NEW TRAITS IN PIG BREEDING

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INTRODUCTION

In comparison with other domestic species, defining the aim of pig production may seem simple because it is a single-objective production, i.e. meat production. However, many traits have an economical importance in pig industry and have to be taken into account by breeders for the genetic improvement of their populations (Ollivier, 1998). Conventionally, two groups of traits are considered, based on central station testing and on farm testing records: the group of reproduction traits, which concerns male and female reproductive characteristics, and the group of production traits, which concerns growth and carcass characteristics. Most often, “Female” and “Male” populations are selected independently in order to produce terminal crossbred individuals. Weights applied to each group of traits differ according to population type: “Female” lines are mainly improved for reproductive performances and “Male” lines for productive performances (Ollivier et al., 1990). Even though the selection criteria vary among genetic schemes, it has to be emphasised that the most important traits considered as objectives in genetic evaluation procedures are always the same (Ducos, 1994): sow prolificacy, post weaning growth and carcass lean content. Other traits are sometimes also taken into account but often rather as secondary traits, as for example meat quality predictors (Sellier, 1998).

Jointly to this classical breeding design which remains valuable, new questions appear nowadays. Firstly, progresses in metrology allow to obtain new measurements leading to a better prediction of animals genetic values. The most famous example of evolution in the definition of a selection criterion is the case of carcass leanness, from post mortem measurement of backfat thickness on the carcass in 1960s to present in vivo scanning data (Sellier, 1998). A large part of these progresses are due to the development of electronic devices allowing more and more stringent measurements. Furthermore, some traits, for example individual feed intake, were seldom recorded on testing before this electronic revolution because it would have been too expensive. Finally, other traits, for example maternal behaviour, are never quantified because there is no tool to measure them. All these progresses in metrology are discussed in details by Merks and de Vries (2002) in the other invited paper of the present session. Here, we will rather talk about evolutions due to new requests towards pig production. Actually, as the economical context has undergone large changes, the relative weight of “conventional” traits in the global breeding goal may vary and “new” traits have to be taken into consideration. Moreover, all the partners of the pig industry, from the breeder to the consumer, and more generally to the “citizen”, have particular requests about pig production. Compared to the past, the demand, particularly for the qualitative aspects of the production that have to be taken into account, is becoming much stronger. For these reasons, some traits have become, or will become certainly in a near future, more and more important in pig breeding.
ECONOMICAL CONTEXT

Up to now the prolificacy of sows and the speed of lean growth have been the common components of the selection objective in most breeding schemes around the world, but a tendency to a more differentiated selection has been initiated over the last few years. There are two major reasons for this evolution.

Genetic trends. The genetic gains for some selected traits have been very high thanks to modern methods of selection worked up in the last forty years. Indeed, annual genetic gains of the order of 0.5 to 1.5 % of the mean have been reported for growth and carcass composition traits in large purebred populations (Sellier and Rothschild, 1991). Consequently, the need for further improvements of these traits is now lower and their respective weights in the global breeding goal have already been reduced in several countries (Sellier, 1998). This allows a higher selection intensity to be applied on other traits, and “new” traits to be incorporated in the selection objective (Ollivier et al., 1990). Furthermore, since all commercial lines have reached a similar very good level of performance for these traits, it is all the more important to distinguish them by using specific objectives. At this stage, the most frequent choice concerns product qualities for which the request has increased, as will be seen below.

Otherwise, some of these gains also induce new needs. For instance, the increase in litter size at birth enhances the importance of piglet survival. The genetic parameters characterising piglet survival are still relatively poorly documented (Blasco et al., 1995) but it seems established that the number or percentage of piglets weaned or dead have low heritabilities ($h^2$ between 0.05 and 0.07 ; Rothschild and Bidanel, 1998). Moreover, the use of these criteria for selection on piglet survival would imply a stringent record of piglet exchanges across litters.

However, genetic gains can be expected on piglet survival either by selecting on piglet vitality, as a characteristic of the piglet itself or as a consequence of the uterine quality of the sow, or by selecting on mothering abilities of the nurse sow. It appears that the genotypes of these three individuals influence piglet survival, very roughly in equal parts (Knol, 2001).

Piglet vitality is classically linked to litter weight at birth, which has a moderate heritability ($h^2$ around 0.3) and is genetically correlated with survival rate ($r_g = 0.13$ ; Rothschild and Bidanel, 1998). A lot of QTL have been reported as affecting birth weight (on SSC 1, 3, 4, 7, 11, 12 and 13 ; Bidanel and Rothschild, 2002). Moreover, Knol (2001) emphasized the main role of the uniformity in birth weight on survival rate, finding a genetic correlation of 0.3 between these two criteria. Selecting for the uniformity of birth weight may then be an attractive way to improve piglet survival. It is possible to genetically reduce the variability of a trait using “canalising” selection (San Cristobal et al., 1998). In the case of birth weight, it would be necessary, however, to estimate the potential gain of such a canalising selection, which depends on the extent of the genetically controlled part of the environmental variance.

With respect to mothering abilities of the nurse sow, indirect criteria such as teat number, maternal behaviour or milk production traits may be interesting selection criteria. These indirect criteria seem to have moderate heritabilities ($h^2$ between 0.2 and 0.3 ; Rothschild and Bidanel, 1998). Yet, their genetic determinism and particularly the level of their genetic correlation with the final objective are still relatively poorly known. Actually, most of these...
traits have seldom been measured in large enough samples to allow their genetic parameters to be estimated. However, it seems important to emphasise that substantial improvements of mothering abilities will also certainly be obtained by a good use of genes from Chinese breeds. For example, some favourable results can already now be pointed out concerning numerous major genes or QTL (on SSC 1, 2, 3, 7, 8, 10, 11, 12, 16 and 17) influencing teat number detected in crosses implying the Chinese Meishan breed (Bidanel and Rothschild, 2002).

**Economical trends.** The economical context of pig production has undergone large changes over the last decades. After the Second World War, pig production expanded in Europe in a dearth context (Teffène et al., 1998). Otherwise, American pig industry quasi-exclusively preferred cost minimisation and developed very big production units. In both cases, the main efforts were devoted to the genetic improvement of productivity, with a margin that is proportional to the quantity of meat produced. Thus, the pork world-wide market has increased continuously. It is always characterised by a low level of exchanged volumes as compared to the world-wide production, and by the limited number of exporting or importing countries, as most countries apply an auto-store policy (Guyomard, 2001). The degree of auto-store in the European Union (EU) has been around 106 % for several years; which has resulted in a more competitive market (Teffène et al., 1998). Thus, economists agree to think that the future success of pig industry in the EU will depend on its ability to evolve towards a differentiated market with a total traceability. In this context, pig breeders will have to take into consideration the diverse requests concerning qualitative aspects of the production. However, it has to be emphasised that, for pork consumers, the classical request for a “low price” remains valuable, even if it is less important than for bovine meat. As an illustration, the elasticity coefficient for the price of pork has been estimated in France at about – 0.5; this estimation is similar to that of poultry meat, whereas the elasticity coefficient for bovine meat is close to – 1 (Guyomard, 2001). As a consequence, the other demands always have to be considered marginally to product costs.

**REQUEST ON PRODUCTS**

The genetic improvement of pork quality has been discussed for more than thirty years (Monin et al., 1998). However, it has often been limited in practice to the eradication of strong defaults affecting lean tissue, *i.e.* PSE or acid meats (Sellier, 1998). Nowadays, it appears necessary to progress in order to develop a genetics of products quality rather than a genetics of quality defaults.

**Technological qualities.** One particularity of the pig industry is the multiplicity of its products and especially the potential existence of a large market share for transformed products. In France, for example, 80 % of the pig carcass value is represented by salt meat products. In comparison with other meat productions, this implies a more complex definition of meat quality criteria. For example, transformers' requests depend on the product considered, *i.e.* dry or cooked pork, and may even be antagonist to the requests of the fresh meat consumer (Sellier and Monin, 1993). However, there are several examples of serious defaults on pig meat leading to “bad” meat whatever it is used for, *i.e.* DFD, PSE or Acid meat (Sellier, 1998). As a consequence, the genetic improvement of meat qualities often consisted in the eradication of
unfavourable alleles of the HAL and RN major genes, n and RN⁻, partly responsible for these large defaults (Le Roy and Sellier, 1994).

In less extreme cases, it may be difficult to define if the agronomic answer is more suitable than an adaptation of the industrial process to raw material. However, it is certain that the main problem for transformers is always the heterogeneity of the raw material. In such a context, selecting the involved traits for optimum values would be suitable (Hovenier et al., 1993). The quality of products, then, is a good example of set of traits on which canalising selection could have a real interest. San Cristobal et al. (1998) showed that a high response to canalising selection can be expected on ultimate pH of the semimembranosus muscle through a strong reduction of the genetically controlled part of environmental variance.

Another important request from transformers in the near future might concern the technological qualities of fat. Actually, the firmness of fat is a highly heritable trait (h² around 0.5 for instrumental measurement) but is also moderately correlated with carcass lean content (r_g around - 0.4 ; Sellier, 1998). Then, the strong selection intensity applied on carcass leanness in most of commercial populations has probably led to a decrease of fat technological qualities. On the other hand, selection against backfat has probably increased the dietetic qualities of fat tissue. Indeed, the ratio of polyunsaturated over saturated fatty acids also seems to be highly heritable (h² around 0.5 ; Sellier, 1998), but is unfavourably correlated with fat firmness (r_g between −0.2 and −0.3 ; Maignel et al., 1998). Concerning individual genes effects, only one QTL has been reported as affecting fatty acid composition on SSC 4 in an Iberian x Landrace population (Pérez-Enciso et al., 2000). However, the relative lack of QTL reported as influencing fat technological characteristics has to be related to the lack of records for these traits in the whole-genome scan experiments published to date.

Consumption qualities. Concerning the sensorial qualities of pork, the main problem is that good predictors of these complex traits, i.e. aspect, tenderness, juiciness and flavour, still have to be established. Generally, their measurement involves trained panels of experts who give scores on several sensory attributes. These scores are lowly (h² around 0.10 for juiciness and flavour) to moderately (h² around 0.30 for tenderness) heritable and unfavourably correlated with carcass leanness (r_g between − 0.2 and − 0.5 ; Sellier, 1998). This pronounced "quantity-quality" genetic antagonism, as well as the cost of these measurements, explains the lack of selection on these scores in the past. Yet, in a recent experiment, Malek et al. (2001) reported the existence of several suggestive QTL influencing chewiness (SSC 12), tenderness (SSC 2, 14 and 15), juiciness (SSC 17), intensity of smell (SSC 6), intensity of taste, subacid smell (SSC 4), flavor (SSC 15) and off-flavour (SSC 2 and X) scores. These putative QTL, which are often in the same chromosomal regions as those affecting some objective measurements of meat quality (Bidanel and Rothschild, 2002), might allow a selection on sensorial qualities of pork if these QTL do not have pleiotropic effects on carcass leanness.

Among the physico-chemical characteristics of the lean tissue, ultimate pH is very well correlated with sensorial scores (r_g between 0.50 and 0.60) and is moderately heritable (h² around 0.20 ; Sellier, 1998). These estimates show that a selection to increase ultimate pH could be efficient to improve both technological and sensorial qualities of meat. Meat ultimate
pH also has moderate unfavourable correlations with carcass leanness ($r_g = -0.13$; Sellier, 1998). Finally, the RN major gene (Le Roy et al., 2000), as well as numerous QTL (SSC 4, 5, 6, 9, 11, 14, 15, 18 and X; Bidanel and Rothschild, 2002), was reported to influence meat ultimate pH. The RN gene, and may be some of the above-mentioned QTL, also has pleiotropic effects on carcass composition (Le Roy et al., 2000). The study of the RN gene, along with the major difficulty to get in vivo predictors of pork quality, led to define the notion of muscular glycolytic potential (GP; Monin and Sellier, 1985). GP is an estimator of the muscular glycogene content, which can be assessed in live animals from a *longissimus* muscle biopsy. The interest of GP for the RN-allele eradication has been demonstrated (Le Roy and Sellier, 1994). In the populations free of the RN allele, the heritability of in vivo GP is moderate ($h^2$ around 0.25) and GP is highly correlated with ultimate pH ($r_g$ around -0.50; Larzul et al., 1998a). Hence, in vivo GP could be a good alternative to ultimate pH for the genetic improvement of meat quality, even in a free RN-allele situation (Larzul et al., 1998b).

Another criterion often considered as influencing the sensorial qualities of pig meat is intramuscular fat content (IMF). However, it must be emphasised that, generally, an increase of IMF should not be accompanied by a high level of marbling because of its negative effect on meat aspect (Fernandez et al., 1999). IMF is highly correlated with the overall acceptability of pork ($r_g = 0.61$; Sellier, 1998), while its genetic correlation with tenderness is lower ($r_g = 0.15$; Sellier, 1998). Its genetic correlation with either carcass fatness or average daily gain is moderate ($r_g = 0.30$; Sellier, 1998) allowing a joint genetic improvement of these traits. Several QTL (SSC 1, 2, 4, 6, 7, 13, X; Bidanel and Rothschild, 2002) and a putative major gene (Janss et al., 1997) affecting IMF have been detected. Chromosomal regions influencing the marbling score have also been detected, among which two are apparently independent of the previous QTL (SSC 8 and 10; Malek et al., 2001).

Finally, a last set of traits potentially involved in the establishment of pork qualities is muscular fibres characteristics, i.e. number, cross-sectional areas, contractile (I, IIA, IIB) and metabolic (oxidative and nonoxidative) properties of the fibres. Fibre traits are moderately to highly heritable ($h^2$ between 0.20 and 0.60; Larzul et al., 1997) and two QTL affecting the myofiber number have been detected (SSC 7 and 8; Bidanel and Rothschild, 2002). However, some controversial values were obtained concerning the relationships between fibre characteristics and production traits. Thus, the role of fibre number and cross-sectional area on pork qualities, as well as their relation with growth potential, requires further investigations.

**SOCIAL REQUEST**

The more or less classical request that concerns the lean and fat tissue qualities, now tends to be extended to the quality of the whole production system, and is recognised as a “social” demand existing in most countries. These terms contain three important questions about modern society: human health, animal welfare and environmental protection. Concerning this last topic, the best way to genetically improve animals is certainly to increase its lean growth efficiency, as the more a pig is efficient, the less it pollutes. However, the request for “coming back to tradition”, often results from anxiety about environmental protection and animal welfare, but may lead to several problems.
**Human health.** The request about human health has two components: the requirement for innocuity and the search for a better food equilibrium. While the hygienic qualities of products have drastically increased during the last decades, the requirement for innocuity became more and more important for all agricultural productions (Chevassus-au-Louis, 2001). In most countries, it is clearly the first request, before sensorial quality or image requirements, and it is very strong in the case of livestock production, especially in EU after the BSE crises (Porin and Mainsant, 1999). However, this request, which first concerns product traceability, does not necessarily imply any modification of the raw material characteristics. The quest for a better food equilibrium is a more recent concern, but may become determinant in consumers’ purchase decision. Compared with other meats, pork presents the advantage of a relatively low cholesterol content and its content of monounsaturated fatty acids is high (Monin et al., 1998).

Available genetic parameters seem to show a moderate heritability for the ratio of polyunsaturated over saturated fatty acids in the lean tissue ($h^2 = 0.36$) and its genetic quasi-independence with lean growth rate (Maignel et al., 1998). Hence, selecting for a more dietetic pork seems possible.

In the context of more traditional i.e. “alternative” production systems, adaptation traits will become more important because genotype by environment interactions are likely to appear with the application of alternative management techniques. Genetic resistance to infectious diseases and parasitism is certainly the most important group of traits in this area. One topical example in the EU is the consequence of prohibiting the systematic use of antibiotics in the pig diet, which increases the interest for a better general disease resistance. This resistance can be predicted by immune responsiveness (Rothschild, 1990) measured by sanguine immune parameters such as serum immunoglobulin level, specific antibody production or cellular responses (Lunney and Butler, 1998). On the basis of diverse experiments, very variable heritability estimates of immune response have been obtained ($h^2 = 0.05$ to $0.52$; Rothschild, 1990) depending on the protocol and the immune response parameters used. This lack of universal immune response criteria, as well as some negative correlations between immune response and production traits, makes it extremely difficult to select on these traits (Rothschild, 1990). Furthermore, considering specific disease resistance generally leads to more complex measurements such as responses to experimental infection, which are difficult, if not impossible, to apply on a large scale. Using individual loci, i.e. QTL or major genes, influencing specific disease resistance could then be an attractive way to select for disease resistance. However, if some QTL influencing immune capacity have been detected, the detection of individual genes associated with disease resistance has so far been very limited in pig (Bidanel and Rothschild, 2002).

**Animal welfare.** Another component pointed out by these “new” production systems, is animal behaviour. Under this general concept, stress-related emotional and “abnormal” behaviours can be especially distinguished (Mac Glone et al., 1998), as animal welfare is generally associated with these groups of criteria. The most widely used prediction of stress-related behaviour is based on the exposure of the individual to a novel situation (open field test) and the measurement of emotional behavioural responses (ambulation, exploration, vocalisations, faecal boli, urinations …). The variation of plasma levels of ACTH and cortisol due to such challenges can also be used (Mormède et al., 1984). Several studies have shown
that large differences exist among breeds and allow to postulate a genetic control of these traits (Dantzer and Mormède, 1983). Yet, heritabilities and genetic correlations of emotional behaviour with production traits are still poorly documented, even though some interesting results show the potential interest of selection for behaviour (Hemsworth et al., 1990). Concerning individual loci, stress susceptibility is well known to be influenced by the halothane sensitivity gene (RYR1 locus). Additionally, QTL influencing some behavioural and neuroendocrine responses in an open-field test were recently detected by Désautès et al. (2002) in a F2 cross between Large White and Meishan breeds (SSC 1, 7, 8 and 17).

Only few estimates of heritabilities were reported on “abnormal” behaviours, i.e. biting tails and ears, chewing penning materials, drinking excessive amounts of water, sitting excessively, and so on, and are generally low to moderate (Mac Glone et al., 1998). “Abnormal” behaviours would then be probably heritable but it would be useful to more precisely estimate their genetic parameters in order to predict possible genetic gains through selection. However, nobody knows if animals are more comfortable in the state of showing low or high levels of these “abnormal” behaviours, making it difficult to define the selection goal (Mac Glone et al., 1998).

CONCLUSION
As pig production is spreading through a more differentiated market, it appears necessary for pig breeders to take into consideration new requests, which may concern product qualities or the image given by the production. This evolution has already started, even though the genetic determinism of several of the “new” traits pointed out in this overview are still relatively poorly known and have to be investigated in more details. Actually, whatever the objective, the main difficulty will certainly remain the choice of pertinent selection criteria, which will generally imply a good knowledge of the physiological basis of the traits investigated. However, the availability of molecular biology techniques and their integration in genomics programs could help research to progress more rapidly than in the recent past.

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