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Genetic management of the Göttingen Minipig population ☆

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A B S T R A C T

The Göttingen Minipig is a laboratory animal of worldwide importance. The breed was developed in the 1960's at the University of Göttingen, Germany, using the founder breeds Minnesota Minipigs, Vietnamese Potbelly Pig and German Landrace. After the initial period under free range conditions the population was stocked under high hygienic standards. In 1992 an exclusive licence contract was made between Ellegaard Göttingen Minipigs ApS in Denmark and the University of Göttingen. Since 2002 the production and marketing of Göttingen Minipigs in the USA is managed by Marshall Farms, Inc. under licence from Ellegaard Göttingen Minipigs A/S. Today, there are three Danish, one American and one German population. The genetic management for all populations is provided by the University of Göttingen. The main focus is the maintenance and reduction of inbreeding and genetic drift, the maintenance of a high degree of uniformity and genetic progress in the main selection traits. The main selection trait in the past was the number of piglets born alive. By producing many piglets per sow and year, a fast genetic exchange of breeding animals could be achieved leading to a minimised inbreeding in the populations. To satisfy the market demands of a small and easy to handle minipig and to overcome the problem of an antagonistic relationship between litter size and body weight, the trait body weight reduction was included in the selection scheme using a restricted selection index. It is planned for the future to include temperament traits in the breeding scheme. Due to fast developments in genome-based breeding applications, these new methods can soon be implemented for an efficient control of genetic drift and inbreeding or even for genome-based selection.

1. Introduction

The Göttingen Minipig is a unique resource for various reasons:

- it is a relatively young population; the final genetic bottleneck was only in 1991/1992;
- it is a quite small population and the number of active breeders is limited to a few hundreds;
- the entire breeding population is located in just three physical locations (Ellegaard Göttingen Minipigs, Dalmose, Denmark; University of Göttingen, Relliehausen, Niedersachsen, Germany; Marshall Farms, North Rose, Rochester (NY), USA);
- the entire population history is extremely well documented. All matings are recorded back to the start of the development of the population in the 1960's.

For all of these reasons the Göttingen Minipig is an interesting and valuable case-history in the development and management of an animal breed. In the present review we describe the history and characteristics of the Göttingen Minipig, and the principal features of the genetic management of the Göttingen Minipig population.

2. Population history

The Göttingen Minipig is a relatively young composite breed. Its development started in the 1960's through an initiative of Prof. Fritz Haring and his co-workers (especially Prof. Ruth Gruhn and later Prof. Peter Glodek) at the former Institute of Animal Breeding and Genetics of the Georg-August University Göttingen, Germany. The development of the breed was inspired by the existence of similar miniature breeds, like the Minnesota Minipig, in the United States, and from the beginning aimed at developing an experimental model animal for medical and pharmacological research.

The development of the breed started in 1960 with an import of three male and two female Minnesota Minipigs from the Hormel Institute in Austin, Minnesota (USA).

The Minnesota Minipig itself is a composite breed which was developed at the Mayo-Clinic in Rochester, Minnesota by Professor Winters from the Hormel Institute in Austin, Minnesota. The development was started in 1949, based on black Guinea hogs from Alabama, feral boars from the Pacific island of Catalina, and Piney Woods "rooters" from Louisiana. In 1957 animals of the Ras-n-Lansa breed from the island of Guam, with strongly expressed dwarfism, were introduced to reduce size (Beglinger, Becker, Eggenberger, & Lombard, 1975). It is interesting to note that two out of four founder breeds of the Minnesota Minipig are island-based strains, making use of the evolutionary phenomenon of so-called island dwarfism, reflecting the observation

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that isolated populations on small islands tend to develop dwarf variants in many mammalian species.

The Minnesota Minipigs were reciprocally bred with three male and four female Vietnamese potbelly pigs from the Wilhelma Zoo in Stuttgart, Germany. The resulting population was spotted and phenotypically strongly affected by the (undesired) characteristics of the potbelly pigs. To widen the genetic basis four additional Vietnamese female potbelly pigs were imported in 1965 from the Friedrichsfelder Zoo in East Berlin, leading to a smaller and less coloured pig (Glodek & Oldigs, 1981).

It was soon realised that for many applications, especially in dermatology and growth/muscle studies, a leaner (less potbelly-type) pig with white skin would be desirable. For this purpose, genetics of commercial German Landrace pigs were introduced by artificial insemination during the years 1965 to 1969. At that time, separate lines of coloured and white minipigs were established. Glodek and Oldigs (1981) reported that the proportional representation of the three original breeds in the white line 1969 was 60% Vietnamese potbelly pigs, 33% Minnesota Minipigs and 7% German Landrace. An overview of the main characteristics of the founder breeds is given in Table 1.

The resultant Göttingen Minipig is a dwarf breed, characterised by "proportional dwarfism"; all body parts are reduced in size, but the proportions (e.g. relative bone lengths) are comparable to normal-sized pigs. This type of dwarfism often is referred to as "pituitary dwarfism" and is thought to be caused by growth hormone deficiency, especially a deficiency of the insulin-like growth factor 1 (IGF-1). While this type of dwarfism is characteristic for a number of farm animal breeds in various species (besides minipigs e.g. Dexter cattle, Shetland pony) and is genetically fixed in those populations, it can also be caused in humans by psychogenic factors. It is in contrast with the achondroplasia type of dwarfism, which is characterised by severe shortness of proximal limbs, increased spinal curvature, and distortion of skull growth. This type of dwarfism is generally considered as a genetic defect. It should be noted that achondroplasia is also present in some domesticated animal species, primarily in some dog breeds (e.g. Basset hounds).

To date no genetic analysis of the cause of dwarfism in Göttingen Minipigs has been conducted. Several studies have reported that IGF-1 is responsible for growth in pigs and that lower IGF-1 levels were found in blood plasma of small pig breeds compared to normal-sized pigs (Lauterio, Trivedi, Kapadia, & Daughaday, 1988; Owens, Gatford, Walton, Morley, & Campbell, 1999). A detailed genetic study in dog breeds of a different size concluded that a single IGF-1 allele is the major determinant gene for small size in dogs (Sutter et al., 2007). Based on these results the genetic basis for small body size in Göttingen Minipigs can be hypothesised; a pilot study is underway to characterise the IGF-1 variants in comparison to normal-sized pigs.

Table 1
Characteristics of the founder breeds of the Göttingen Minipig.

Minnesota Minipig	Colour: red, black and spotted Phenotype: small, wild boar-type Fertility: medium to poor Behaviour: easy to handle
Vietnamese potbelly pigs, Stuttgart	Colour: grey Phenotype: small, very fat Fertility: early mature, good fertility Behaviour: aggressive, difficult to handle
Vietnamese potbelly pigs, Friedrichsfelder Zoo	Colour: black and white spotted Phenotype: very small, fat Fertility: good Behaviour: aggressive, difficult to handle
German Landrace	Colour: dominant white Phenotype: large, low fat content Fertility: medium to high Behaviour: well domesticated, easy to handle

In the first years, the Göttingen Minipig breed was developed under "free range" conditions on an experimental farm in Friedland, which was characterised by a rather low hygienic standard. Although from the very beginning the breed development is completely documented and all records are still available (on paper), most of the phenotypic records at that time (litter size, weight etc.) are difficult to interpret since they are masked by extreme environmental fluctuations. Also, there was a high frequency of losses and poorly developing animals due to infection pressure (Glodek, Bruns, Oldigs, & Holtz, 1977).

In 1970, the experimental farm in Friedland had to be given up, and a new experimental farm was established in Dassel-Relliehausen. There, with the financial support of the Volkswagen-Foundation, a new minipig housing unit was built which was for the first time suited to keep the population on a reasonable hygienic level in an indoor-facility. The unit was stocked by means of hysterectomy (done by Prof. Diedrich Smidt, with technical support of the commercial pig breeding company Schaumann-Hülsenberg).

In the new unit, a closed population with 50 sows was maintained under specific pathogen free (SPF) conditions, composed of nine white and eight coloured lines (Bollen & Ellegaard, 1996). A line was defined by the paternal strain (i.e. animals of one line had the same sire, grandsire etc.), while the maternal origin rotated (within the white and coloured lines, respectively). This is a well-known pragmatic design to minimise genetic drift in closed populations of small size. Also, the number of matings per animal was limited to keep the family size small.

The move to the new unit resulted in a massive change in phenotypic performance. This is demonstrated for the average weight at different ages in Fig. 1. Both for the white and the coloured lines, the weight at later ages (100 and 154 days, respectively) was practically doubled as a consequence of the better environment and health status. Thus, much of the seemingly achieved miniaturisation until 1970 was merely an artefact caused by poor environmental conditions and high infection pressure. As can also be seen from Fig. 1, the increase in size caused by the import of Landrace genetics starting in 1965 was quickly counterbalanced by means of selection, so that there was no systematic weight difference between the white and the coloured lines at the time of sanitation.

At that time, animals were sold to various industrial and scientific users. Also, small sub-colonies were started in different places around the world, however most of them from an insufficient number of founder animals, so that long-term maintenance as closed herds was hardly possible. From 1970 to 1990 the Göttingen Minipig started to become an established and well-known experimental animal, but far

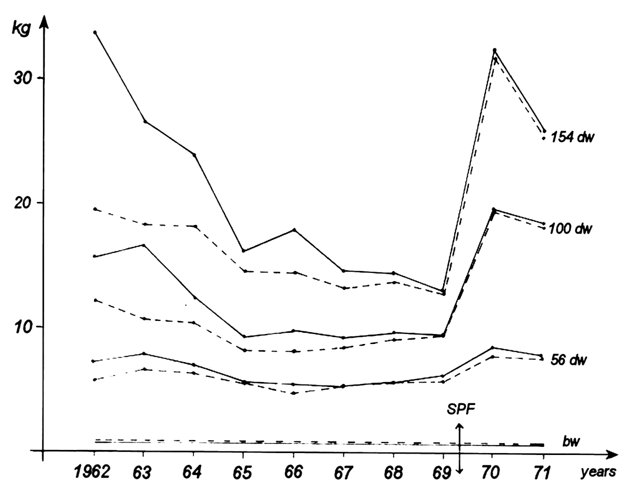

Fig. 1. Average weight at 56 days (56 TG), 100 days (100 TG) and 154 days (154 TG) of the white (———) and the coloured (- - - - -) lines for the years 1962 to 1971. The hygienic sanitation and move to the SPF-unit in Relliehausen is indicated as "SPF".

from the level of standardisation and uniformity that is required today.

The next qualitative step in the development of the breed was taken in 1992. At that time, one of the main breeders, Lars Ellegaard in Denmark, signalled his interest to set up a professional multiplier herd to become the world-exclusive provider for Göttingen Minipigs on a well-defined and higher standard (with regard to population uniformity, health status, recorded breed characteristics etc.) than had previously been possible.

Based on this offer a licence contract between Ellegaard Göttingen Minipigs ApS (EGM) and the University of Göttingen was filed. In accordance with this contract, EGM built a production facility in Dalmose, Denmark. Hysterectomy of 38 pregnant sows imported from the experimental farm in Relliehausen was used to establish the new production facility under full-barrier conditions. From the piglets that were born, 122 breeding sows and 53 breeding boars were used to start production. Once the new production unit in Denmark was implemented and running on a routine basis, the production unit in Relliehausen was emptied, thoroughly cleaned, and restocked with a re-import of breeders from Denmark to obtain the same hygienic standard.

Simultaneous with this genetic bottle neck, it was decided to give up the coloured lines and exclusively produce white animals. This was to some extent due to the fact that the coloured lines were slightly more variable than the white lines, but primarily the market preferred white animals, especially for dermatology studies. Also, the white colour is a special and unique feature of the Göttingen Minipig among all commercially available minipig breeds.

The good business development led to an increase of the production capacity with the addition of a second production unit in Dalmose (which was built in 1998 and increased in capacity in 2004). In 2002 EGM subcontracted out production and marketing of Göttingen Minipigs in North America to Marshall Farms, Inc., North Rose (NY) USA, who started a minipig production unit in August 2003. By December 2007, the production capacity of the unit in Germany has been increased by 60%. In the year 2009, a third production unit was opened in Dalmose leading to currently 5 subpopulations of Göttingen Minipigs worldwide.

For hygienic reasons, all subpopulations are kept completely isolated after the separation. There is no genetic flow between populations, either through the exchange of animals or through biotechnological means such as the use of artificial insemination or embryo transfer. The maintenance of separated subpopulations in three countries (on two continents) is considered as a safeguard against the complete loss of the minipig populations as a consequence of a disease outbreak and/or veterinary interventions.

3. Genetic management of the Göttingen Minipig

The genetic management of the entire breeding population of the Göttingen Minipig is uniformly provided by the Animal Breeding and Genetics Group at the Georg-August University Göttingen, since 2001 under the responsibility of Prof. H. Simianer.

In general, the genetic management of the Göttingen Minipig population has the following objectives:

- to maintain the genetic integrity of the population by avoiding (as far as possible) inbreeding and genetic drift;
- to maintain the genetic uniformity of the subpopulations;
- to balance adverse effects of inbreeding (e.g. reduced fertility, increased susceptibility to diseases, monitoring and selection against genetic defects);
- to pursue desired breeding objectives (smaller size, smoother temperament).

It is not a trivial problem to achieve these objectives simultaneously, since some of these objectives are antagonistic. However, up-to-date breeding methodology provides tools to pursue this much more efficiently than it was possible in the past.

4. Inbreeding, genetic drift and effective population size

In a closed population of finite size, a continuous increase in inbreeding and loss of alleles through genetic drift are inevitable mechanisms. Inbreeding is defined as the probability that the two homologous alleles at an autosomal locus of an individual are "*identical by descent*" (ibd), i.e. can be traced back both maternally and paternally to the same allele of an ancestor. In other words: an offspring is inbred, if its parents have a common ancestor, i.e. are related. Inbreeding is measured by the inbreeding coefficient (Wright, 1922), which is closely related to the relationship coefficient: the inbreeding coefficient of an individual is half the relationship coefficient of its parents. Malécot (1948) has introduced the alternative concept of kinship, where the kinship of two individuals is half the relationship as defined by Wright. All three coefficients (inbreeding, relationship, kinship) can be calculated from the pedigree data.

Inbreeding increases the probability of homozygosity and reduces the probability of heterozygosity. There are two basic undesirable effects of inbreeding:

- in inbred populations or individuals, there is an increased probability of showing recessive genetic defects;
- inbred animals show an inbreeding depression, which mainly is expressed by a reduction in fitness, i.e. reduced reproductive performance and increased susceptibility to complex diseases.

Genetic drift is a related, but different phenomenon. Conceptually, the process of forming an offspring generation from a parent generation includes a random sampling process: the gametes (sperms and oocytes) leading to the animals of the offspring generation are a random sample from the genetic pool of the parent generation. As in every random sampling process, the entities to be sampled (i.e. alleles) are not uniformly distributed, but follow a random (in this case: Poisson) distribution, so that some alleles are more frequent in the offspring — than in the parent generation, others are less frequent, and some are even lost. This leads to a random fluctuation of allele frequencies from generation to generation, which is called genetic drift. This process leads to random differences between generations. The least desirable consequence of genetic drift is the loss of alleles and the fixation of genes, reflecting a loss of genetic diversity over time.

Both inbreeding (more precisely, the inbreeding rate (ΔF), which is the increase of the inbreeding coefficient (F_i) from one generation to the next) and genetic drift (the variance of allele frequencies between generations) are inversely proportional to the *effective population size* N_e. The effective population size is defined as the size of an ideal (Fisher–Wright) population which leads to the same inbreeding rate or genetic drift as an existing population. Since both inbreeding and genetic drift are proportional to $(2N_e)^{-1}$, it is in principle sufficient to control N_e to minimise adverse effects caused by inbreeding and genetic drift. In a farm animal context, an effective population size of $N_e = 50$ (equivalent to a 1% increase of inbreeding per generation) usually is considered to be the critical lower limit.

There are different approaches to estimate the effective population size of a population. Where the full Pedigree data are available, one of the most reliable approaches is to estimate the rate of inbreeding ΔF first, which is the change of the average inbreeding coefficient (F_i) from one year to the next. The linear regression coefficient of birth year on $-\ln(1-F_i)$ is a robust estimator of ΔF. Effective population size per generation then is estimated by $(2L\Delta F)^{-1}$, where L is the average generation interval. With $L = 2$ years, the estimated effective population size N_e of the actual populations lies above 100. This indicates a sufficient genetic size of the populations, which is mainly due to the active genetic management of the populations.

5. Genetic distance between subpopulations

The genetic distance describes the genetic diversity between populations. To assess the genetic distance between populations empirically the genetic differences are measured based on differences between allele frequencies at several neutral loci (e.g. unlinked microsatellite marker loci). One problem in this definition and measurement of genetic distances is that the within population diversity is not taken into account. Eding and Meuwissen (2001) proposed to use the average kinship within and between breeds as a more comprehensive approach to describe the overall phylogenetic structure of subdivided populations. Kinship can be calculated based on the available pedigree information, but also estimated based on marker information. Both approaches were used for three subpopulations of the Göttingen Minipig; the two Danish (unit 1 and unit 2 in Dalmose) and the German population (DK1, DK2, GE) by Flury, Weigend, Ding, Täubert, and Simianer (2007). The pedigree-based results are shown in Table 2.

The average kinship coefficients within populations range between 0.172 for the German and 0.178 for the second Danish subpopulation. Average between subpopulation kinship is on a lower level, being 0.148 between the German and either of the Danish populations and 0.159 between the two Danish populations. These numbers reflect the fact that there is a certain (unavoidable) amount of genetic differentiation, mainly due to genetic drift, between the subpopulations. However, differences are of small magnitude and are not statistically significant, so that at the present time a continuous monitoring of the population differentiation (for the future also including the US subpopulation) is considered to be sufficient. If population differentiation reaches a critical level, a transfer of novel genes (presumably through artificial insemination and/or embryo transfer) needs to be considered to re-establish the genetic integrity and homogeneity of the entire population.

6. Selection

To improve the performance for a trait in a breeding population from one generation to the next, the best animals in that trait from the parent population are selected as breeding animals. “Trait” in this context encompasses simple measurable traits, like weight at a certain age or litter size, but also highly complex and unobservable traits like susceptibility to certain diseases or temperament. To achieve comparability between the animals in a population a breeding value for each animal is estimated on the basis of its own and/or its relatives' performance. Based on these estimated breeding values (EBVs) the animals can be ranked and animals with highest EBV for the considered trait will be chosen as parents for the next generation.

Estimation of breeding values is a well developed methodology in animal breeding and is based on the concept of best linear unbiased prediction (BLUP; Henderson, 1973). Based on this fundamental concept, a number of specific applications have been developed to model e.g. binary or multinomial data (like healthy–sick or litter size), longitudinal data (like growth curves) or time spans (like longevity or time to first litter). Where appropriate all these methods are adopted to be used in the genetic management of the Göttingen Minipig populations.

The main breeding goal after establishment of the first Göttingen Minipig population was to avoid inbreeding with a high exchange of breeding sows and boars. From the beginning Göttingen Minipigs were selected for low body weight on the basis of the 154-day weight. After building up the new experimental farm in Relliehausen Göttingen Minipigs were mainly selected on weaning weight. Due to hygienic problems and resulting masking effects on the body weight the selection on low body weight was stopped in 1976 (Glodek &Oldigs, 1981).

Next to body weight a desirable litter size was a main breeding goal. Due to the increasing demand for Göttingen Minipigs the number of piglets born alive (NBA) had to be increased. Especially in the beginning it was difficult to reach this aim due to a fast change in breeding sows used and a physiologically low performance of gilts in this trait. Also, there is a genetic and physiological antagonism between litter size and body weight: in all multiparous species, smaller animals produce smaller litters. And since reducing body weight of Göttingen Minipigs was always of primary interest, a correlated (negative) selection response in litter size was unavoidable. Today, breeding values are estimated at regular intervals for the trait NBA and only animals (both males and females) that inherit a high performance in this trait are used as breeders.

The main goal in the near future will be the combination of the two economically important traits litter size and low body weight in a total merit index. Therefore genetic parameters for body weight had to be estimated.

Köhn, Sharifi, Malovrh, and Simianer (2007) have analysed a comprehensive and very substantial data set (almost 200,000 body weights from more than 33,700 Göttingen Minipigs from the two Danish subpopulations). In Fig. 2, the daily average weights are given for the range from birth to 700 days of age (Köhn, Sharifi & Simianer, 2007). Among 11 linear and non-linear mathematical functions the third order polynomial was identified as the best fitting growth curve according to Akaike's information criterion AIC (Akaike, 1973).

Considering the growth curve, the most striking observation is the almost linear growth from birth to day 400 with an approximate daily gain of 65 g. This curve deviates from the usually observed sigmoid growth curve as found, for example, in production pigs. This is demonstrated in Fig. 3, where the growth curve of the Göttingen Minipig is compared to the growth curve of intensively and restrictively fed slaughter pigs (data from Kusec, 2001). Both curves have been standardised to the line-specific weight at 160 days, the normal endpoint of performance tests of slaughter pigs. Again the

Table 2
Average kinship coefficients within and between populations ± standard errors for randomly sampled animals from the German (GE) and the two Danish (DK1, DK2) populations.

	GE	DK1	DK2
GE	0.172 ± 0.029	0.148 ± 0.005	0.148 ± 0.003
DK1		0.176 ± 0.031	0.159 ± 0.005
DK2			0.178 ± 0.026

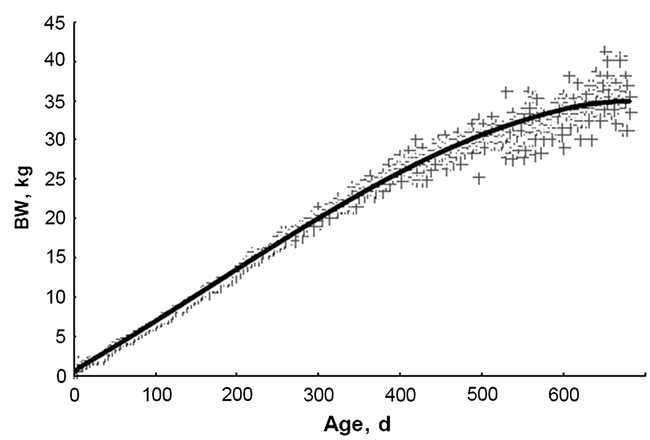

Fig. 2. Mean body weight per day (+) and third order polynomial as growth curve over the range from birth to 700 days of age for Göttingen minipigs (data from the Danish subpopulation 1).

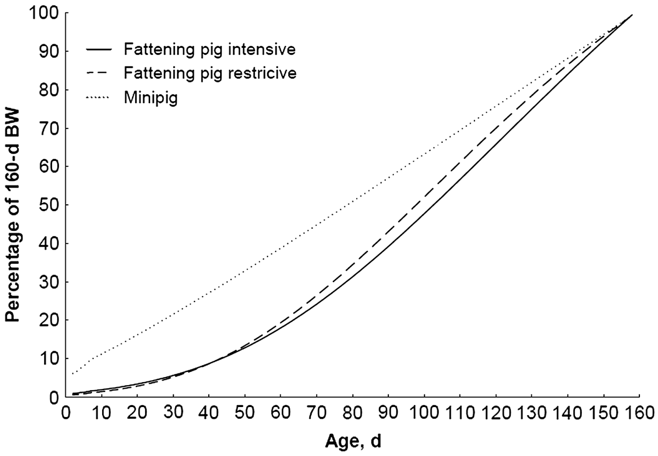

Fig. 3. Relative body weight development of male minipigs of unit 1 and normal, fattening pigs from birth weight to 160-d body weight (160d-BW) .

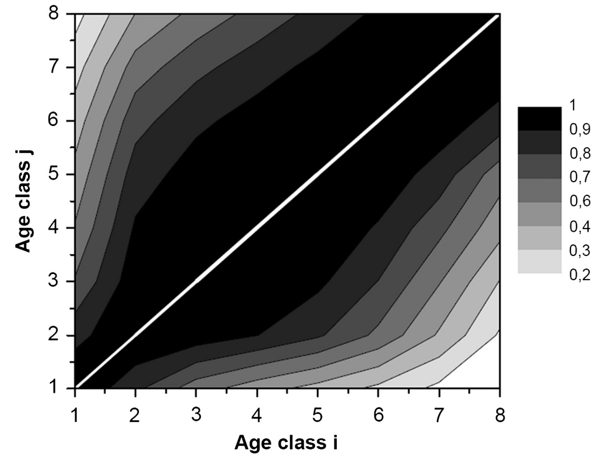

Fig. 5. Genetic correlations (shown above the diagonal) and phenotypic correlations (shown below the diagonal) between body weights in different age classes.

linear growth curve of the Göttingen Minipig clearly contrasts with the concave growth curve of juvenile slaughter pigs under both feeding regimes, characterised through a relatively slow growth in the pre- and post-weaning phase but highly accelerated growth after day 60.

Based on body weight data of the two Danish populations, moderate heritabilities were estimated which indicate that breeding for low body weight is possible. In Fig. 4 it is shown that the animal effect, reflecting the additive genetic component, accounts for 20 to 25% of the phenotypic variance in the time window between weaning and day 400.

Genetic correlations were estimated between body weight measurements in early and later ages (Fig. 5). It was shown that these correlations are decreasing with increasing time distance between the body weight measurements (Köhn, Sharifi, Täubert, Malovrh, & Simianer, 2008).

It was concluded that too early selection on low body weight can have several disadvantages because estimated breeding values are based just on few information of a single animal and selection does not necessarily lead to lower body weight in the adult minipig. After selecting on low body weight based on breeding values estimated at 150 days of age Köhn et al. (2008) calculated a predicted genetic progress of 3.9% body weight reduction per year. Assuming a 3 or 6 year selection programme not only a reduction of body weight, but also a change of the shape of the growth curve is predicted (Fig. 6).

The predicted change in the growth curve will also be influenced by many non-genetic effects like hygienic and management conditions. It must also be assumed that intense selection on reduced body weight will reduce the genetic variance through the so-called Bulmer-effect (Bulmer, 1971) and that physiological limits may be reached. It therefore must be anticipated that the real genetic progress per year will be less than predicted, but nevertheless a substantial reduction in body weight in Göttingen Minipigs is expected in the future when selection is carried out on the basis of breeding values.

Because of a known positive genetic correlation between litter size and body weight in pigs (Ferguson, Harvey, & Irvin, 1985) and the lack of generally applicable economic weights for the two trait complexes the combination of these two traits in a total merit index with the aim of genetic progress in both traits is difficult. In the Danish populations the genetic correlation between litter size and body weight was estimated to be 0.2. This is not a very strong correlation, however a reduction in litter size when selecting on low body weight is expected. To overcome this problem a restricted selection index will be developed, where the trait litter size is kept constant and the genetic progress in the trait low body weight is maximised under this constraint.

Next to the selection of animals based on their information for a specific trait the potential breeders are also selected phenotypically. The animals obtain subjective scores for several traits. Based on these scores and the importance of the trait, animals can be excluded from selection before the consideration of breeding values for the two main traits litter size and body weight. The evaluated traits are besides others the number of teats, the hair coat (less hair is preferred), black

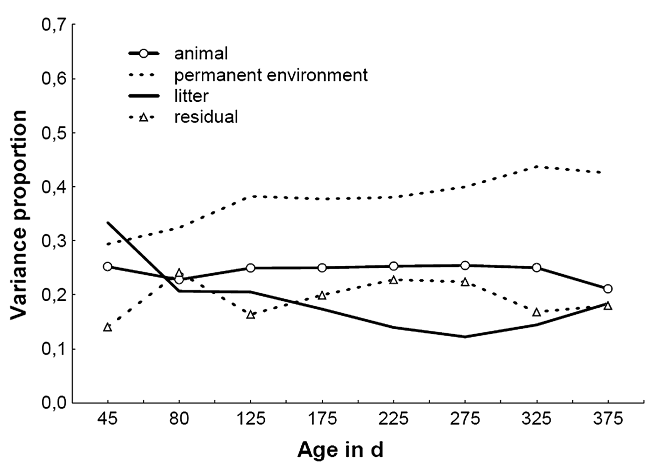

Fig. 4. Variance proportions for the random and residual effects estimated with the random regression models (Köhn, Sharifi, Malovrh, et al., 2007).

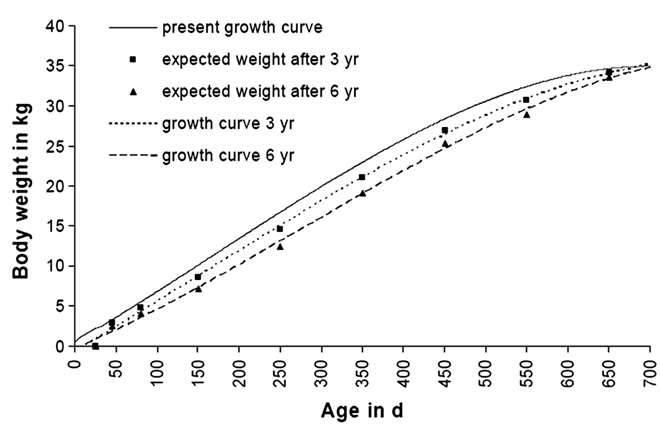

Fig. 6. Changes in the current growth curve after 3 and 6 years of selection at 150 days (Köhn et al., 2008).

hair or spots (should be eliminated), abnormalities (e.g. cryptorchism) and different body shape parameters like saddle back, position of legs and jaws. While focusing just on the phenotype the Minnesota-type with a long snout and as little saddle back and potbelly as possible is preferred.

Further, temperament is a very important trait in laboratory animals. Pigs in general tend to be nervous and anxious whereas these characteristics are highly undesirable for minipigs used in medical research. In general, temperament and behaviour traits in domestic animals are often found to be of remarkably high heritability. In pigs the main aspects of behaviour studied so far are maternal behaviour and pig to pig interaction within groups (McGlone, Desaultes, Mormede, & Heup, 1998), but little is known on the genetic basis of pig–human interaction, which is of major relevance for minipigs used as laboratory animals. For this reason a standard behaviour scoring scheme has been implemented in the Danish populations and genetic parameters for temperament were estimated. Scores were given in typical handling situations like catching and fixing the pig. Heritabilities for the different traits were low to moderate assuming that selection on temperament traits is possible (Köhn, Sharifi, & Simianer, 2009). It is therefore planned to include temperament traits in the selection procedure.

7. Balancing inbreeding, genetic drift and genetic improvement

Sustainable genetic improvement can only be achieved when the proper balance is maintained between an intensive selection of a small number of breeders and the goal to keep enough genetic variation in the next generations. Especially in small and closed populations the increase of inbreeding while improving the genetic progress has to be observed carefully. It is most desirable that long-term genetic contributions of selected parents are balanced (Weigel, 2001), i.e. that on the long term each contemporary ancestor has the same proportional impact on the population. This can be obtained by applying the optimum genetic contribution theory. Different authors suggested strategies to take the relationship between selected parents into account. One such strategy was to apply a cost factor dependent on the relationship of the selected parents (Meuwissen & Goddard, 1997; Wray &Goddard, 1994). Meuwissen (1997) suggested a method where the genetic progress is maximised while the relationship between the selected animals is constrained to a predefined acceptable value. This method is also applicable if different numbers of male and female animals have to be selected and if the population consists of overlapping generations.

This approach is implemented in the current breeding scheme of the Göttingen Minipig population and clearly contributed to the remarkable slow-down of the development of inbreeding in the subpopulations under selection, leading to the very acceptable inbreeding rates and effective population sizes.

8. Novel tools to control genetic integrity and diversity

Control and monitoring of the genetic diversity to date is based on pedigree information, i.e. relationship, inbreeding, and phylogenetic distances are expressed as expected values given the pedigree information or, in other words, as an average over all potential loci in the genome. Novel genetic technologies, like the availability of high throughput SNP genotyping devices, open new options to develop more targeted strategies for the genetic management of the population in the future. The use of high density SNP-chips (e.g. with 50,000 informative and evenly distributed SNPs) will allow the establishment of a haplotype inventory of the entire populations. The objective of the genetic management then will not be to minimise average inbreeding, but to maintain the genetic inventory of the population as complete as possible. Rare haplotypes will obtain special attention by using their carriers preferably as parents of the next generation. This will shift the “unit” in genetic management from whole genomes to well-defined chromosome segments. Combining the positional information with results of the pig genome sequencing and comparative genetic studies will also allow assignation of a special value to chromosome segments harbouring important genes or gene complexes, also allowing (for example) the development of segment specific partially or completely isogenic lines.

These new approaches need to be implemented in the near future and will help to make the Göttingen Minipig even more genetically well-defined than it is today. A first step toward this goal is the characterisation of the Göttingen Minipig population using the SNP-chip technology as soon as it becomes commercially available.

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