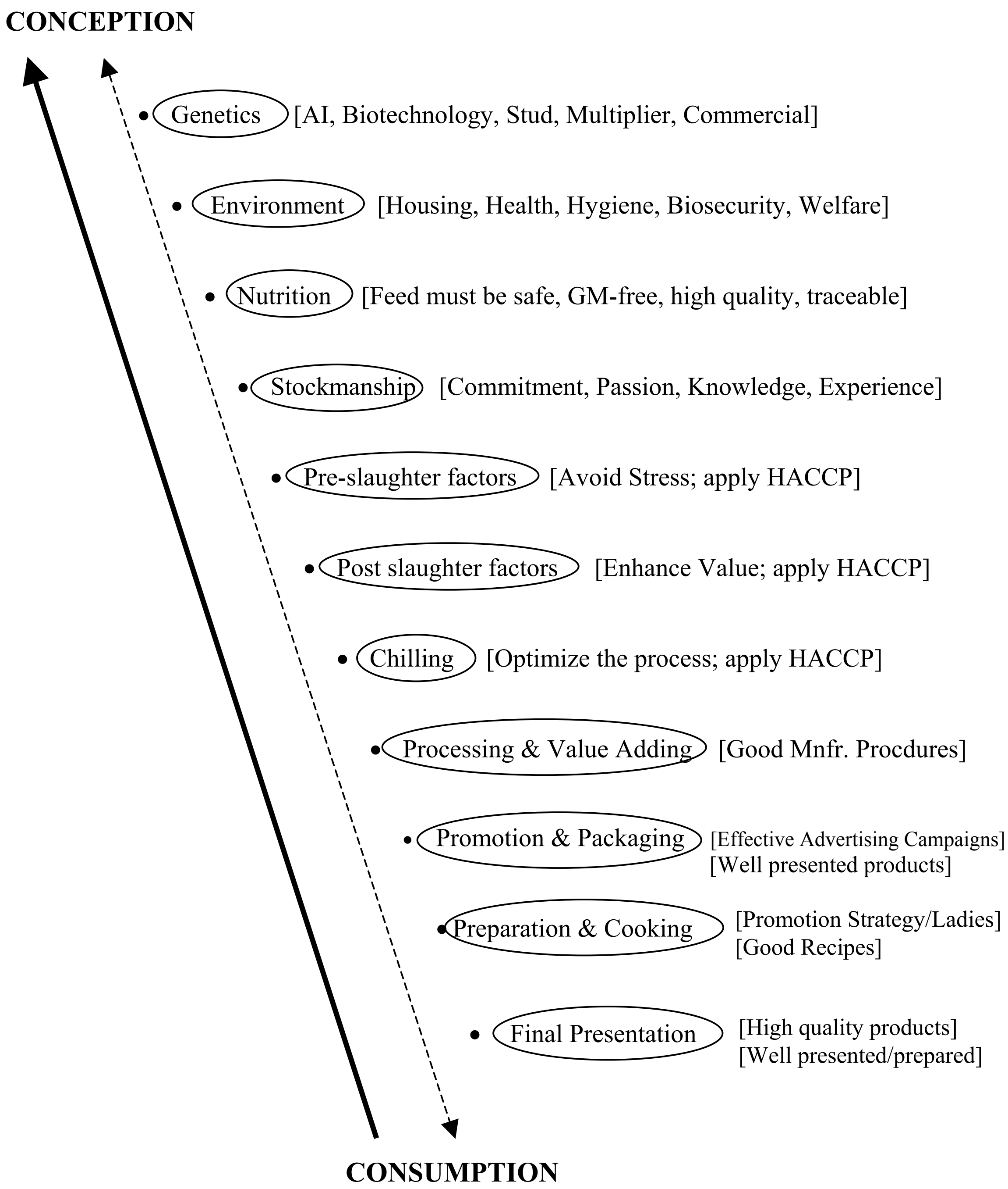

Fig 5.2 Science to guarantee eating quality (Dundon, Sundstrom & Gaden, 2000)

• Critical Control Points

- - → Traceability

← Consumer Feedback

(Pivotal to any quality guarantee or assurance plan is that **all** [ ] the factors that can have an influence on quality must be identified, described and accounted for).

5.2 BREEDING OBJECTIVES - GENERAL PERSPECTIVES

During the period from 1960 to 1990 studbreeders and breeding companies across the globe exploited the strong positive genetic correlation between ultrasonic backfat thickness and carcass lean meat percentage. Fowler, Bichard & Pease (1976) indicated that the then object of future pig production was to produce lean meat as cost effectively as possible. The eventual genetic merit of commercial pig production that is fixed in the seedstock populations (nucleus herds), must reflect precisely the production goals at commercial levels (Clutter & Brascamp, 1998). Goddard (1998) described the breeding objective as... *"a profit function (directive) that takes genetic values as input and produces profit as outcome"*. The traits in the **profit function,** however, must be a true reflection of all sources of income and costs. Furthermore, the traits that are included in the breeding objective must allow the geneticist and studbreeder to accurately predict and monitor genetic change.

According to Webb (1998), genetic/breeding objectives can be classified in two distinct objectives:

I Selecting for those traits conducive to higher performance levels:

- lean tissue growth rate
- lean percentage
- feed conversion (by using FIRE[21])
- uniform carcasses
- conformation
- pigs per sow/year.

II Selecting for those traits that increase the existing potential on the farm:

- disease resistance (or healthy pigs)
- adaptability
- eating behaviour
- stress resistance.

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[21] FIRE stands for Feed Intake Recording Equipment or electronic feeding stations, where feed intake is recorded electronically through transponder ear tags. Thus individual feed intake for pigs (penned in groups of 12-15) is precisely monitored since each meal (time eaten and amount eaten) is recorded individually. The system furthermore provides detailed measurements of feeding patterns and behaviour for different breeds and sexes. Through FIRE the opportunity exists to identify pigs that eat more in the early part of their lives (up to 40 kg) and less in the later parts (from 40-100 kg) [Vide Fig 5.3].

Clutter & Brascamp (1998) indicated that **the overriding objective** of the pork enterprise is to produce quality lean meat as efficiently as possible. Thus the lean gain potential and the lean gain efficiency are two important components of the breeding objective. To achieve the overriding objective, the economically important traits must be included in the breeding objective as well as their relative economic importance. De Vries (1989) described the economic value of the trait to be calculated as follows: *"The ratio of the change in profit (or efficiency) to a (small) unit change in the genetic level of the trait"*. These calculations should be based on individuals, parents and progeny and finally (but most importantly) total herd efficiency. According to Ollivier, Gueblez, Webb & Van der Steen (1990) an important prerequisite for breeding objectives is that it should be defined according to the selection regime applied. Cameron (1998) indicated that the efficiency of nutrient utilization will constitute a major component of the breeding objective. It is thus important to take cognizance of the fact that the breeding objective can not be viewed in isolation. In this regard Webb (1998) indicated that the main selection objective for the future should be lean tissue growth rate. Furthermore...to identify those pigs with appetite and the ability to convert the extra feed to lean meat rather than fat. This can now be monitored through FIRE (Vide Fig 5.3).

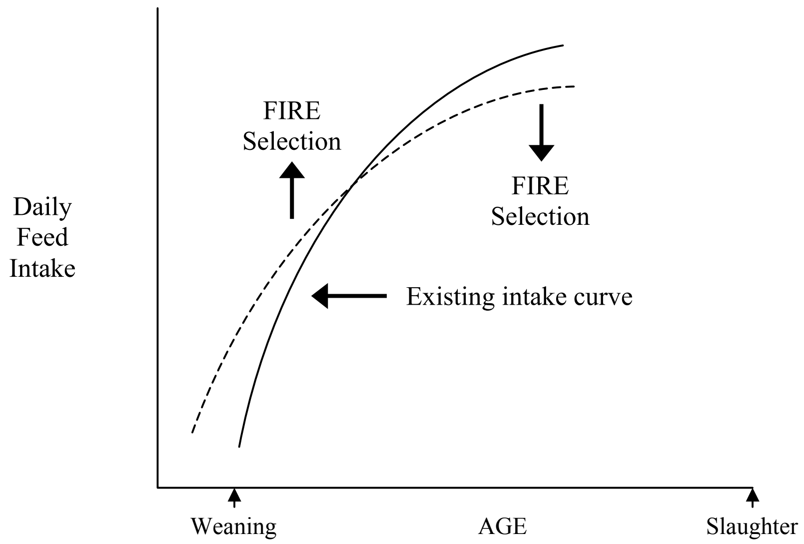

Fig 5.3 FIRE assisted selection to improve early feed intake and control late feed intake (Webb, 1998)

5.2.1 Economic Aspects of the Breeding Objective

According to Fowler, Bichard & Pease (1976), all measurable traits that affect the profitability of pig production AND which have a genetic component should be included in the breeding objective. The balance should be to maximize the accuracy of the EBV for profit and minimize the cost of measurement (Goddard, 1999).

A frequently asked question is: *"Which traits should be included in the breeding objective or the profit function?"*. Goddard (1998) provided thoughtful guidelines in this regard:

i) Distinguish between traits[22] in the breeding objective and traits in the selection criteria (practice)

ii) Traits in the profit function should be a true reflection of all sources of income and costs

iii) Do not exclude traits because information is lacking

iv) Only exclude traits if no genetic variation exists

v) Do not replace a trait by a prediction, unless the prediction is completely (100 %) accurate

vi) Traits that are left out, should be predicted from the other traits, using the genetic regression

vii) Covariances should be stated explicitly in matrices of genetic parameters (and not be incorporated in the profit function)

viii) Special emphasis should be put on the exact definition of those traits that determine profit.

According to the author points (v) and (vi) are contradictory and should be viewed with caution or omitted.

Ponzoni & Gifford (1990) indicated that the development of breeding objectives for most species, generally involves the following distinct phases:

i) Specify the breeding, production and marketing systems

ii) Indentify the sources of income and expense in commercial herds

iii) Ascertain those biological traits that impact on income and expense

iv) Derivation of the economic value[23] of each trait and finally the relative economics of the various traits.

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[22] Traits in the breeding objective that determine profit are not necessarily the same as those traits that are actually applied in practice (selection criteria).

[23] The economic value of each trait can be calculated as $P^Y - P$. P is the difference between income (**I**) and expense (**E**), calculated at the mean for all traits. P^Y is the value of **I - E**, after increasing a specific trait by one unit. P can be expressed as a function of the traits in the breeding objective as follows:

$$P = \sum_{i=1}^{m} Exprs._i (V_i - C_i)X_i - K$$

$Exprs._i$; V_i and C_i are the number of expressions, the Value per unit and the Cost per unit in monetary terms for the trait X_i respectively. K represents the fixed cost (Ponzoni & Gifford, 1990)

The profit function on a herd basis is written as follows:

$\bar{y} = \bar{f}(\bar{g};m)$ .... (1) Goddard (1998)

$\bar{y}$ = farm profit

$\bar{g}$ = vector of mean genetic values of the herd (one per trait)

m = vector of the management controlled variables

[For an individual, the profit function is written as: y = f(g;m) where f and $\bar{f}$ are the parameterization used for an individual or group respectively]

This profit function (1) describes the effect of a genetic change on profit. The profit function can be altered as follows:

$\bar{y} = \bar{f}(\bar{g};n) = n(r - c) - F$, where

n = number of animals in the herd

r = returns per animal

c = cost per animal

F = fixed costs

An important consideration in the profit function is the derivation of economic weights. The economic weights are the effect thereof on herd profit by increasing (or decreasing) g by a small amount for each individual. Thus:

$$\frac{\partial \bar{f}}{\partial \mathbf{g}}(\bar{\mathbf{g}}_c) = E\left(\frac{\partial f}{\partial \mathbf{g}}\right)$$, where $\bar{g}_c$ is the current (herd) mean.

If **g** is normally distributed and f is linear or quadratic, the economic weight is expressed as:

$\frac{\partial f}{\partial g}(\bar{g}_c)$ .... (2) Goddard (1998)

The question that arises, is: "How, should profit be expressed and/or justified?"

(i) From the producer's, the breeding company's or the industry's perspective

(ii) In which format to express profit (per sow per year; per baconer marketed, per kg meat sold or per kg meat sold per square meter)?

(iii) Should profit (y) be calculated as: R - C or R / C ?

(where R = total returns and C = total costs)

(iv) Profit per animal for a farm with a given number of animals (n) is expressed as:

$$y/n = \frac{f(g;n)}{n}$$

Profit can also be expressed by means of (i) a bio-economic model, which incorporates all sources of income and costs comprehensively (Stewart, Bache, Harris, Einstein, Lofgren & Schinckel, 1990) or (ii) a regression approach which uses field data to estimate a multiple regression equation (Goddard, 1998).

Should consensus be reached on the fiscal objective of profit per farm per year or profit per day as desirable, achievable and correct, it should also be discounted from a supply chain perspective, namely:

Link in the supply chain ➡	PRODUCER ⬇	PROCESSOR ⬇	CONSUMER ⬇
Objective	• Highest possible profit/sow/year • Total herd efficiency • Maximum profit per day	• throughput • uniformity • carcass quality • reliability of production	• To get a safe product with value, acceptance, wholesomeness and taste (Fig 5.1)- continuously of the same quality
How to achieve	• Business Approach • Applying science and breeding technology such as DNA probes, MAS, AI and BLUP	• Quality Genetics • Quality Assurance • Traceability • Blueprint for optimum slaughter, processing and meat quality	• Stay in close touch with the consumer • Efficient consumer feedback • Consumer surveys

5.2.2 Traits to be Included in the Breeding Objective

Inclusion of traits in the breeding objective should be viewed within the context of the breeding programme or breeding policy of the stud herds and the broader pig industry. To achieve the objectives mentioned above, special attention must be given to the following aspects:

(i) **Health** has evolved over the last decade especially as a major issue for the consumer. Furthermore, the cost to control diseases and health are estimated at 10 - 20 % of production costs. In this regard Webb (1998) stated that disease(s) will pose the single biggest threat to sow productivity and pig production in future. Thus, health *per se* and healthy pigs (that grow faster, more efficiently and cost less) must feature as a building block in the breeding objective. From a genetic point of view disease resistant genes and antibody encoding genes could enhance the improvement of health.

(ii) **Selection methods** and traits included in the initial breeding objective in the genetic or input link of the supply chain will be manifested eventually in the histochemical and biochemical properties of the muscle of the product and ultimately be accepted or rejected by the consumer and/or processor. In pursuit of selecting for leaner pigs and subsequently a bigger proportion of large muscle fibres, the end product could be reduced meat quality accentuated by insufficient oxygen transfer, poor capillarisation and the elimination of end products such as lactate and CO_2 (carbon dioxide) (Karlson, Klont & Fernandez, 1999).

(iii) **Optimization of crossbreeding programmes** in pigs can be traced back to the pioneering work (in the 1960's) of the late Professor Charlie Smith on the effect and utilization of heterosis in commercial pig production. Optimization of breeding programmes is *inter alia* dependent upon the utilization of sire and dam lines (Vide ANNEXURE VI). Specialized selection in sire and dam lines has the advantage of:

(a) enhancement of heterosis

(b) diversity in these lines will ensure flexibility in the breeding system and also enable the breeder to adapt to market changes

(c) counteracting the genetic antagonism between lean tissue feed conversion (LTFC) and reproduction.

5.2.2.1 Reproductive Traits

Litter size (being the most important economic trait from a reproduction and production perspective) will always constitute a major component of selection goals, mostly in maternal lines[24], but also other lines. Although reproductive traits in general have a heritability of less than 10 %, certain components of fertility have a moderate heritability (Vide Table 5.1).

In this regard Rydhmer (2000), furnished pig scientists and geneticists with an in-depth and thoughtful review on lifetime genetics of sow reproduction. Nicholas (1997) indicated that reproductive traits normally have near zero genetic correlations with other traits, implying that sustained selection for reproductive performance is attainable and practical. Extreme care should be taken of adequate backfat levels in the pig industry. Although pork is being perceived as too fat

[24] The objective in the maternal lines is genetic improvement in prolificacy, mothering ability, sow longevity and to improve (shorten) sexual maturity - thus higher lifetime reproduction efficiency in nucleus and stud herds.

by the consumer (Vide 2.6), adequate backfat levels are conducive to improved reproductive efficiency and palatability of the product.

Table 5.1 A summary of the different reproductive traits and their heritabilities (h^2) to be included in the breeding objective (Rothschild & Bidanel, 1998; Smital, 2001)**

BOARS		SOWS	
Reproductive trait	**h^2**	**Reproductive trait**	**h^2**
Age at sexual maturity	0.33	Decreased age at puberty	0.33
Libido and mating ability	0.15	Ovulation rate	0.32
Testes size (circumference, volume and weight)	0.37	Number of services per conception	0.27
Sperm quantity and quality	0.35	Weaning to oestrus interval	0.25
Total number of sperm** (PO)	0.42	Weaning to conception interval	0.30
Hypothetical insemination dose ** (ID_H)	0.39	Milk production (21 day litter weight)	0.17
Teat number	0.21	Teat number	0.21
		Number of piglets born alive	0.10
		Number of piglets weaned (pre-weaning mortality)	0.07

** Smital (2001) indicated heritability estimates of 0.42 and 0.39 for the two compounded semen traits: PO (total number of sperm) and ID_H (Hypothetical insemination dose) and recommends inclusion of one of these traits in breeding value estimation, on condition that the animal model is being used.

5.2.2.2 Production Traits

During the production phase of pig production the emphasis is overwhelmingly on:

- time efficiency (to grow and reach the desired target (carcass) weight in the shortest possible time)

- input efficiency (to utilize all resources and raw materials efficiently)
- output efficiency (to obtain the heaviest carcass, with the highest dressing percentage and the highest percentage lean meat).

Since the mid 1960's, selection efficiency, through performance testing in South Africa, had uninterruptedly been on growth rate, feed conversion, reducing backfat thickness (thus improving lean meat content) and structural soundness.

Genetic improvement of post weaning production traits, especially the efficiency of lean tissue growth rate and lean tissue feed conversion, has become increasingly important in modern day pig production. Clutter and Brascamp (1998) indicated that LTGR (Lean Tissue Growth Rate) and LTFC (Lean Tissue Feed Conversion) should be included in the breeding goal due to:

(i) moderate heritabilities of 0.34 and 0.31 respectively and
(ii) the accuracy of predicted growth responses in the components of the two traits.

Growth and feed conversion can be expressed differently under different testing scenarios.

TRAIT	EXPRESSION OF TRAIT	PRIMARY TESTING SCENARIO
Growth rate	• lean tissue feed conversion	• monitor feed intake, but allow ad lib feed intake
Growth rate	• lean tissue feed conversion	• monitor feed intake, but restrict feed intake
Growth rate	• lean tissue growth rate	no monitoring of feed intake, but allow *ad lib* feed intake
Feed conversion	• feed: lifetime gain efficiency	individual feed intake or group testing, but individual feed intake (FIRE)
	• feed: carcass lean efficiency	• extrapolate feed efficiency to kg of carcass lean produced

The question arises which testing environment/scenario should be applied to optimise these two traits. Fig 5.4 gives a summary of the various combinations between selection types and feeding type.

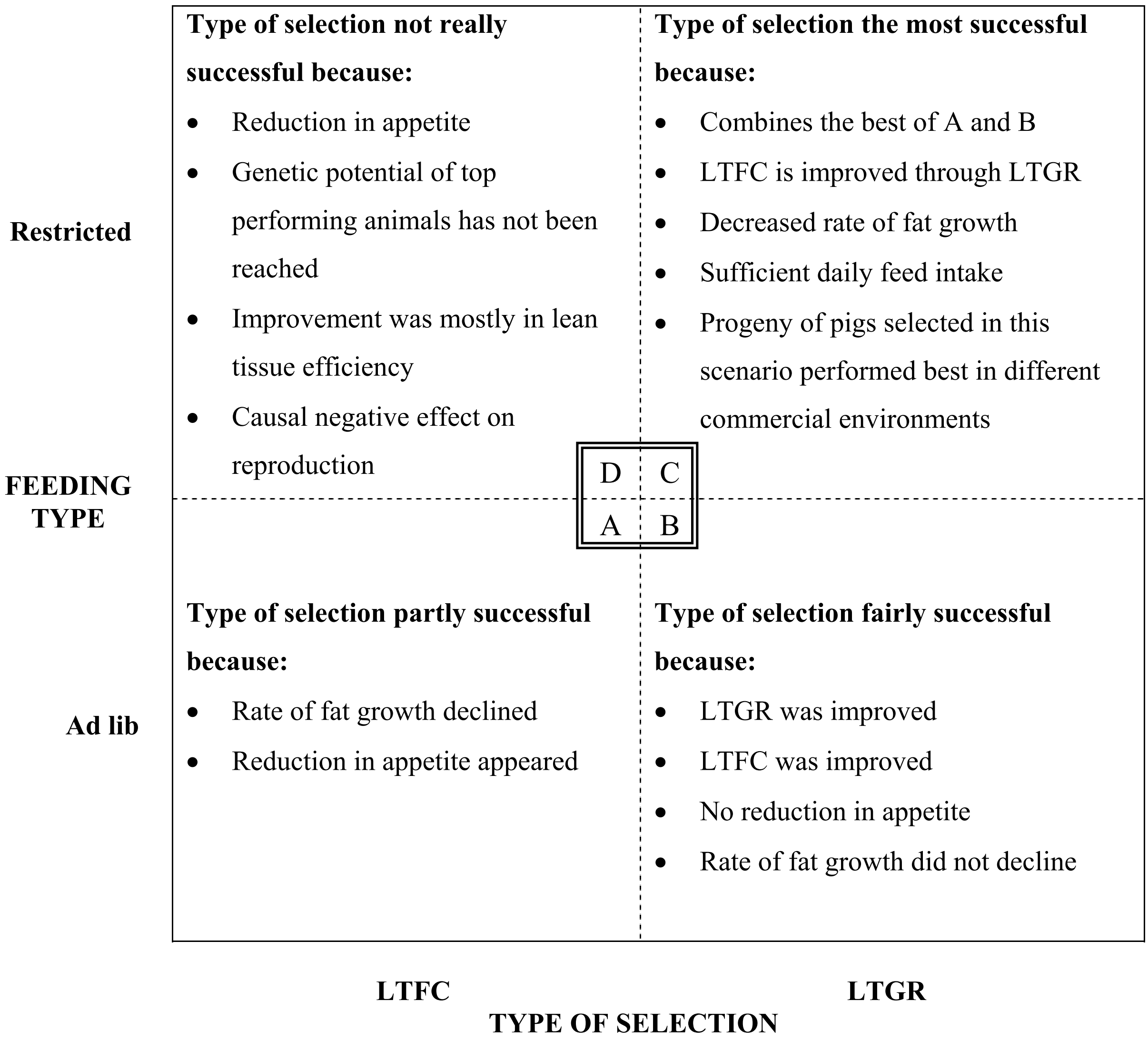


Fig 5.4 Different production effects that can be expected when two different types of selection are compared with two different feeding types (After Clutter & Brascamp, 1998)

From this diagram it appears that the most conducive combination is where the breeder selects directly for lean tissue growth rate under a restricted feeding type (Quadrant C). Although this theory of selection had been proved decades ago, it is not convincingly practiced in South Africa. Application of this method of selection could bear positive results for the stud and commercial pig industry.

5.2.2.3 Carcass Traits

Predictions of carcass parameters based on information obtained from the live animal, either through weighing or ultrasound devices, are valuable tools to assist the studbreeder but will never replace the true (full) carcass evaluation and determinations. A detailed carcass evaluation on the other hand (dissecting the carcass meticuously to ascertain the lean meat, fat and bone percentages) is labour intensive, time consuming, expensive and takes time before the information is readily analyzed, released and assimilated by the industry. For the studbreeder and producer the two most important carcass traits are: (i) dressing percentage and (ii) percentage Hennesy lean meat produced per carcass. Higher carcass weights are normally associated with better profit margins. The genetic parameters for the carcass traits of the S.A. Large White, S.A. Landrace and Duroc breeds were discussed in CHAPTER IV.

5.2.2.4 Meat Quality Traits

An unenviable situation in pig breeding is the marginal genetic antagonism (-0.25) between meat quality criteria (tenderness, juiciness, flavour and overall acceptability) and carcass leanness. Sellier (1998) indicated that the overall acceptability index of pork has positive genetic correlations (r_A) of 0.59; 0.46 and 0.61 with pH_u (ultimate pH), water holding capacity (WHC) and intra muscular fat (IMF), respectively. Ultimate pH (pH_u) has positive genetic correlations (r_A) with almost all components of meat quality (Vide Table 5.2).

Table 5.2 Genetic correlations of certain meat quality traits with pH_1 and pH_u (Le Roy & Sellier, 1994)

Trait	pH_1	pH_u
Drip loss	- 0.27	- 0.71
Water Holding Capacity	- 0.65	0.45
Cooking Loss	- 0.14	- 0.68
Technological Yield	-	0.70
Colour Reflectance	- 0.38	- 0.53
Tenderness	0.27	0.49

As indicated earlier, future breeding objectives must take cognizance of:

(i) The modern demands of the consumer
(ii) The perception (and sometimes moral conviction) of the consumer

A consumer orientated production will necessitate the inclusion of traits such as WHC, pH_u , colour and intramuscular fat whilst the eating qualities (of pork), as preferred by consumers, are wholesomeness, freshness, leanness, juiciness, tenderness, taste and nutritional value. Karlson, Klont and Fernandez (1999) indicated that pre-mortem microscopic factors such as: interaction between muscle fibres, energy metabolism and muscle cell metabolism have a causal effect on post mortem changes and ultimately meat quality. Many factors influence the pre-mortem and post mortem transformation of muscle into meat quality (Vide Fig 5.5). Total understanding of real meat quality and all the factors influencing it, necessitates a **macroscopic**/holistic interpretation of genetic, non-genetic and various other factors.

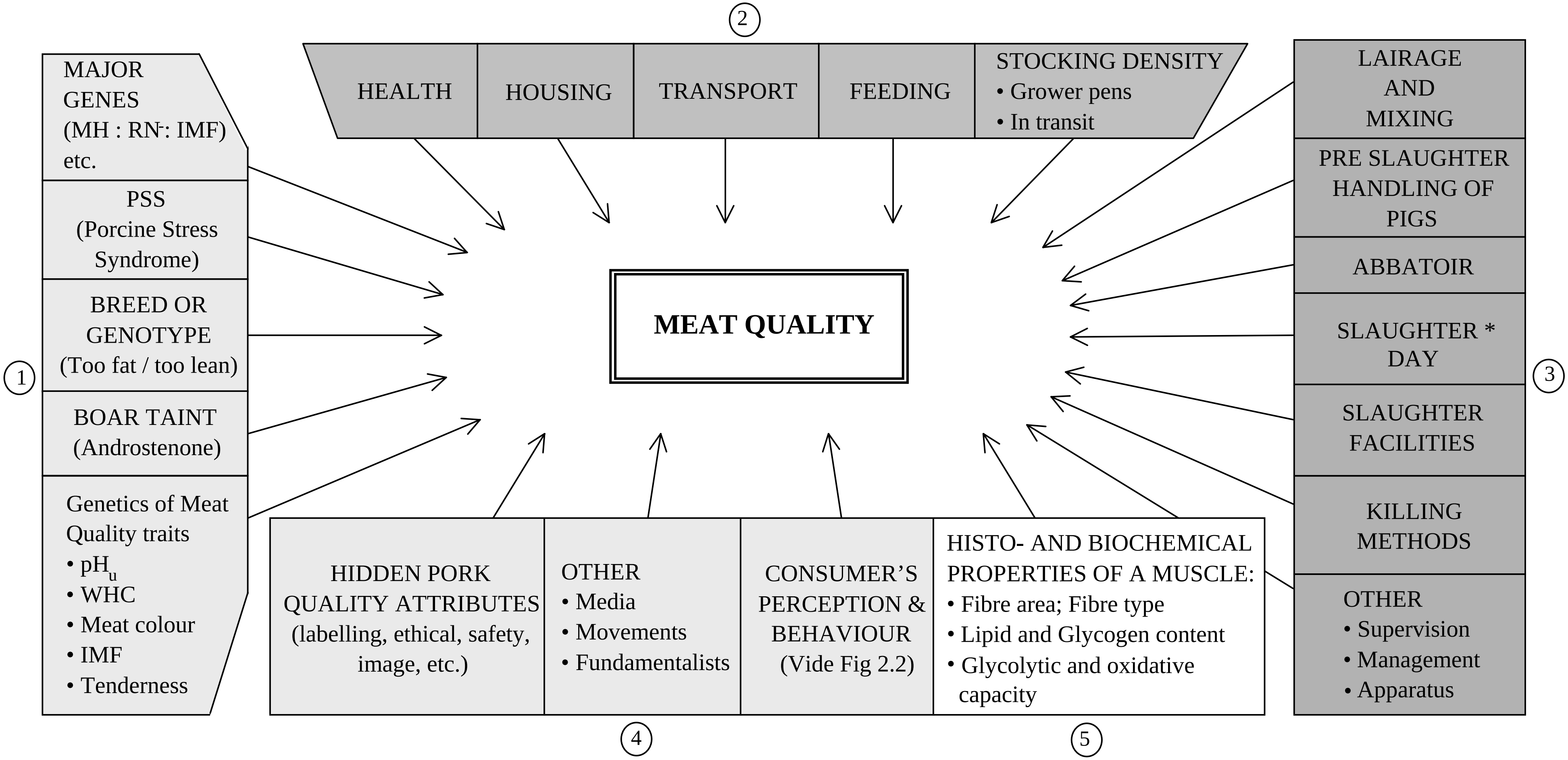


Fig 5.5 Important factors that have an influence on meat quality (Visser, 2001)

(1) = Genetic (2) = Management (3) = The Slaughtering Process (4) = Consumer Related (5) = Chemical Properties

* Hovenier (1993) indicated that "day of slaughter" can be regarded a major factor influencing the ultimate meat quality of pigs. In fact "*...the amount of variance explained by day of slaughter was equal to or larger than the heritabilities of all meat quality traits except intra muscular fat*".

Table 5.3 The effect of major genes, within and across different pig breeds, on meat quality (Visser, 2001)

Breed	Major Gene	Effects
Pietrain, Landrace, Large White, Duroc, Hamphire & Composites	MH*	• Risk of stress deaths • Fast pH decline post mortem • PSE Meat • Excessive drip loss in carcasses
Meishan and Duroc	IMF**	• Positive effect on juiciness and taste • Enhanced eating quality
Hampshire, Laconie and Penshire	RN^{-}***	• Decline in processing and technological yield • Higher cooking loss • Lower waterbinding capacity • Low ultimate pH (pHu)
Tamworth and Large White (certain lines)	Androstenone	• Boar taint • Major consumer resistance • Moderate to high heritability (0.25 - 0.55)

* The MH-gene is a classical example of a major recessive gene that has different effects on different traits simultaneously. In this regard Gueblez *et al.*, 1995, as quoted by Goddard (1999), showed that the MH-gene has a big (negative) effect on meat quality, a medium (positive) effect on lean meat percentage and a minor effect on growth rate.

** Recessive major gene for intra-muscular fat, originating from the Meishan breed but also present in the Duroc breed. As the % Duroc genes increased from 0 % to 75 %, taste panellists scored the meat to be more juicy and tender with a better flavour. According to Hermesch (1997) a higher intra-muscular fat content is genetically related to a higher pH_{45} and subsequently a reduced drip loss percentage and a darker colour of meat.

*** The RN^{-} gene only partially explains variation in the water loss in pork. The additive effects of many other genes also impact on pork quality.

In pursuit of quality and even more so from a breeding objective point of view (Vide Table 5.3: *), prudent elimination of the halothane gene (MH-gene) should be encouraged. Webb (1998) provided four irrefutable reasons in this regard:

(i) reducing the shelf life and natural appeal of fresh pork
(ii) an increased lean meat percentage has an adverse cumulative effect on meat quality
(iii) high cost of maintaining stress susceptible (nn) populations
(iv) the impact undetected carriers can have on a population.

According to Sellier (1998), the difference between **NN** (homozygous normal) and **nn** (homozygous recessive) pigs with regard to meat quality is substantial ranging from 0.5 to 3.0 standard deviation (Vide Table 5.4).

Table 5.4 The difference between NN and nn pigs with regard to meat quality (Sellier, 1998)

Meat quality trait	**Advantage of NN over nn pigs** Expressed in phenotypic standard deviation (SD)
pH_1	3 SD
Meat colour (L* value)	1 SD
Drip loss (WHC)	1 SD
Tenderness	1 SD
Technological yield (ham)	0.5 SD

For sensory meat quality, Hovenier (1993) regarded the following five traits as being important:

- pH_u (0.30)
- water holding capacity (0.29)
- meat colour (0.30)
- intra-muscular fat (0.61)
- tenderness (0.30)

[Brackets are indicating the approximate heritability values of the different traits - Vide Table 2.5] Sellier (1998) indicated heritability estimates for flavour and juiciness to be in the region of 10 % (h^2 = 0.10) and heritability for the compositional traits (water, stearic and linoleic acid contents) to range from 0.35 - 0.65.

The inclusion of meat quality in the breeding goal must be evaluated from the following angles of incidence:

(i) The **genetic antagonism** that exists between the production and meat quality traits (Vide Fig 5.6)

(ii) The many **genetic and even more non-genetic factors** (Vide Fig 5.5) that influence meat quality. In this regard, the effect of "slaughter day" has a profound effect or impact on meat quality

(iii) Ascertaining **meat quality on the live animal** is difficult and not completely accurate. A thorough meat quality evaluation on the carcass is preceded by killing the animal. Meat quality as perceived by the consumer is best described by taste panels and market surveys. Ascertaining meat quality on the genetic or molecular level, calls for genome mapping, identification of major genes related to meat quality, marker genes and other available/ affordable tools, scientists and well equipped laboratories fuelled by patents and/or licencing agreements (which are inherently expensive).

(iv) Can the time, labour and slaughtering costs, sacrifice of life, costs of laboratory equipment and **long turnaround** times before the data can be used at the breeding (input) level be warranted/justified?

(v) **Differences between the levels of production** and meat quality traits will increase during each generation when the end products from two different breeding programmes (one with and the other without meat quality in the breeding goal) are compared with each other (Hovenier, 1993).

(vi) Finally, **which tier in the supply chain is the most likely to benefit from the inclusion of meat quality in the breeding goal** and which tier is the most likely to incur costs without any benefits? (Vide Table 5.5)

Table 5.5 The different tiers in the pig production chain that will incur expenses (-) and that will benefit (+) from the inclusion of meat quality in the breeding goal

TIERS	EFFECTS	Will benefit (+) Will incur costs (-)
Breeding and Multiplication	- DNA Tests	- - - -
	- Measuring the meat quality traits in breeding and slaughter stock	- - - -
	- Marker Assisted Selection	- - - -
Commercial Producers	- Obtaining the right stock with the desired genetic composition	- -
	- Correlated responses with production traits	- -
	- No guaranteed payment system	- -
Weaner Production	- Uncertain	0
Abattoirs	- Improved water holding capacity	+
	- Improved lean meat content of the carcass	?
	- Measuring meat quality and align payment	-
Processing Industry and Retail Trade	- Improved meat quality	+ +
	- Improved technological yield	+ +
	- Improved freshness/keeping ability	+ +
Consumers	- Improved sensory attributes	+ + +
	- Improved tenderness, taste & flavour	+ + +

Source: Hovenier (1993)

Given the causal positive effect of meat quality traits on consumer acceptance and ensuring sustainable long term market share to the stud breeder it is recommended that the meat quality traits pH_u, water holding capacity, tenderness, intramuscular fat and meat colour (to a lesser extend), should be included in the breeding objective (Vide Table 5.6 and ANNEXURE VII).

Table 5.6 Meat quality traits which are recommended to be included in future breeding objectives for the South African pig stud industry

Trait	Reason for inclusion
pH_u (ultimate pH of the meat 24 hours after slaughter)	• This trait has very favourable genetic correlation with almost all components of meat quality (Vide Table 5.2). A higher pH_u is associated with lower drip loss, meat with a darker colour and improved tenderness of meat
Water holding capacity	• Positive correlation with overall acceptability • It has essential technological quality attributes • It has a positive effect on yield and also saleability
Tenderness	• Most important sensory trait for the consumer • One of the primary consumer acceptance criteria of pork
Intra-muscular Fat	• Affects the juiciness, taste and tenderness of pork positively • Heritability of this trait is high (0.5 - 0.61) • Trait has a high overall acceptability as indicated and experienced by taste panellists • Selection for increased intramuscular fat (IMF) and increased lean meat content can be done <u>simultaneously</u> due to: relative low genetic correlation (-0.25 to -0.37) between the two traits and the high heritability (0.5 - 0.61) of this trait (Vide 5.3.4).
Meat Colour*	• It affects the consumer's impression and acceptance of pork • Aesthetic appreciation is accentuated by colour • Positive effect on saleability and yield

* According to Cameron (1990) the use of repeat measurements (using between- and within -animal variance components) for meat colour traits (especially muscle light reflectance) is recommended to increase the accuracy of an animal's EBV for selection purposes, should this trait be included in the breeding objective. Meat colour is also a function of the density and structural conditions of the muscle fibres (Lo *et al*., 1992) and can be measured subjectively or objectively (Vide ANNEXURE VII).

5.3 GENETIC CORRELATIONS BETWEEN THE VARIOUS TRAITS LINKED TO PIG PRODUCTION

Genetics (excluding the effect of major genes) account for approximately 30 % in the most meat quality traits (Vide 2.4.3). The heritability range of meat quality traits (as depicted in Table 2.5) is moderate, which implicates that modest genetic improvement can be attained by selecting directly and/or indirectly for these traits. Genetic correlations between the different sets of traits within an animal or population are synonymous in animal breeding (Vide Fig 5.6). It is doubtful whether any study or review will be sufficient to completely cover the various genotypic and phenotypic correlations in animal breeding: Fig 5.6 gives a diagrammatic explanation of the positive and negative genetic correlations between different sets of traits within the pig, a breed or a population. ANNEXURE VIII and ANNEXURE IX give an overview of heritabilities and genetic correlations for pigs fed under *ad libitum*; *semi-ad libitum* and restricted feeding conditions, respectively.

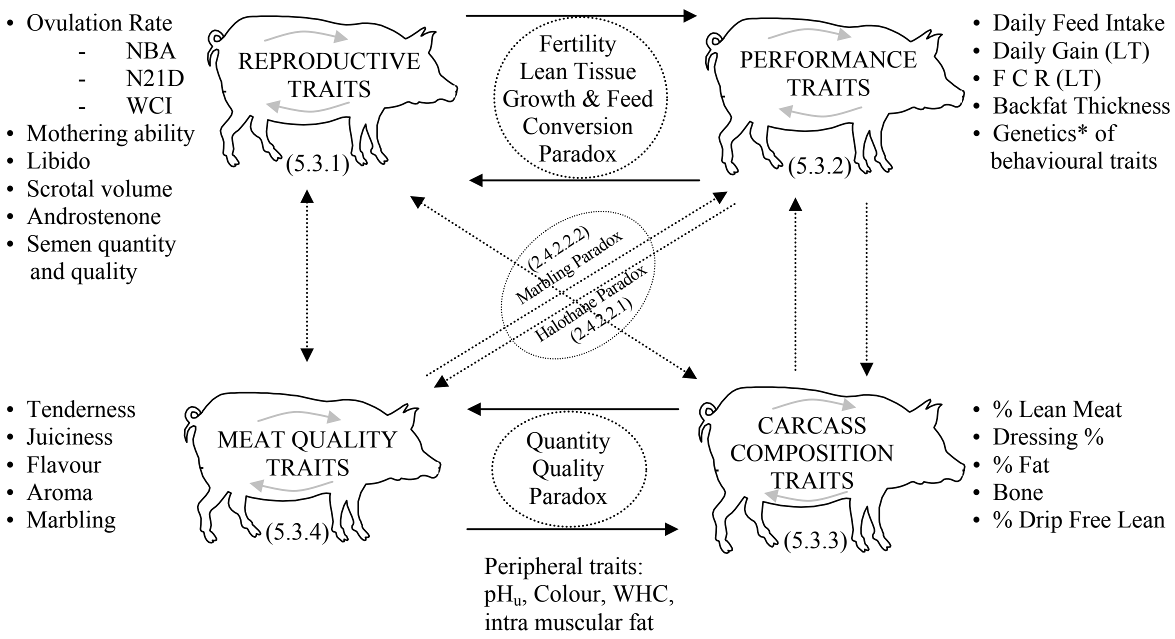
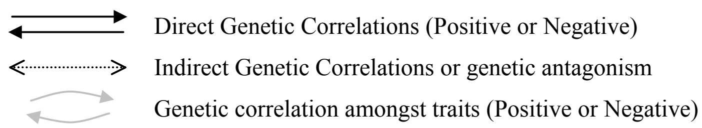


Fig 5.6 Explanation of the genetic correlations between different sets of traits within the pig, breed or a population. Conformational traits, structural soundness and their correlations were omitted from the diagram.**



* The genetic basis of temperament has not been investigated thoroughly in the pig, but major genes related to agressive behaviour in mice have been identified. Dominant pigs will also have an inhibiting effect on the feeding behaviour of penmates. A distinction must be drawn between pecking order and dominant or behavioural aggressive pigs. Nicholas (1997) indicated a high heritability estimate of 0.52 for stomach ulcers.

** Structural soundness (or absence of leg weakness) is important in any breeding programme from a genetic improvement point of view, an economic point of view and a genetic correlation point of view. Structural soundness can be improved through direct selection and by utilizing the moderate heritability estimates for leg weakness. In general, focused selection for daily gain will not have an adverse effect on leg weakness.

5.3.1 Reproduction

Selection against androstenone, with the intention of reducing boar taint, could adversely affect reproductive traits. Hermesch (1997) referred to an experiment where gilts (selected from a line renowned for high concentrations of androstenone) exhibited their first oestrus 14 days earlier than gilts selected from the low androstenone line. Higher levels of testosterone were also observed from the males of the high androstenone line. Selection against androstenone content in the male could impair testicular growth, scrotal volume and reproductive efficiency.

Hovenier (1993) indicated that the genetic correlation between daily gain and meat quality was found favourable whilst the genetic correlation between lean content and meat quality was unfavourable. Furthermore, the correlation between reproduction and meat quality is almost zero, but can also be slightly favourable (Hovenier, 1993). Nicholas (1997) indicated that reproductive traits normally have near zero genetic correlations with other traits, implicating that sustained selection for reproductive performance is attainable and practical.

Various studies, where genetic correlations between post weaning production traits and reproductive traits were estimated, failed to prove that significant genetic relationships exist between performance and reproduction traits (Clutter & Brascamp, 1998).

Rydhmer (2000) indicated an unfavourable genetic correlation between backfat thickness (as measured during the performance test phase) and age at first farrowing. Kerr & Cameron (1996) as quoted by Rydhmer (2000) reported a negative genetic correlation between conception rate and lean tissue growth rate in gilts. Gilts selected for high lean growth rates on scale feeding had a conception rate of 64 % in comparison to 83 % for gilts selected for low lean growth rate.

5.3.2 Production

Heritability estimates for ADFI (Average Daily Feed Intake) and ADG (Average Daily Gain) are almost similar (McGlone, Désaultés, Morméde & Heup, 1998) at approximately 10 %, whilst the genetic correlation between ADFI and ADG of 0.18 is reported. However, direct and sustained selection for increased daily gain and less body or backfat has a positive improvement on feed conversion ratio, but feed intake is impaired.

In a comprehensive literature review of heritabilities and genetic correlations of production traits in pigs [Clutter and Brascamp (1998) ANNEXURE VIII & IX] estimates were calculated for *ad lib*, semi-*ad lib* and restricted feeding regimes. Testes measurements and testosterone levels show favourable genetic relationships with growth traits. Genetic correlations between litter traits and growth rate, as well as litter traits and carcass traits, including backfat thickness are weakly correlated (Rothschild & Bidanel, 1998).

Clutter & Brascamp (1998) indicated genetic correlations between average daily gain (ADG), daily feed intake (DFI) as well as backfat with daily feed intake to be positive - mostly moderate to high. The genetic correlation between backfat and feed conversion ratio (FCR) revealed that selection for less backfat should improve feed efficiency. According to Clutter & Brascamp (1998) *..."the genetic correlation between ADG and feed conversion is affected by the feeding regime. Correlations under restricted feeding are generally close to -1.0, but with greater access to feed generally differ from -1.0. If heritabilities of gain and feed intake are similar, and the genetic coefficient of variation is much smaller for feed intake than for gain, the genetic correlation between gain and feed conversion will always be highly negative. When the genetic coefficients of variation for feed intake and gain are more similar, the genetic correlation between gain and feed conversion moves toward zero".*

5.3.3 Carcass Traits

Selection for a high lean growth rate is associated with a higher mortality rate amongst piglets (Rydhmer, 2000). The "apparent" heavier birth weights of these pigs are offset by their less mature physiological status at birth, which is manifested by lower blood levels of mobilizable fat, glucose, thyroxin and possible haemoglobin and plasma protein.

Genetic correlations between growth rate and meat quality traits should be regarded as nil (Tribout and Bidanel, 1999). Sellier (1998) indicated an antagonism between feed conversion ratio (FCR) and most meat quality traits, with special reference to meat colour. A negative correlation between carcass lean content (CLC) and pH_u (ultimate pH 24h post slaughter) is indicated by Tribout and Bidanel (1999). Furthermore the most meat quality traits are unfavourably correlated with CLC or muscle quantity.

In France the aggregate breeding objective (ABO) includes the following traits: average daily gain, feed conversion ratio, dressing percentage, carcass lean content (CLC) and a meat quality index (MQI), where: MQI = f (pH_u; Colour reflectance; Water holding capacity). Le Roy & Sellier (1994) indicated an unfavourable genetic relationship between the MQI and the other traits in the ABO. The most profound genetic antagonism involved feed conversion ratio.

5.3.4 Meat Quality Traits

Hermesch (1997) indicated a strong genetic correlation (rg) of 0.42 between intra-muscular fat and backfat. An unenviable situation in pig breeding is the marginal genetic antagonism (-0.25) between meat quality criteria (tenderness, juiciness, flavour and overall acceptability) and carcass leanness (Sellier, 1998). According to Jones (1998), it should be possible to select for increased intra muscular fat (IMF) and lean meat content simultaneously. This is achievable due to the high heritability of IMF (0.50 - 0.61) and the low genetic correlation (ranging from -0.25 to -0.37) between the percentage IMF and lean meat content. On the contrary, studies in Britain and Denmark indicated a high correlated response of reducing carcass fatness and also reducing the percentage intra-muscular fat. Webb (1998) stated that for every percent increase in genetic lean content, intra-muscular fat is likely to be reduced by 0.07 %.

Hermesch (1997) provides practical guidelines when emphasis is put on different traits (Vide Table 5.7).

Table 5.7 Implications when selecting for and against certain production traits (Hermesch, 1997)

SUPPOSED CURRENT SELECTION OBJECTIVE	RESULT OF SELECTION
• Improved growth rate	Higher backfat Better appetite Higher intra muscular content
• Improved feed conversion ratios	Improved lean meat percentage Poorer appetite
• Decrease in backfat (improve the lean content)	Impaired reproduction Decrease in intra muscular fat content Increase in PSE

5.4 POSSIBLE FUTURE SCENARIOS FOR PIG BREEDING IN SOUTH AFRICA

5.4.1 Present to Near Present (2003 - 2005)

1. Multi-Trait BLUP Methodology (MTBM) is widely used in all prominent pig producing countries and also South Africa. This methodology should be extended to incorporate reproductive, performance, body composition (carcass) and meat quality traits simultaneously in an all encompassing National BLUP, which is executed weekly (Vide CHAPTER IV for detail).
2. PIG BLUP (the within herd genetic evaluation programme) must still be used optimally, until replaced by a more advanced programme.
3. Optimal utilization of our National Database (INTERGIS) to address all the immediate and near immediate shortcomings.
4. Benchmarking the S.A. Large White, S.A. Landrace and Duroc in terms of the most important meat quality traits (Vide Table 5.6).
5. Inclusion of meat quality traits in the aggregate breeding objective. Simultaneously, funding should be obtained to purchase all the required equipment and technology.
6. Measuring meat quality (marbling) on the live animal through real time ultrasound and computerised video image analysis.
7. The inclusion of insulin growth factor 1 (IGF-1) as an indirect measure of FCR in on-farm group testing should be considered. Food conversion is genetically correlated with the concentration of IGF-1 in the blood of growing pigs. The cost implications, techniques involved, undisputed scientific merit and commission (royalty structure), etc. must first be evaluated carefully.
8. An effective AI Strategy should be followed, through:
   - (i) Routine parentage testing. Using DNA-technology and 10 - 12 highly variable microsatellite markers to recognize and rectify pedigree errors is recommended. This is essential for AI-boars.
   - (ii) DNA Micro Chip identification of all imported semen and donor animals is required.
   - (iii) Thorough scrutinization of the semen of AI-boars to ascertain chromosomal defects in the sperm.
   - (iv) Utilizing the OPTIBRAND System, a permanent non-invasive and unalterable identification and traceability system for livestock.
9. Development and utilization of electronic equipment such as FIRE to ascertain feed intake patterns and feed intake within a group.

10. International collaboration, networking and exposure of local scientists and leaders in agriculture to **international** scientists and congresses and multinational companies must be sustained.

5.4.2 Intermediate Advancements (2006 - 2009)

1. Mapping of QTL's[25] (quantitative trait loci) in pig breeding programmes using advanced statistical methods.
2. Detection of molecular markers for quantitative trait loci (QTL's) through porcine genome scanning and DNA Technology.
3. Identification of those chromosomes and chromosomal regions with major effects on performance traits (Chromosomes indicative in this regard are chromosomes 4, 6 and 7).
4. Identification of candidate genes and ascertain associations between polymorphisms within the candidate genes and performance (Archibald & Haley, 1998).
5. Application of genetic markers to introduce advantageous genes (like the ESR-gene) through marker assisted introgression into commercial/maternal genotypes [Gene markers provide the foundation for the partitioning of an EBV (Estimated Breeding Value) into QTL and polyenic effects (Kerr, Henshall & Tier, 1999)].
6. Goddard (1999) indicated that the cost of DNA testing should come down in future. This will make DNA testing more affordable to breeders, and allow the breeder to screen a larger number of pigs as well as to screen for more tests. This in turn will imply more effective DNA-testing, larger portions of populations to be screened and selecting only the high potential animals for final phenotypic performance testing.
7. The inclusion of muscle fibre types in breeding programmes to further enhance meat quality along with techniques such as single fibre dissection and quantitative biochemical analyses (Karlson, Klont & Fernandez, 1999).
8. Fig 5.7 gives a diagrammatic explanation, indicating how traditional genetic evaluation will in future be complemented by marker information, QTL effects and probabilities, locus and residual polygenic values and accuracies which are ultimately combined into an aggregate Rand Value Index.
9. The application of advanced electronics and technology to obtain detailed anatomical and carcass information from measurements on the live animal.
10. Through molecular biology and more specific genome scanning it is highly likely that major genes in pigs that influence behaviour will be identified. Should it be possible to

[25] A QTL is a location in the genome, which has an effect on a quantitative trait.

alter the behaviour of pigs genetically, a corresponding increase of up to 20 % in growth rate could be expected.

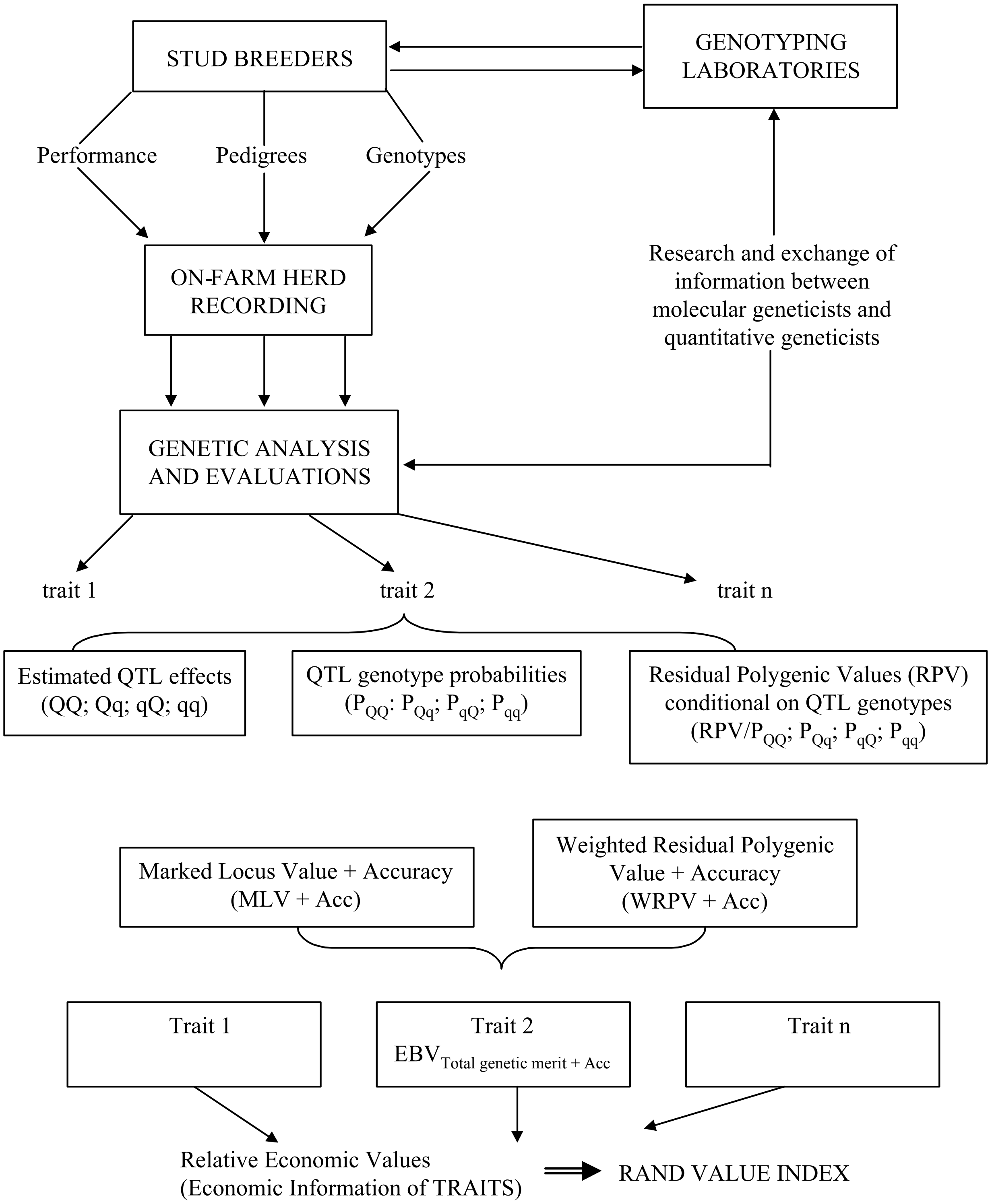


Figure 5.7 Diagram indicating how genetic evaluations of progressive stud herds will in future be complimented by marker information, QTL effects, probabilities and various other factors to achieve a better predictation of the total genetic merit of an animal (Kerr, Henshall & Tier, 1999)

5.4.3 Progressive Advancements (2010 and Beyond)

The knowledge of genes that affect quantitative traits (as part of the Pig Genome Map[26]) has increased drastically over the last 3 - 4 years (Visscher, Pong-Wong, Whittemore & Haley, 2000) and is expected to rise sharply in future. The question is: "How will genetic markers be used in future pig breeding programmes"? *In Vitro* Embryo Production (IVEP), where these follicles are collected at abattoirs or from superior live females, together with non-surgical embryo transfer, embryo storage and freezing techniques could have far reaching results on the future of the pig industry (Vide Fig 5.8).

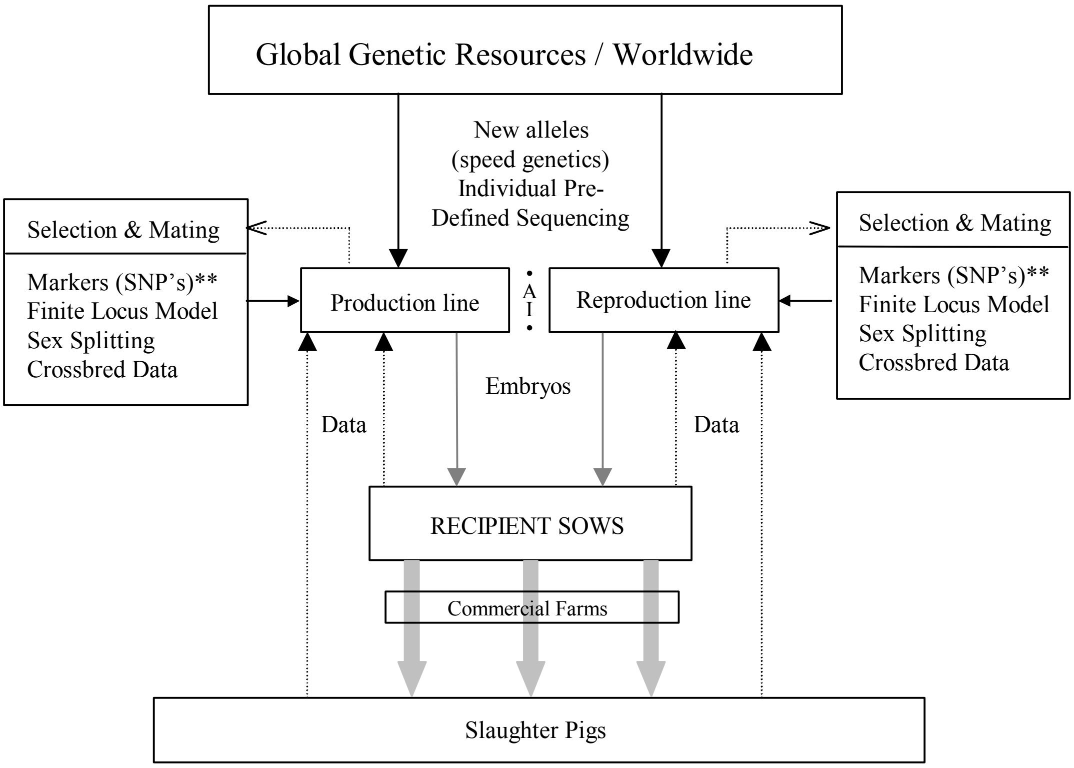


Fig 5.8 A diagrammatic explanation of the potential impact of future biotechnology on the breeding structure (Visscher *et al*., 2000)

** SNP is a marker at a specific DNA nucleotide where different alleles are due to single base changes.

[26] The Pig Genome Map endeavours to find thousands of marker loci which in turn provide an invaluable resource for quantitative trait locus (QTL) mapping. Furthermore, a QTL is a location in the genome, which has an effect on a quantitative trait (Visscher *et al*., 2000).

Through AI, embryos are produced from superior (nucleus) sows, and implanted into recipient sows (renowned for early sexual maturity and selected for large reproductive capacity). Piglets born are transported to commercial farms and finished off, resulting in less sows required at the multiplier level and more effective control over the multiplication process. Such a scheme might remove the need for the purebred multiplication tier and also reduce the crossbred tier in the industry. Furthermore, the slaughter genotype might be totally unrelated to the reproduction genotype.

5.4.3.1 Molecular Techniques

In future, the microscopic difference between individuals at DNA level can be identified through molecular genetic techniques. Van Arendonk, Bink, Bijma, Bovenhuis, De Koning and Brascamp (1999) indicated that molecular genetic information can be used in four (different) ways to enhance the genetic evaluation of domestic animals, namely:

(i) The incorporation of known genotypes, such as the RN^- locus and/or Halothane locus.

(ii) Marker assisted genetic evaluation

- Marker loci provide information on the transmission of genes from parents to offspring
- A mixed linear model can be constructed to evaluate fixed effects, genetic effects (at the QTL) and the additive polygenic effects simultaneously.

(iii) Construction of a Marker-Based Relationship Matrix, where each QTL is weighed according to its genetic variance. Furthermore, in a simulation study, total allelic relationships resulted in a better genetic response than pedigree based relationships.

(iv) Genomic models incorporating aspects such as Medelian autosomal genes, maternally and paternally imprinted genes and sex specific genes in genetic evaluations.

5.5 CONCLUSIONS TO CHAPTER V

(i) If it becomes the objective to improve pork quality in the supply chain, this will have a causal effect on all the tiers of the supply chain. This objective is manifested in tiers that will benefit and those that will have to incur the initial costs (Vide Table 5.5). It is recommended that the meat quality traits (as described in Table 5.6) be included in the breeding goal/objective. Hence, additional measurements and equipment are required to determine and measure pH_u, WHC, meat colour, IMF and tenderness. Optimizing the inclusion of meat quality traits in the breeding objective calls for economic calculations, ascertaining relative economic weights of traits, provision for genetic parameter estimations in the data base, estimations of breeding values and genetic improvement and ascertaining costs (labour, time and equipment) of the extra measurements.

(ii) The genetic links (correlation) between poor meat quality and low appetite in pigs selected for low backfat, suggest that selection procedures which reduce carcass fatness, yet increase appetite should be pursued for the sake of good meat quality. Simultaneously, benchmarking of the three most important pure-bred pig breeds (Large White, Landrace and Duroc) in the country in terms of meat quality and/organoleptic characteristics is recommended.

(iii) In future, the Marbling Paradox will be addressed through DNA technology by means of marker assisted selection and QTL's whereby individuals within and across herds will be identified on the genome level. This will contribute to meat quality, whilst simultaneously having a carcass with a high lean yield composition.

(iv) The inclusion of pH_u (as probably the most important meat quality trait) has been explained already. This trait is furthermore of vital importance to the processing and retail industries because of its relationship with WHC (water holding capacity), meat colour and the keeping properties of meat.

(v) Loss of genetic variance through inbreeding should be addressed for in the breeding objective. Breeders should identify the right individuals (possessing the right traits) and find the correct selection methods and mating plans to optimize the ultimate breeding objective, whilst taking special cognizance of the genetic correlations in pig breeding (Vide Fig 5.6). **Irrespective of which traits are included in the breeding objective, they must be well defined and preferably directly selected for.**

(vi) Meat quality is a multifactorial pursuit and each segment of the supply chain must therefore contribute or add to meat quality.

(vii) The use of ultrasound technology for the assessment of carcass or body composition in live pigs will accelerate the on-farm genetic improvement of lean meat yield and meat quality. Ascertaining the percentage marbling on the live animals as accurately as possible will be beneficial to the breeder, producer, processor and consumer simultaneously. (The positive relationship between the amount of intramuscular fat and eating quality must be noted in this regard). According to Maignel (2002) performance testing in France has advanced to the stage where:

(a) On-farm testing incorporates muscle depth at 100 kg (measured on the live animal between the 3^{rd} and 4^{th} last rib and which gives a good indication of loin eye area) and pH_u (thus meat quality) on pigs slaughtered from the farms.

(b) Central testing now also incorporates daily feed intake (recorded through electronic feeders) to provide EBV's for appetite and eating behaviour. Carcass evaluation incorporates dressing percentage, carcass lean content and a meat quality index.

(viii) Breeders must be compensated for meat quality, if it is to be included in the breeding objective. Should pig producers be compensated on carcass composition as well as the meat quality of their pigs, the reward will be complete.

(ix) Goddard (1998) refers to distorted breeding objectives, caused by distorted market signals. This distortion is reached when studbreeders are purchasing breeding material selected through an objective that is different from the profit function that is being applied on their own farms. Thus, breeding or selection objectives should be defined (and practised) according to the selection regime applied in order to avoid distortion of breeding objectives.

(x) Structuring of future breeding objectives will exceed the traditional approach of the profit function *per se* that takes biological and genetic values as inputs and produces profit as output. Future breeding objectives must also be planned against the background of the non profit factors (Vide Table 5.8) such as:

- environmental impact (especially pollution and odour)
- welfare (diseases and traceability)
- health and safety (consumer responses in terms of GM foods)
- **the consumer's** perceptions, preferences and acceptances/rejections in terms of the end product
- global trends and globalization.

Table 5.8 The importance of profit and non-profit factors in meat demand

TYPE OF MEAT	1955 – 1979		1975 - 1994	
	Profit	Non-profit	Profit	Non-profit
BEEF	95	5	68	32
PORK	98	2	55	45
MUTTON	84	16	58	42

Source: Bansback (1995) as quoted by van Schalkwyk (2001)

Finally: Optimal structuring of breeding objectives calls for networking, collaboration and interaction between geneticists, breeders, producers, engineers, nutritionists, veterinarians, pharmaceutical companies, slaughterhouses, processors, wholesalers, retailers and ultimately must be consumer orientated.