USING TODAY'S TECHNOLOGY FOR BREEDING PIGS FOR TOMORROW'S CONDITIONS

Jan ten Napel
Animal Breeding and Genomics Center of Wageningen UR,
Wageningen, the Netherlands
e-mail: Jan.tenNapel@wur.nl

ABSTRACT

Pig production systems in Asia vary enormously, ranging from backyard pig farming to very large-scale operations. Allowing for some variation between countries, the approximately 20% largest pig farms produce 80% of the pigs. This paper concerns pig breeding on the other 80% of the farms, which are mostly small-scale farms. Small-scale pig farming has other functions than large-scale pig production. Supporting family-size farms does not necessarily contribute to national self-sufficiency of pork production, but may help to increase rural income and local availability of good quality protein. Yet many small pig farms struggle with poor reproduction, high mortality, very slow growth rates and lack of uniformity. The combination of these problems is a symptom of a mismatch between the genotype and the production environment. Improving conditions is an obvious but not always attainable solution, especially for availability of sufficient good-quality protein and improvement of health status. Alternative solutions are to utilize locally-adapted breeds, either as purebred animals or crossed with a productive line, or to identify robust productive lines that are suitable for the given production environment. Participatory breeding programs can be used to adapt the chosen lines further to the local conditions. Empowering smallholder farmers to breed from the best-adapted stock requires a collaborative approach with data collection on small-scale farms and central evaluation of performance measurements. Such an approach requires a link to the local market and a party that takes the lead. Modern breeding technology is only effective and profitable when embedded in such an initiative.

Keywords**:** Genetics, Pig Production, Small-Scale Farming, Genotype-Environment Interaction

INTRODUCTION

Food security is a major item on the policy agenda of many countries. A sustainable food system encompasses more than just increasing productivity and number of large-scale farming operations, but aims for improving domestic food production, self-sufficiency and creating a viable, sustainable, and healthy agricultural sector (Garnett *et al.*, 2013). Food security goals of individual countries in the Asian region vary. For instance, for most low-income developing countries, availability and affordability of foods are vital, while in most developed nations, safe food production is the key priority (FFTC, 2010).

Countries like China, Taiwan, Korea, Thailand and the Philippines increased the national production of pork in the last two decades by creating large-scale pig farms using modern genotypes and high-quality feed. As a consequence, a small number of farms produce a relatively large proportion of the pork in each of these countries.

Small-scale pig farms are much more abundant and embedded in the local rural economy than large-scale farms. Increasing productivity from subsistence farming to commercial production may contribute to a sustainable livestock production sector, provided that the income increases faster than the production costs and other current functions are not lost. In an attempt to increase productivity, small-scale farmers adopted Western productive breeds and had to adapt the environment they provide for imported pigs to that nearer to that of the source of the purchased animals at a significantly increased production cost.

Small-scale pig farms may benefit from technology and know-how developed in pig production in other parts of the world, provided it is tailored to the needs and local conditions of such farms. In the area of pig breeding, large increases in productivity have been achieved in some countries in the last two decades. The key question is how to adapt and utilize this expertise for improving small-scale pig farming in South-East Asia.

The objective of this paper is therefore to discuss practical methods for breeding pigs that are suitable for production environments on small-scale pig farms in Asian countries in order to improve the income of these farms.

SMALL-SCALE PIG FARMING IN ASIA

Characterization

Individual countries use different definitions of small-scale pig farms. Statistics on small-scale pig farming cannot be compared easily for this reason. The wide range of definitions, reflecting the differences between countries in the structure of the pig production sector is obvious when looking at individual countries.

In the Philippines, a backyard farm has 20 or less adult pigs or 40 or less grower pigs (Philippine Statistics Authority, 2013). About 64 percent of the total stocks were raised in backyard farms and 36 percent were in the larger commercial farms.

In Taiwan, the smallest category is farms with less than 100 pigs, which could be all finisher pigs or 25-30 sows with weaners. About 37% of the farms have less than 100 pigs. About 90% of the pigs in Taiwan are kept on farms with 500 pigs or more (Taiwan Livestock Research Institute, 2013).

In Thailand, 99.7% of the sow farms have less than 500 head including a piglet, which makes up only 52% of the Thai sow population. A total of 97.4% of finisher herds have less than 500 head, which is only 18% of the Thai finisher population (David Steane, 2014; personal communication).

Small-scale pig farms are generally run by a family. The financial resources on these farms are low in many cases, so the facilities are basic and they have limited access to feed with sufficient good-quality protein. Pork prices are too low and feed costs too high to improve productivity by using more productive commercial crossbred breeding stock.

Some studies distinguished zones of small-scale farms, with low-input, low-output systems in remote rural areas and higher-input, higher-output small-scale farming in the proximity of cities (Oosting *et al*., 2014). Herold *et al.* (2010) apply this concept in their proposed pig breeding program for Northwest Vietnam, too. They distinguish subsistence farming in remote villages, market-oriented farming in remote villages and villages close to the market. Farms in remote areas get low prices for their products and high-quality feed is relatively expensive, both due to costs of transport. They tend to use adapted breeds and locally available feedstuff. Small farms in the vicinity of cities do not have the disadvantage of high transport costs, and seek to utilize improved breeds and feed.

Functions

Whereas large commercial farms focus on efficient production of pork, pig production on small-scale farms has other functions, too. It is important to consider how to maintain these functions when attempting to increase productivity of small farms.

First of all, small-scale farms are more embedded in the local rural economy. They generate local economic activity. Feed and bedding, if any, are sourced locally, pork is sold in the local market and is a source of high-quality protein into the local community. Further, manure is dispatched to fields in the vicinity of the farm, possibly after generating biogas from the manure first. The location of the farm in relation to a city is an important factor for the market demand.

Secondly, pigs add value to local food waste and crop waste, which would be otherwise unsuitable for food production. In this way, pig production contributes to a sustainable local agriculture by closing local mineral cycles and removing waste.

Thirdly, in countries with banks and insurance companies that are not accessible for poor farmers, pigs may be a savings account for large expenses. Selling one or two pigs may generate just enough money to pay for a hospital check or school fees.

Fourthly, pigs in certain areas have a cultural or traditional function, too, for example in religious ceremonies. In the south of Bhutan, some families keep a slow-growing pig to be ready for slaughtering at the next religious festival.

Challenges

The main challenge for a small-scale pig producer is to generate income from keeping pigs. With low prices for pork and high costs for good-quality feed, the producers minimize the input as much as possible and aim to feed locally available products. In doing so, they often do not meet the minimum requirements of their growing and breeding pigs.

Many small-scale pig farmers struggle therefore to maintain the reproductive performance of sows at an acceptable level. Problems are anestrus of gilts and young sows, small litters of older sows and a high piglet and weaner mortality. Poor technical results make it much more difficult to earn money from pig production.

An important cause of poor reproductive performance is that productive Western breeds have a high mature weight, a high body protein mass and a high protein requirement in the diet. Failure to feed sufficient good-quality protein will delay puberty and a normal onset of cyclic activity after weaning in any breed. Older sows with excessive loss of body condition will produce smaller litters of less viable pigs, or do not conceive from the first service. Using Western productive breeds will aggravate the problem of lack of available good-quality protein in the feed. Local breeds selected in an environment with low availability of protein are much smaller in mature size and lower in body protein mass than Western breeds. Examples are the Gungroo in Northeast India, indigenous pigs in Bhutan, the Mong Cai in Vietnam and the Meishan in China.

Weaner pigs are often fed diets that are only suitable for older pigs. The weaning age is often too low for the quality of the weaner diets. Without milk products in the weaner diet, the weaning age should not be lower than 5 to 6 weeks. A gradual change from milk to suitable solid feed is critical for the adaptation of the gut of the weaner pig. If weaner diets are unsuitable, pigs do not grow for several weeks after weaning and look pale and hairy, even at higher ages at weaning. These pigs will eventually compensate for the lost growth with organ tissue and body fat, but not lean meat, so levels of backfat are generally much higher at slaughter weight. The food conversion ratio of fat deposition is very high, so a lot of feed is wasted on accumulating potentially unwanted body fat. As another consequence of the poor weaner diets, variability between pigs increases, both in weight at a given age and in fat depth at slaughter weight. An overly fat carcass is inefficient to produce and more difficult to sell at a good price.

So the challenge of many small-scale pig farms is that productivity is quite variable and problems are common. It leaves these farms very vulnerable to financial losses and with little opportunity to grow out of it. The issue in this paper is whether pig breeding can be used to grow out of this. Before addressing this question, it is useful to consider pig breeding programs in general and the state-of-the-art of practical technology for pig breeding.

PIG BREEDING PROGRAMS

Functions of a pig breeding program

A pig breeding program serves many purposes. Depending on the ambition of the breeders, the objectives of the program and the available means, it may include all, some or just one of them. The functions in order of increasing ambition are:

1. to produce sufficient breeding animals for producing finisher pigs,

2. to make optimal use of heterosis on breeder and finisher farms,
3. maintain purebred populations that are suitable for the target production environments,
4. control inbreeding in these populations,
5. change the purebred populations through genetic selection in a desired direction.

A breeding program on a small-scale farm is often very simple. The cheapest boar available is used to breed the next generation of breeding stock from the best sow on the farm. Having replacement gilts is the main objective. The scale of the breeding program makes it virtually impossible to achieve meaningful genetic change.

A breeding program of a pig breeding organization with genetic selection covers all five functions. Including genetic selection in a breeding program requires data collection on farms, collaboration between farms, sharing information and allocating resources to selecting the most appropriate breeding stock across farms. There are several examples of successful breeding programs structured like this (for examples, see Fig. 2 discussed below).

MODERN BREEDING TECHNOLOGY

Data collection

Genetic selection on traits that cannot be assessed by visual evaluation requires a measurement protocol and data collection. Modern breeding herds use technology for recognition of animals, measurements of weight, backfat and muscle depth and automatic transfer to a central database. Technical equipment is adopted to increase the capacity and reduce the incidence of certain types of recording errors. In a breeding program with small-scale farmers, a technician could use a hand-held computer for data recording when visiting farms. In general, technical equipment may be affordable at the breeding program level, but maybe not at the level of the individual farm.

Basic BLUP models

BLUP (Best Linear Unbiased Prediction) is a property of certain statistical methods to estimate the genetic merit of animals for one or more traits. There are several computer software packages that implement methods with this property (PEST, PIGBLUP, MiXBLUP, and BLUPF90, among others). BLUP methods are the preferred method to predict the genetic merit for a trait of individuals in a population. Provided that a correct model is used, BLUP methods give the best prediction of the genetic merit. The prediction is normally referred to as estimated breeding value (EBV).

Prior to the application of BLUP, breeders used phenotypic selection or selection index theory to identify the future parents of the next generation. Phenotypic selection just takes the best animals in a group of tested individuals, without taking into account the genetic relationships between individuals and information on relatives. It is suitable for highly heritable traits in large populations that are tested in the same conditions. Selection index theory takes some information on relatives into account, but should really be used within populations tested in the same conditions.

BLUP allows identification of potential parents across herds, taking into account any recorded information on any relative in the population. It can deal with traits with a low heritability and with non-genetic systematic differences between animals. Basic BLUP models can be used for traits with a single measurement per pig (for example performance test measurements) and traits with multiple measurements per pig (for example sow reproduction traits). Especially with selection for reproduction traits, control of inbreeding is more critical when using BLUP, as it is more likely to select related individuals.

The theory of BLUP was developed by Dr. CR Henderson in 1950, but his 1975 paper paved the way for application in the context of a population under selection, which is the normal situation in animal breeding (Henderson, 1975). The first application of BLUP in pig genetic evaluation procedures was in Canada in 1985. The first practical applications in a commercial pig breeding program were in 1986 by Cotswold Pig Development Company Ltd and JSR Healthbred Ltd, both in England. It has since been adopted by the vast majority of pig breeding organizations across the world.

The advantage of BLUP over previous methods can perhaps be illustrated with the average litter size in Dutch pig herds between 1982 and 2011 (Fig. 1). BLUP was introduced around 1993, setting off an acceleration in improvement per year from 0.06 pig per year between 1982 and 1996 to 0.18 pig per year between 1997 and 2011.

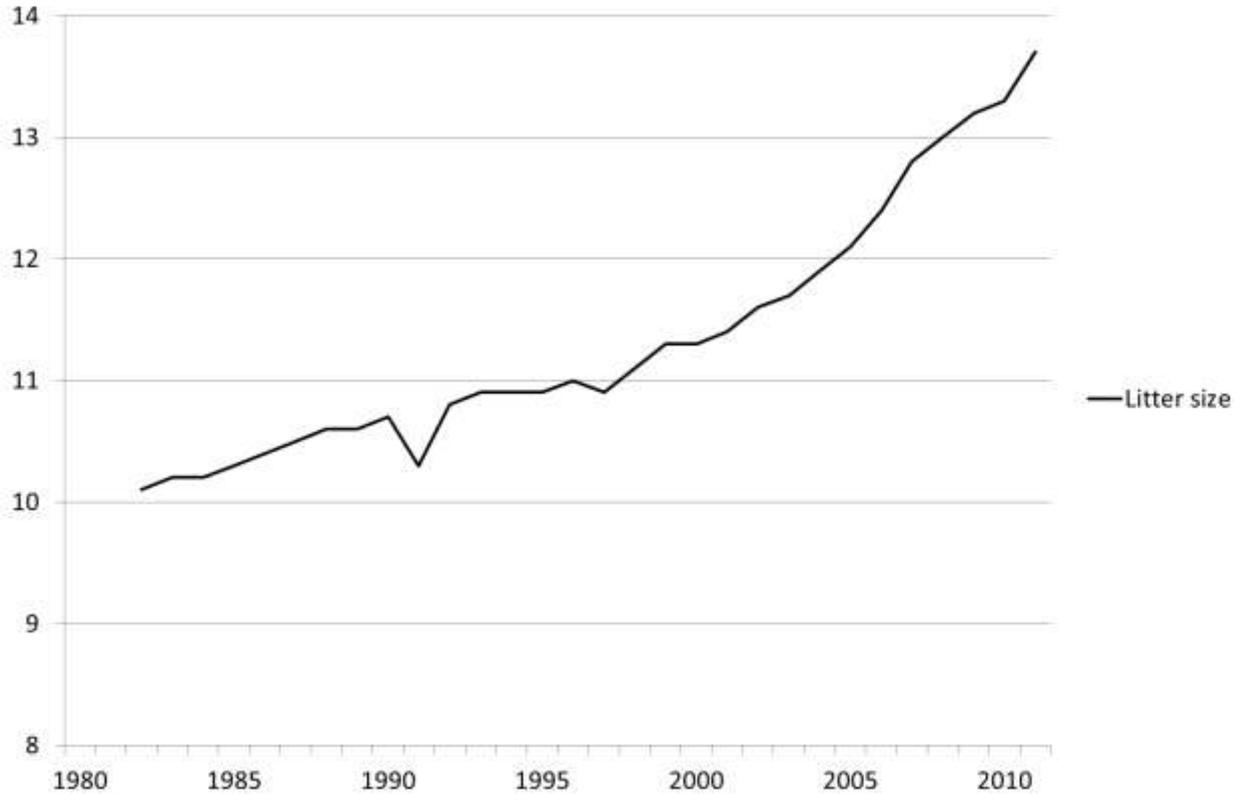

Fig. 1. Average number of pigs born per litter in Dutch herds between 1982 and 2011. Reproduced from: Ten Hove (2012), citing Agrovision as the source of the data.

BLUP methods need variance and covariance components as input. Heritability, genetic correlations and residual correlations are calculated from these components. When sufficient data is available, a Residual Maximum Likelihood (REML) estimation procedure can be used to determine the correct model and the components of variance and covariance. Examples of REML software are ASREML, VCE, MTDFREML and DFREML. Alternatively, Markov Chain Monte Carlo methods such as Gibbs Sampling can also be used.

Advanced BLUP models

Several more advanced BLUP models have been developed in the last two decades. Not all of these models have been implemented in standard software packages for BLUP, yet.

Random regression models. The first advanced model is a random-regression model. This type of model can be used for repeated measurements that form a curve in time. Weight does not increase linearly in time and daily gain at 6 weeks of age may be genetically a different trait than daily gain at 5 months of age. This can be modelled with a random regression model (Huisman *et al.*, 2002). The EBVs of such a model define the animal-specific genetic curve. Another application is for measurements that are dependent on an environmental variable. These are reaction-norm models. Examples are growth rate as a function of stocking density and reproduction traits as function of day temperature.

Social interaction models. Pigs in a pen form a social group. The achieved growth rate is not only affected by the pig's own genotype, but also by the behavior of its pen mates. For example, a dominant pig may get more than its share of feed at the expense of lower-ranking pen mates. This social effect on other pigs in the same pen also has a genetic component. Social interaction models estimate the direct genetic effect and the indirect social genetic effect simultaneously (Bergsma *et al.*, 2008). In a competitive environment, the direct genetic effect and the indirect social genetic effect have an unfavorable genetic correlation.

Categorical traits. There are many traits that have a discrete, qualitative, rather than a continuous, quantitative nature. Examples are normal resumption of the estrous cycle after weaning, lameness, conception after service, type traits, etc. Especially when the incidence in a category is less than 15%, it is not trivial to estimate breeding values with BLUP. It is possible to use a logit or a probit model or to use a threshold model.

Environmental sensitivity models. The sensitivity to micro-environmental changes within the target range of production systems varies among animals and may be under genetic control. For example, progeny groups of some boars may have a larger residual variance in growth rate in challenging conditions than progeny groups of other boars. The larger residual variance can be interpreted as being more sensitive to the challenging conditions. It is meaningful to take this element into account when aiming at breeding robust farm animals. Linear mixed models with genetic effects in the residual variance part of the model can be used for this purpose (Ronnegard *et al.*, 2010).

Marker-assisted selection

Marker-assisted selection (MAS) is an indirect selection process where a pig is selected on one or more traits of interest, not only based on measurements of the traits themselves, but also on one or more genetic markers associated with variation in the traits. For example, MAS is widely used for selection against malignant hyperthermia (porcine stress syndrome or halothane sensitivity), in which case the genetic marker is actually the causal mutation.

For quantitative traits, the first step is to map quantitative trait loci (QTL) in a QTL-mapping study. Any markers to be used should be close to the QTL of interest in order to ensure that only a minor fraction of the selected individuals will be recombinants that have the favorable marker allele but not the favorable QTL allele. It is best to use two flanking markers for a QTL, if possible. Although marker-assisted selection is widely used in plant breeding, its use in pig breeding for quantitative traits is fairly limited.

Genomic selection

Genomic selection uses a very large number of genetic markers to predict the genetic merit of animals. In contrast with marker-assisted selection, it does not require a QTL-mapping step. All informative genetic markers are included. The genetic markers are typically single-nucleotide polymorphisms (SNPs).

There are basically two methods. In the first method, (genomic) relationships between individuals are estimated from the similarity of the SNP genotypes. Those genomic relationships are much more precise than pedigree relationships. For example, genomic relationships are able to capture variation in relationships amongst half sibs, while all pedigree relationships among half sibs are equal to 0.25. The BLUP model is unchanged, but the pedigree relationship matrix between individuals is replaced by the genomic relationship matrix.

The second method is ridge-regression. This is a random regression of the phenotypic measurements on a very large number of SNP genotypes. The analysis yields a regression coefficient for each fitted SNP marker. The EBV of an individual is constructed after the analysis by fitting all SNP markers of the individual.

Genomic selection is most advantageous for selection on traits that are expressed later in life (survival), in one sex only (reproduction traits), or post-mortem (meat quality traits), as it increases the accuracy of the EBV of an animal without a trait measurement. A potentially interesting application is also that a blood or tissue sample may replace the collection of parent information on animals with data. If all animals with data and all selection candidates are genotyped, BLUP can be used with a genomic relationship matrix.

Reproductive technology

The most commonly used reproductive technology is artificial insemination (AI). Its use for a village breeding program lies in genetically connecting herds breeding purebred pigs and transferring the genotypes of the nucleus to farms crossbreeding pigs. For farmers, it is an advantage not to have to keep a boar for a small number of sows. Using AI instead of village boars also reduces the transfer of diseases from farm to farm.

IMPROVING PRODUCTIVITY AND ADAPTATION ON SMALL-SCALE FARMS

Interplay of environment and genotype

Livestock production is the interplay between the animal's genotype, the local climate, the design of the production system, the conditions on the farm and the management and feeding practices of the farmer. Imported productive breeds show impressive results in the countries of origin, which is the environment in which the breeds were selected. Fig. 1 shows the increase in average technical performance by country for five countries with significant pig production. The Netherlands and Denmark have a relatively uniform, well-controlled, indoor production system, Dutch and Danish farmers are quite willing to share their performance data and both countries have one dominant breeding program in the country. Great Britain has a much broader range of production systems, ranging from outdoor pig production and relatively harsh indoor systems with poor pig health to well-controlled, high-health pig farms with qualified staff. There are also at least four competing pig breeding programs. So because of the size of the breeding programs and the diversity in the target range of production systems, the achieved rate of improvement between 2002 and 2011 was in Great Britain only 53% of the achieved rates in the Netherlands and Denmark, but still substantial and meaningful. Fig. 2 therefore shows the potential of the methods of modern breeding programs in different pig production sectors.

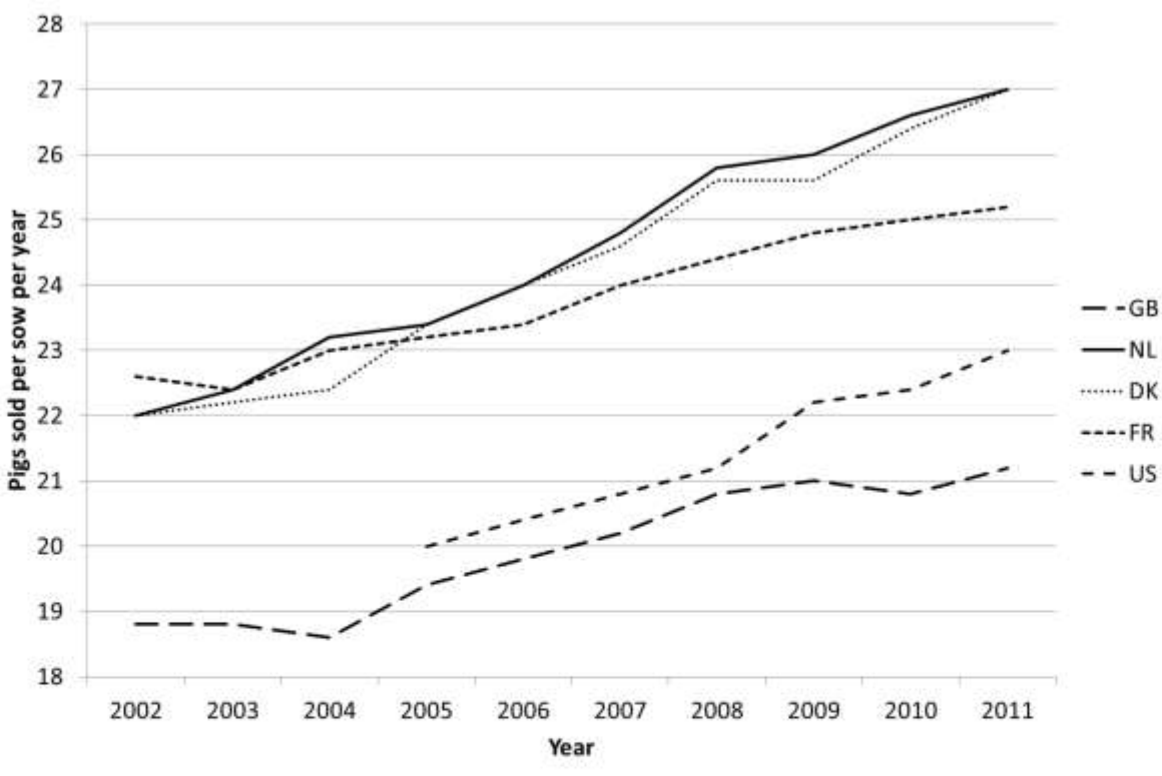

Fig. 2. Average number of pigs sold per sow per year for Great Britain (GB), Netherlands (NL), Denmark (DK), France (FR) and the United States of America (US), as collected by InterPig. InterPIG is an international network of pig production economists from fifteen countries. Reproduced from: Hoste (2013)

The five main pig breeding companies in the world became truly global companies in the 1990-ies and in the process they developed their lines for suitability in each of their markets world-wide. Without exception, they focused in upcoming markets like in Asia on the large-scale pig production that was being developed. Suitability for traditional small-scale pig farming in these markets has not been a concern for these companies, which is understandable, as working with a few large pig production companies is a more realistic business model for them than working with a very large number of small-scale pig producers without money.

In other words, imported productive breeds were never intended nor developed for the challenging conditions on small-scale pig farms. Farms that nevertheless use Western productive breeds are likely to suffer from a mismatch between genotype and production system. The symptoms of such a mismatch are a combination of poor health, poor growth, increased variability, increased mortality and poor reproductive performance.

There are two approaches to resolving the mismatch: improving the conditions, if possible, or using more suitable breeds. These two approaches are not mutually exclusive. In fact, they go hand in hand. Improving the conditions is a fast working solution, but it has to be repeated constantly. Using suitable breeds and improving suitability is a more long-term, but permanent solution. In general, farmers should try to improve what is realistically possible and improve suitability through breeding for dynamics that are beyond their control.

Improving conditions, feed and management

Improved genotypes require diets with a sufficient level of high-quality proteins (Table 1). Generally speaking, concentrates with synthetic amino acids (especially lysine) are adequate to meet these requirements. Deficiency of essential amino acids may cause poor growth, poor appetite, predisposition to disease, poor litter size and failure to come into heat or conceive from service (Muirhead and Alexander, 1997).

Table 1. Dietary lysine requirements of growing pigs with unrestricted access to feed[a]

Body weight range (kg)	Lysine (%, total basis)
5-7	1.70
7-11	1.53
11-25	1.40
25-50	1.12
50-75	0.97
75-100	0.84
100-135	0.71

[a]Mixed gender (50% barrows and 50% gilts) of pigs with high to medium lean tissue growth rate from 25 to 125 kg body weight (NRC, 2012)

Climatic conditions such as large differences between night and day temperature in spring or fall may require additional protection to avoid respiratory diseases. A possible solution is to create a micro-climate in the pen with an elevated floor and a lowered ceiling and provide bedding. The pigs are quite capable of finding the most comfortable zone in a pen depending on the ambient temperature (Napel et al., 2011).

Accumulation of changes for weaner pigs is a substantial stressor that makes the pigs temporarily vulnerable to diseases, so even commonly-present micro-organisms may become pathogenic. In many cases, removal of the sow, presentation of dry feed, relocation to a different house and pen, mixing into a different social group and exposure to new micro-organisms all happen at once. Often the negative consequences are counteracted with the use of preventive antibiotics for a few days, if the farmer can afford it. This routine use of antibiotics, however, is one of the reasons of the current worldwide increase in multi-resistant bacteria, which is a challenge to human health. The younger the weanling, the more difficult it is to cope with these changes. At weaning, the changes should be spread out. For example, leave the piglets a few days in the farrowing pen after removing the sow and get them used to the dry feed before relocating and mixing the piglets. Suitable dry feed should already be provided during lactation.

Finding the best-matching genotype for the conditions on small-scale pig farms

There are many situations in which it is not possible to improve conditions or management. Protein availability in a region may be a given limitation. The impact of the climate may also be difficult to control without a significant investment. . Vaccines or medication of sufficient quality might not be available, either. In such cases, it is best to breed stock that is suitably adapted to the dynamics of the local situation. Breeds that have been selected for survival in these conditions, but not productivity, may be a good starting point, but require genetic selection for productivity given the local limitations. Adaptation of productive breeds may be improved by using crosses of a local and a productive breed. It may also be possible to select lines of productive breeds for suitability for small-scale farms.

BREEDING FOR PRODUCTIVITY AND ADAPTIVE ABILITY ON SMALL-SCALE FARMS

Finding the best-matching genotype for the local conditions requires a systematic approach. The following steps can be distinguished.

1. Formulate the objective of the breeding approach clearly and in sufficient detail
2. Design the breeding approach
3. Monitor progress and control implementation

Breeding goal

The breeding goal is the overall objective of all efforts to change the characteristics of the next generation of a population. For a pig producer, the next generation needs to be more productive, but with relatively fewer problems, so mortality is lower, uniformity is higher and reproduction is normal in the current local conditions. If locally available waste products are the main component of the diet, the ability to utilize such products may be more important than feed efficiency. For a buyer of finisher pigs, the pigs need to be in the right weight range, with the correct fat cover and with the desired carcass quality. Defining the breeding goal should involve a structured evaluation of the preferences of the small-scale farmers for the traits to be included (Roessler *et al.*, 2008).

Paradigm of the breeding approach

Before discussing the design of the breeding approach, it is worthwhile to consider the historic differences in paradigm in animal breeding in Asia compared to Europe and the Americas.

In Europe, there was no conscious breeding of pigs up to the beginning of the 19^{th} century, so natural selection was the main selective force determining the characteristics of populations. The geographical barriers determined the breeding populations. In the second half of the 19^{th} century, groups of breeders started to define breeds and establish herdbooks to register which animals were suitable for breeding in a particular breed, according to the breed's true type.

The European and American paradigm to breeding developed out of this thinking and aims to develop a relatively closed population from within. The challenge is then to maximize genetic progress, whilst maintaining the rate of inbreeding close to 0.5% per generation.

The historic Asian paradigm to breeding is different. A breeding population is a breeding pool to which animals from other populations can be added to improve characteristics. The breeding pool is bred for a number of generations with little to no conscious genetic selection, until it is considered necessary to bring in new breeding animals from another population. Culling of any unsuitable animals from the breeding pool can be considered a form of natural selection in the breeding pool.

Modern pig breeding in Asia still struggles with these different paradigms as many large-scale pig operations regularly buy populations of breeding stock to add to their breeding pools of Landrace lines, Large White lines and terminal boar lines. Several of these companies use BLUP software, but do not rely on it for genetic improvement.

A recent series of studies in Northwest Vietnam involved the Ban and the Mong Cai breeds. A village breeding program was proposed to structure the crossbreeding program on village farms (Herold et al., 2010), but the approach to maintaining and improving the pure breeds is unclear and appears to be based on the Asian paradigm.

The Asian paradigm is not inferior to the European paradigm. People involved in establishing a pig breeding program just need to be aware of it. When working from the Asian paradigm, it is more critical that breeder groups consider the historical selection environment of a population to introduce into the breeding pool, to avoid adaptation problems. Within the European paradigm, there is an intention to continue to develop the newly introduced population in the target production environment.

Design of the breeding approach

The breeding approach consists of all efforts to change the characteristics of future generations of breeding sows and finisher pigs in the desired direction.

Maintaining sufficient sows to breed replacement gilts. The most important aspect of the design of a breeding program is that it should produce sufficient replacement breeding stock. This may seem trivial, but it is an issue for complex breeding programs in small herds. If only a small number of breeding gilts of a particular type are required per year, it is difficult to have them available when they are required. A less complex breeding program, purchasing of breeding gilts if only a few are required or collaboration with other breeders may be a better solution in such cases.

Making cost-effective use of heterosis. Heterosis or hybrid vigor can be seen as the opposite of inbreeding depression. Inbreeding depression occurs when related parents have progeny with traits that negatively influence their fitness due to homozygosity. When parents come from lines that do not share a common origin, the heterozygosity in the progeny is restored. Average growth rate and reproductive performance of such crossbred pigs are higher than the average of the parental lines. Although a three-way or a four-way crossbred finisher pig is optimal for heterosis, the size of the breeding program may not sustain three or four populations. In such a case, a two-way crossbred finisher may be more cost effective.

Identifying lines and crosses of lines that meet the breeding goal the best. In the traditional Asian paradigm, it consists of identifying breeding populations that have the desired characteristics and add breeding stock of these populations to the breeding pool or one of the breeding pools. The breeding pools are bred for a number of generations without selection until the need arises to make a fresh contribution to one of the breeding pools. The commercial pigs may be crosses of breeding pools.

In the European paradigm, identifying the most suitable populations is just the first step towards attaining the breeding goal. The most suitable lines yield a crossbred sow and finisher after crossing that is as close as possible to the breeding goal.

Maintaining the breeding population with minimal inbreeding. Minimizing inbreeding comes down to (1) selecting sufficient parents for the next generation and (2) aiming for an equal contribution of the selected parents to the next generation. Minimizing inbreeding is mainly an issue for closed breeding populations, in other words breeding populations that cannot bring in unrelated breeding pigs. One reason for not bringing in breeding stock is maintaining a high health status. Another reason is that it concerns a rare local breed with unique characteristics, for which there just no other is breeding stock to bring in. A third reason could be competition, as there may not be a similar population of a line with the same level of productivity that is available to acquire.

Controlling inbreeding becomes difficult when the population of sows for pure-line breeding is less than 75 sows. The minimum number of replacement boars per generation is 15. If the population is poorly connected, i.e. multiple genetically unrelated subpopulations exist, then the rate of inbreeding is much higher in each of the subpopulations. Circular group mating (Nomura and Yonezawa, 1996) can be useful in controlling inbreeding in small populations, where groups of small-scale farmers or villages can be considered mating groups.

Selecting the best-adapted animals for future generations. The next step is to design a genetic selection protocol to identify in each generation the best animals as parents to move the next generation closer to the breeding goal. Such a selection protocol consists of unique identifying individuals for a very long time (> 15 years), recording parents, and recording performance in the target production environment, evaluating performance with statistical tools like BLUP, selecting animals on estimated breeding values and limiting the impact of a single individual on the next generation in order to control inbreeding.

The breeding goal determines which sow and boar traits need to be recorded and which finisher traits need to be measured in a reasonably standardized protocol. The minimum percentage of pigs tested should also be defined and non-random testing must be avoided.

The parents and performance of tested pigs need to be stored in a database that has an interface with BLUP software so a data file and pedigree file can be produced for BLUP and the estimated breeding values be read back into the database. The database should produce selection reports for choosing replacement breeding. Farmers should be trained to use the information on selection report to make full use of the genetic selection protocol.

If more than one trait is included in the breeding value estimation, it becomes difficult to rank animals. The common solution is to derive a selection index of estimated breeding values that reflects the importance of individual traits in the breeding goal. Generally economic weightings are used for such an index.

Special attention is required for selection and structured use of superior breeding boars. If boar farms are the main source of breeding boars, they should be involved in establishing the breeding program and not be considered a third party.

Monitoring progress and controlling implementation of the breeding approach

Having a structured approach to breeding is no guarantee of getting results. A breeding program involves a large number of small decisions over time made by individual people. Getting all people involved to work as a team towards a common goal is the main challenge of getting results out of a breeding program. It means that individual farmers need to be motivated to implement the protocol in their own interest. Monitoring reports are essential to verify that everyone involved continues to make the right decisions. These reports can be used to provide feedback to farmers on the success of selection on the farm.

The most important parameters are the selection intensity per year and the rate of inbreeding per generation. There are many statistics that can be calculated to aid the control of these two parameters. The rate of inbreeding should be well below 1% per generation (FAO criterion) and closer to 0.5% per generation for sustainable breeding. Given this restriction, the selection intensity per year can be maximized. Selection intensity is the superiority of the selected individuals over the group from which they were selected. It is expressed in standard deviations, so a selection intensity of 1.5 for boars means that the selected boars were 1.5 standard deviations better than the group from which they were selected.

The selection intensity depends on the replacement rates of breeding stock. It is common practice to divide the selection intensity by the generation interval to get the selection intensity per year. The generation interval is the average age of parents when their progeny are born. The selection intensity per year largely determines the genetic change in the breeding goal. The realized genetic change in the breeding goal is monitored with genetic trends and phenotypic trends.

ORGANISATIONAL ASPECTS OF A BREEDING PROGRAM

Minimum size of a breeding program

The minimum size of a breeding program is determined by the ambition of the breeders involved. It is equally true that the ambition of the breeders is restricted to the minimum possible size of the breeding program. Breeding sufficient replacement gilts can be done by farms of any size. The other functions of a breeding program require that small-scale pig farmers collaborate. Utilizing heterosis in finisher pigs requires at least two lines, one for sows and one for boars. Utilizing heterosis in the sow requires three lines and at least two types of sows: grandparent sows and parent sows.

There are breeding programs that allow smaller farms to utilize heterosis if they cannot afford or do not want to buy replacement gilts, for example a rotational cross. The farm has two types of sows when using two lines, say A and B. Type 1 is 1/3 A 2/3 B and type 2 is 2/3 A 1/3 B. Type 1 sows are always mated to a boar of line A to produce type 2 gilts. Type 2 sows are mostly mated with a terminal boar to produce finisher pigs, but some of the 'trouble-free' performing sows are mated with a boar of line B, to breed replacement gilts of type 1. This works particularly well when using AI. A typical make-up of the herd is 10% type 1 and 90% type 2, with 1-3% of type 2 being mated to line B.

The minimum population size to minimize inbreeding without the possibility to introduce unrelated stock is 75-100 sows with sufficiently coordinated breeding. The rate of inbreeding per generation can be kept at 0.75% per generation if sufficient males are selected per generation. The FAO considers a breed in a critical state if the predicted rate of inbreeding per generation from the number of breeding males and breeding females is higher than 1%.

For meaningful genetic improvement, a terminal boar line (sire line) needs to have at least 200 sows, as an indication. A sow line (dam line) needs to have at least 300-400 sows. Genetic change does not stop below these numbers, but control of inbreeding will increasingly restrict the selection intensity and as a consequence, the genetic change.

Participatory pig breeding

It is clear from the above that small-scale farms cannot achieve genetic change that is meaningful for their production systems without combining forces. Imported lines are expensive and less suitable for small-scale pig farming. Improving productivity of locally adapted lines is too fragmented and too much lacking focus if breeders do not work together in breeder groups or cooperatives.

Participatory breeding is a potentially viable way to move forward. Participatory means that farmers are more involved in the breeding process and breeding goals are defined by farmers instead of global pig breeding companies with their large-scale breeding programs focused on large-scale pig farming throughout the world. Farmers' groups and NGOs, for example, may wish to empower small-scale pig farmers to breed from the best-adapted stock, build farmers' technical expertise, or develop new products for niche markets.

In a participatory pig breeding program, a group of small-scale farmers with similar production systems work together to improve their lines. Firstly, they learn from each other how to identify the best-adapted stock to use for breeding replacement stock. If at all possible, they collect parent information and growth and reproduction performance on candidate breeding stock. The information should be stored in a central database and evaluated with a correct statistical model. This requires a link to a local university or college that can host the database and has trained and qualified staff to perform the required analyses and calculations. The EBVs are returned to the farms and the best females selected. The best males are selected centrally and are made available to all or to groups of participating farmers. Participatory breeding groups could also work together by each breeding a sow line and exchanging boars to produce crossbred gilts.

Link to the local markets

The price of full-weight finisher pigs is an important part of the income of the farm. A breeding goal aiming at improving the small-scale farmers’ income should be defined involving people buying finisher pigs or pork products. A properly working pig breeding program could also improve the quality and uniformity of the products they sell.

Governance

A participatory breeding program involves a large number of small-scale farmers, some experienced and some without knowledge of pig breeding, but all are used to work independently. It is critical that one of the parties in the breeding program coordinates the activities of the breeding program. This could be an NGO, a government official, a slaughter house, a purebred-breeding herd, etc.

Stepwise approach

Stimulating and motivating small-scale pig farmers to breed in a structured manner as a means to increase farm income is the primary aim of establishing a participatory breeding program. Introducing breeding technology should support this aim and not be an aim in itself. If the breeding program is functioning, the participating farmers may be more receptive to adopt more advanced technology and make it work in practice. So in some cases, it may be advisable to select only visually for adequate adaptation at the start of the project and change to BLUP selection when the breeding program is functioning properly.

PRACTICAL SCENARIOS

Scenario 1. Small-scale pig farms with independent breeding

Small-scale pig farms breeding their own replacements are the common situation. There is little to no perspective for improving the farm income through genetic selection, due to the small numbers of stock.

Scenario 2. Breeder groups with a boar farm or AI center

If some of the small-scale pig farms work together in a breeder group or cooperative, it may be possible to identify the best boars and gilts across farms, instead of within farms. If the best boars are used as breeding boars across farms, meaningful genetic change is possible. The best boars can be made available through boar farms or AI centers, if possible. Genetic selection is limited to visual evaluation for suitability for the local production systems.

Scenario 3. Breeder groups, boar farm and recording of sow data

Reproduction data of sows on local farms are very useful for genetic selection for productivity in the local conditions. If the information can be combined with the parent information and collected in a central location, it is possible to estimate breeding values for sow reproduction, which can be used in the selection process. Such a breeding program requires input from an NGO or government institutes to establish a robust data collection and evaluation system. BLUP would be the preferred evaluation method.

Scenario 4. A local supply chain of well-adapted breeding stock or finishers

A slaughterhouse or a local government may decide to establish a breeding farm of sufficient size that supplies breeding stock or finishers to local small-scale pig farms. The pig farmers are involved in defining the breeding goal, but the implementation is done by the breeding farm. The pig farmers sell their full-weight finisher pigs back to the slaughterhouse. This can be a viable business model for all parties, in which the breeding farm gets an income either directly from the slaughterhouse or by selling replacement stock or weaners for finishing. Similar supply chains have been implemented in Kerala and Assam in India.

Scenario 5. A structured participatory breeding program with clear breeding goal

Breeding programs with a robust data collection and evaluation system can easily be extended with a simple protocol to monitor finisher performance. The simplest way is to record weight and back fat at slaughter, if pigs are killed in a central location. The BLUP breeding value estimation can easily be extended with finisher traits. An example of a structured participatory breeding program without genetic improvement in the pure lines is presented by Herold *et al.* (2010).

CONCLUSION

Small-scale pig farmers with production systems that differ substantially from large-scale pig farms need to find or develop a line or cross of lines that is suitably adapted to their local conditions. A mismatch between genotype and production environment creates problems with health, mortality, reproduction, growth performance and carcass quality. Modern breeding uses an extensive set of technology, which can be used to develop productive and yet adaptive lines of pigs for small-scale pig production in a sustainable and integrated local agriculture. Using the methods of modern breeding has more potential than using the products developed in a very different context, if production environments are too different. Breeding technology is not effective when used by individual small-scale farmers. Farmers should combine forces, work together, share information and learn from each other. Adoption of more advanced breeding technology will require the involvement of a large stakeholder, such as a slaughterhouse or a local government to facilitate the breeding program to establish a shared breeding goal and a central database for data collection and estimation of breeding values.

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