Breeding programme for Piétrain pigs in Bavaria with an estimation of genetic trends and effective population size

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\section*{A B S T R A C T}

Population structure, performance testing and breeding scheme of the sire breed Piétrain in Bavaria were analyzed as a basis for further optimization studies of the breeding programme. To evaluate the current breeding programme, genetic trends and effective population size were estimated. Four data sets were used which contained breeding animals born between 1981 and 2005, estimated breeding values of traits in the breeding goal, records from young boars in field test and records from purebred and crossbred progeny on test stations. The population is subdivided in many small herds. That has disadvantages with respect to a uniform breeding goal used across herds and with respect to selection intensity and the avoidance of inbreeding. The idealized selection practice consists of three selection stages. On the first two stages information from half and full sibs on test stations is most important so that the risk of co-selecting related animals is increased. The breeding scheme is a mixture of a half sib design and a progeny testing design, but both have disadvantages. Nevertheless, genetic trends are in the desired directions. To improve accuracy and intensity of selection, only AI-boars should be used instead of natural service sires. Though the effective population size is high, the recent trend of inbreeding shows that the extensive use of popular AI-boars can lead to a rapid increase of inbreeding.

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\section*{1. Introduction}

Bavarian herdbook breeders provide natural service sires and AI-boars of the sire breed Piétrain for the Bavarian piglet production herds. The task of the breeders is to improve the competitiveness of pigs in the commercial production through their genetic improvement programme. To improve efficiency of the breeding programme, both a new breeding goal and a new breeding value evaluation utilizing both purebred and crossbred performances have been implemented in 2005 (Habier et al., 2004, 2007). Furthermore, to avoid genotype–environment interactions between the test on station and the commercial production, the housing system on Bavarian test stations is being converted from 2-pig pens to big pens for 12–14 pigs. The next step is a comprehensive optimization of the performance testing and breeding scheme.

The objective of this paper is to analyze the current population structure, performance testing and breeding scheme of the Bavarian Piétrain as a basis for further optimization studies of the breeding programme. To assess the current breeding programme, genetic trends and effective population size were estimated.

\section*{2. Materials and methods}

\subsection*{2.1. Materials}

The pedigree data set used contains Piétrain animals of the Bavarian herdbook population, born between 1981 and 2005. Estimated breeding values were available for these animals from the official evaluation in March 2006, which utilized...
performance records from purebred and crossbred progeny on Bavarian test stations (Habier et al., 2007). The traits considered in this study were average daily gain (ADG) and feed conversion ratio (FCR) between 30 and 105 kg live weight, lean meat content of carcass (LMC) estimated via a standard multiple regression equation used in all German testing stations (ALZ, 2003), pH1 in m. long dorsi and intramuscular fat content (IMF). In addition, two other data sets were used including test progeny of Piétrain animals on station and young boars recorded in field tests. The latter comprises both young boars which later were used as natural service boars and those used as AI-boars.

2.2. Methods

2.2.1. Population structure, performance testing and breeding scheme

The number and age structure of sows as well as the number and size of breeding herds were derived from the active Piétrain population in March 2006. The contribution of herd size classes to boar sales and their participation to the test on station were analyzed using field data of young boars and records of test progeny on station. The current structure of performance testing was inferred from breeding animals born between 2001 and 2003 and their progeny on test station.

Generation intervals, proportion of progeny-tested animals contributing to the next generations and average number of purebred breeding sows mated per boar were calculated between 2001 and 2003 and their progeny on test station. Performance testing was inferred from breeding animals born from animals with at least one offspring in the pedigree. This means that each animal in this part of the analysis was at least once successfully used as a breeding animal.

In addition, breeders were asked for their breeding strategy with respect to the age of the animals when selection decisions are taken, the proportion selected and the criteria used. The proportion of selected male piglets in breeding herds was verified with data from young boars recorded in field tests.

2.2.2. Genetic trends

Genetic trends for traits of the breeding goal and the selection criterion were estimated using a regression of estimated breeding values on birth year. Only animals born once successfully used as a breeding animal.

Suppose that the ith individual has a number of s potential sires and a number of d potential dams with probabilities of being the true sire $p_{ij}$ and the true dam $q_{ik}$. Then, the $(n, i)$-element of the NRM is

$$a_{n,i} = 0.5 \left[ \sum_{j=1}^{s} p_{ij} a_{nj} + \sum_{k=1}^{d} q_{ik} a_{nk} \right]$$

and the diagonal element is

$$a_{ii} = 1 + F_i = 1 + 0.5 \sum_{j=1}^{s} \sum_{k=1}^{d} p_{ij} q_{ik} a_{jk}$$

(Prézé-Enciso and Fernando, 1992). Eqs. (1) and (2) reduce to the usual rules to compute the NRM when parentage is known with certainty, i.e., $p_{ij} = q_{ik} = 1$. If an animal belongs to the base population all its elements except the diagonal are Null (base-animal method).

The average inbreeding coefficient of a cohort ($\bar{F}_t$) is calculated from animals born in year $t$, and the average coancestry ($\bar{f}_t$) is calculated from the coancestries among those animals. By regressing $\ln(1 - \bar{F}_t)$ and $\ln(1 - \bar{f}_t)$ on birth year $t$, the annual effective size ($N_a$) is estimated from

$$\hat{N}_a = \frac{1}{2(1 - e^{\beta})}$$

where $\beta$ is the slope, which equals $\ln(1 - \frac{1}{n})$ (Prézé-Enciso, 1995). Generation and annual effective population size are transformable into each other with the approximate formula $N_a = N_e \times \bar{f}$ (Hill, 1979). Standard errors of the estimates were derived by using the Taylor series approach.

3. Results and discussion

3.1. Population structure

The Bavarian sire breed population consists of Piétrain animals only. There are 41 herds with a total of about 1200 sows, where one third of the herds has less than 10 sows, one third between 10 and 30 sows and one third up to 115 sows. Among these herds there are four state farms, pure Piétrain
breeders as well as breeders keeping both sire and dam breeds. All of the three herd size classes produced market boars in 2005, and 35 herds participated in the performance test on station. Because selling AI-boars requires progeny-tested parents, only sows of these 35 herds should be regarded as the active population. All of the herds excluded from the analysis keep less than 10 sows. Table 1 shows the age structure of the active breeding sows.

Piétrain sows of the Bavarian population are about one year old at first farrowing, they have 1.95 litters per year and rear 9 piglets per litter on average (Rahbauer et al., 2004). Sows having at least one offspring in the pedigree farrow about 5 times on average. The proportion of sows mated to AI-boars increased during the last 10 years from 30% to about 67%.

The breeders keep 112 natural service sires, of which 52 are progeny-tested. Furthermore, on the three Bavarian AI-stations there are 488 proven boars and annually about 285 AI-boars are progeny-tested.

3.2. Idealized selection practice and performance testing

The idealized selection practice consists of three selection stages. The first selection takes place at the age of about 12 weeks. First of all, piglets with growth, conformation and functional deficiencies are culled, followed by a family selection based on breeding values of parents. In this manner 30–35% of the male piglets and 70–80% of the female piglets are selected for rearing. The second stage proceeds at the age of 7–8 months, where male pigs with an average weight of 155 kg are tested during breed registration on markets or farms. Potential female replacements are tested on farm only. Criteria are lifetime daily gain, ultrasonic back fat thickness, conformation traits as well as the breeding values of progeny-tested parents.

The Piétrain population is relatively large, but the subdivision in many small herds has disadvantages with respect to selection intensity on the second stage. On this stage, candidates have to be compared within herds, because own performances as live-time daily gain and ultrasonic backfat thickness are not comparable across herds. One reason is that breeders apply different breeding and feeding strategies resulting in diverse growth curves (Götz, 1996). More important was in the past, however, that genetic herd effects and environmental factors could not be disentangled, because breeding herds were only weakly connected due to the use of natural service sires. Because AI-boars became widely accepted in breeding herds in the last 10 years, this problem should have disappeared to a large extent. However, there are still breeders using only natural service sires. Another concern with respect to selection across breeding herds is hygienic issues, especially regarding the high number of breeding herds. Under these circumstances, selection on the second stage will presumably continue to take place within herds. In comparison to a desirable selection across herds, the effective number of candidates is lower and selection criteria of breeding animals are highly correlated because of the half and full sib family structure. Both reduce the effective selection intensity.

After the second selection stage, young natural service sires and young sows are mated to the Piétrain herdbook breeding population to produce purebred progeny for the new generation and for sending to the test station. AI-boars, however, are mated to sows of the piglet producing farms after a quarantine of about two months to produce crossbred test progeny. The number of crossbred progeny per AI-boar varies widely between 1 and 30. 10% of the AI-boars have less than 10 test progeny and 10% have more than 20. Table 2 shows the number of progeny-tested breeding animals per year and the average number of test progeny on station.

The test capacity on the two Bavarian test stations will comprise about 4300 fattening places after conversion of the housing system from traditional 2-pig pens to big pens for 12–14 pigs. Currently, about two third of the test capacity is used for the sire breed Piétrain, whereof 80% are used for crossbred pigs and 20% for purebred pigs. 80% of the sows are tested with progeny of the first litter and the rest mainly with the second litter. 10% of young test sows are mated to test boars. The progeny test on station lasts 3–4 months, hence natural service sires and breeding sows are about 1.5 years old, and AI-boars are about 1.8–2 years old when the information of all test progeny is available.

Using the information from test progeny, breeding animals are selected at the third stage. Table 2 shows the proportion of progeny-tested animals contributing to the next generations and the average number of breeding sows mated per boar.

Young boars are tested for own performances at an average live-weight of 155 kg, i.e. about 40 kg above the average final live-weight of pigs for the pork industry. This higher weight is chosen by the breeders for sale of their boars. A consequence could be that the informative value of own performance is reduced. Moreover, an earlier test would reduce the generation interval of AI-boars, which is an advantage in progeny testing designs.

Hitherto, sows are not recorded for live-time daily gain and backfat thickness and so the genetic progress is slightly reduced. However, breeders might tend to use the information from half and full sibs on test station only, which increases the probability to select related candidates in the female paths. Consequently, inbreeding could be increased. In conclusion, both young boars and young sows should be

![Table 1](https://example.com/table1.png)

<table>
<thead>
<tr>
<th>Parity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>≥7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion</td>
<td>0.28</td>
<td>0.20</td>
<td>0.19</td>
<td>0.11</td>
<td>0.09</td>
<td>0.06</td>
<td>0.07</td>
</tr>
</tbody>
</table>

![Table 2](https://example.com/table2.png)

<table>
<thead>
<tr>
<th></th>
<th>Natural service boars</th>
<th>AI-boars</th>
<th>Purebred sows</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_A )</td>
<td>43</td>
<td>286</td>
<td>530</td>
</tr>
<tr>
<td>( n_{\text{avg}} )</td>
<td>10</td>
<td>15</td>
<td>187</td>
</tr>
<tr>
<td>( p_m )</td>
<td>0.47</td>
<td>0.18</td>
<td>0.25</td>
</tr>
<tr>
<td>( p_f )</td>
<td>0.70</td>
<td>0.27</td>
<td>0.45</td>
</tr>
<tr>
<td>( \Delta_m )</td>
<td>2.16</td>
<td>2.68</td>
<td>2.15</td>
</tr>
<tr>
<td>( \Delta_f )</td>
<td>2.31</td>
<td>2.82</td>
<td>2.25</td>
</tr>
<tr>
<td>Sows/boar</td>
<td>3.8</td>
<td>3.1</td>
<td>-</td>
</tr>
</tbody>
</table>
tested with weight similar to the final weight in the commercial production.

The guidelines for performance test of boars state that natural service sires have to be tested with at least 6 purebred progeny and AI-boars with at least 13 crossbred progeny. However, the average number of test progeny per natural service sire is higher as can be seen from Table 2. The reason is that 90% of young test sows are mated with already proven natural service boars. Hence, testing capacity for purebreds is not used to its full potential and young natural service sires are in fact selected with fewer test progeny as shown in Table 2. In addition, AI-boars having less than 5 or more than 20 test progeny on station should be avoided.

Since 2005, there is a breeding value estimation utilizing purebred and crossbred information simultaneously as correlated traits, such that natural service sires and AI-boars can be ranked with each other. However, due to the different number of test progeny, there is the possibility that AI-boars are rather found in the extremes of the EBV distribution, whereas natural service sires of the same cohort are more regressed towards the population mean. This argument is difficult to verify, because in the actual data set most natural service sires have 10 test progeny on average for reasons mentioned. It could be verified by analyzing the ranking of boars after each evaluation. If this concern is true, then natural service sires cannot compete with AI-boars and the selection intensity is in fact smaller than expected from the total number of candidates (natural service sires + AI-boars). Furthermore, test capacity on station is wasted and it would be better not to test natural service sires, but to use AI-boars only.

There are important breeders in Bavaria that use natural service sires either exclusively or predominantly in their herds. Thus, poorly-proven natural service sires are mated to the purebred breeding sows of these herds, whereas there are well-proven AI-boars, which are kept by the AI-stations to produce semen for the piglet production. However, cumulative genetic progress is only achieved in the breeding population and not in the piglet production. Thus the testing capacity is not utilized to the fullest extent, if poorly proven natural boars instead of AI-boars are used in the herdbook population.

Regarding the proportions of progeny-tested animals contributing to the next generations (Table 2), male and female paths can be identified. This pattern results especially from the selection on the first two stages, because breeding values of parents have highest accuracy and fewer males than females are selected. Furthermore, AI-boars are selected more intensely than natural service sires, mainly due to the higher number of tested AI-boars. In addition, genetic differences between AI-boars are more pronounced because of the higher accuracy of estimated breeding values. Another meaningful parameter with respect to the selection intensity is the average number of breeding sows mated per boar, which is low for both natural service sires and AI-boars (Table 2). To achieve higher genetic progress, this might be the key parameter to improve.

Generation intervals of natural service sires and breeding sows are very similar, whereas the generation interval of AI-boars is about half a year higher (Table 2). The differences would be even larger, if some of the AI-boars were not mated to the Piétrain population before the end of the progeny test. These boars rather belong to a half sib design, like the natural service sires, and not to a progeny testing design.

In conclusion, the current breeding scheme is a mixture of a half sib- and a progeny testing design. Though the half sib design has a lower generation interval, only few half and full sib information is available when offspring of natural service sires and breeding sows reach their breeding age. Moreover, generation intervals in male paths are quite high for a half sib design. Such a half sib design should be inferior to most progeny testing schemes. AI-boars, in contrast, are selected with higher precision and intensity after progeny testing, but generation intervals are higher. Thus, both schemes within the current breeding programme have disadvantages. To ascertain the optimum breeding scheme, further optimization is needed.

### 3.3. Genetic trends

The genetic trend of all single traits and the aggregate genotype are significant in the desired direction (Table 3).

The highest genetic progress per year and additive-genetic standard deviation was achieved in the traits pH<sub>1</sub>, LMC and FCR with 0.13, 0.12 and −0.12 respectively. The genetic gain in pH<sub>1</sub> might have been obtained mainly due to selection on MHS-genotype (Fujii et al., 1991) between 1990 and 2000. The genetic progress in LMC is not surprising, because it has always played a major role in the breeding goal. FCR has not only an important economic weight, but is also favoured due to the genetic correlations with LMC and ADG. ADG has much lower genetic progress, which might be the consequence of the antagonism with LMC (Habier et al., 2007). IMF was not considered in the breeding goal until 2005 (Habier et al., 2004) and has unfavourable genetic correlations with LMC and FCR (Habier et al., 2007). Thus, an increase could not be expected. One explanation for the small increase in IMF observed might be the favourable genetic correlations with ADG and pH<sub>1</sub> (Habier et al., 2007).

The genetic trend for ADG of 1.33 g/yr found in the present study is smaller than that reported by Kovac and Groeneveld (1990) for Pietrain pigs in Germany between 1979 and 1987 of 6.9 g/yr. The same is true for FCR (−0.011 kg/kg/yr vs. −0.019 kg/kg/yr). On the other hand, the increase in LMC of 0.16%/yr is much higher than the increase in valuable cuts of 0.033%/yr (Kovac and Groeneveld, 1990). Though their data might include Pietrain pigs from Bavaria, this comparison

### Table 3

<table>
<thead>
<tr>
<th>Trait, unit</th>
<th>Abbr.</th>
<th>λ, Euro</th>
<th>ΔG/Δt(s.e.)</th>
<th>ΔG/σA/s.a.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily gain, g/day</td>
<td>ADG</td>
<td>0.04</td>
<td>1.33 (2·10⁻³)</td>
<td>0.04</td>
</tr>
<tr>
<td>Feed conversion ratio, kg/kg</td>
<td>FCR</td>
<td>−1.45</td>
<td>−0.011 (3·10⁻⁴)</td>
<td>−0.12</td>
</tr>
<tr>
<td>Lean meat content of carcass, %</td>
<td>LMC</td>
<td>2.06</td>
<td>0.158 (6·10⁻³)</td>
<td>0.12</td>
</tr>
<tr>
<td>pH&lt;sub&gt;1&lt;/sub&gt; m. long dorsi&lt;sup&gt;a&lt;/sup&gt;</td>
<td>pH&lt;sub&gt;1&lt;/sub&gt;</td>
<td>7.66</td>
<td>0.019 (1·10⁻³)</td>
<td>0.13</td>
</tr>
<tr>
<td>Intramuscular fat, %</td>
<td>IMF</td>
<td>9.11</td>
<td>0.003 (2·10⁻⁴)</td>
<td>0.02</td>
</tr>
<tr>
<td>Aggregated genotype, Euro</td>
<td>–</td>
<td>–</td>
<td>0.71 (1·10⁻²)</td>
<td>0.20</td>
</tr>
</tbody>
</table>

<sup>a</sup> log₁₀[H₃O⁺] in Mol/l.

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either indicates that growth rate was more important in the 1980s or reveals differences in the breeding goals of Bavaria and other regions in Germany. The latter would be expected today (Habier et al., 2004).

Hofer et al. (1992), in contrast, estimated lower genetic progress for ADG measured on on-farm tested pigs in Switzerland between 1976 and 1987. The genetic trends for Yorkshire and Landrace pigs were 0.54 g/yr and 0.86 g/yr, respectively.

Frozen semen of French Large White boars born in 1977 and 1998 was used to estimate realized genetic trends (Tribout et al., 2003). The progress in both ADG and LMC with 3.66 g/yr and 0.36%/yr, respectively, was much higher than in the present study. In contrast, no significant trend was found for both intramuscular fat content and pH1. In this breed, LMC was low and the two meat quality traits mentioned were already high in 1977. Thus, the main reason for the differences in the genetic trends between French Large White and Bavarian Piétrain might be the result of different breeding objectives. In particular, there was selection on the MHS-Genotype (Fujii et al., 1991) in Bavaria, which improved meat quality, but reduced genetic progress for LMC.

Chen et al. (2002) estimated genetic trends for lean growth rate and backfat thickness in Yorkshire, Duroc, Hampshire and Landrace pigs in the U.S. between 1985 and 2000. For lean growth rate, they found 2.46, 3.28, 1.42 and 2.24 g/day. These values were higher than for ADG in this study, especially considering the higher weight of finishing animals or using the uncertain-parentage method.

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3.4. Effective population size

Fig. 1 shows the trend of inbreeding and coancestry in the Piétrain population between 1981 and 2003 calculated with two different methods to treat unknown parents.

The curves of the uncertain-parentage method have steeper slopes than the curves of the base-animal method, yet inbreeding and coancestry run very similar in both methods. Furthermore, the coancestry curves are much smoother than the two inbreeding curves, which fluctuate several times above and below the coancestry curves. This might be the result of varying breeding decisions. If these enhance inbreeding, then inbreeding runs ahead coancestry, which might be observed in the early 1990s and also in 2000/2001. Note also, that coancestry increases faster from 1995 on, which is more pronounced in the base-animal method. One explanation could be the implementation of BLUP for breeding value estimation, which makes better use of pedigree information than the selection index method used before. Thus, selected animals are more related to each other. Moreover, both coancestry and inbreeding increase markedly between 2000 and 2002. The cause is the extensive use of a single AI-boar born in 1998. In 2003, the inbreeding coefficient decreased considerably, which might be a short-term trend resulting from matings of less related breeding animals or from the import of unrelated animals.

Table 4 contains generation and annual effective population sizes estimated from animals between 1985 and 2003.

Effective population sizes estimated from the increase in coancestry and in inbreeding correspond well. According to Caballero (1994), this is expected in a regular breeding

| Table 4 Generation and annual effective population sizes (N_e and N_a) in the Bavarian Piétrain population estimated from drift variance (ΔV_e), increase in inbreeding (Δf) or increase in coancestry (Δq) treating unknown parents either as base animals or using the uncertain-parentage method. |
|---|---|---|
| Base-animal method | Uncertain-parentage method |
| Generation effective size |
| N_e(ΔV_e) | 155 | – |
| N_e(Δf) | 160 (± 14) | 113 (± 7) |
| N_e(Δq) | 163 (± 16) | 116 (± 7) |
| Annual effective size |
| N_a(ΔV_e) | 357 | – |
| N_a(Δf) | 368 (± 21) | 259 (± 10) |
| N_a(Δq) | 376 (± 25) | 266 (± 11) |
scheme, where the rate of increase will eventually converge to the same value, although the average coancestry and the average inbreeding can be different in a given generation. In conclusion, the fluctuation of inbreeding observed might primarily depend on short-term breeding decisions. Furthermore, the drift effective population size estimated by the formula given by Hill (1979) agrees well with the effective population sizes derived from the numerator relationship matrix (Table 4).

Annual effective population sizes obtained from the uncertain-parentage method are about 100 animals lower than treating unknown parents as base animals (Table 4). There is an important exchange of breeding animals between Bavaria and other federal states of Germany, but it is in many cases unknown how these animals are related to the Bavarian Piétrain. Thus, the annual effective population size is located between 260 and 370 animals (Table 4), which is high for a population under selection. The main reason might be the low selection intensity inferred from the low ratio of breeding sows mated per boar (Table 2). These conditions are beneficial for genetic improvement as more genetic variation is preserved for use in future selection. The large number of boars used is favourable regarding the variance between families, whereas the high effective population size is favourable for the variance within families. Consequently, one might conclude that the current breeding scheme is beneficial for long term genetic improvement. The question remains, however, to what extent these conditions are beneficial for short-term genetic improvement and thus for the competitiveness of Bavarian Piétrain.

The recent trend in inbreeding suggests that there is no efficient mechanism to avoid an intense use of popular boars. With increasing use of AI-boars in breeding herds and decreasing population size, risks might even increase in the future.

4. Conclusions

The Bavarian Piétrain population, its effective population size and the performance testing capacity on station are large. Thus, there is great potential to achieve substantial and sustained breeding progress in the future. The breeding scheme and performance testing leave, however, room for improvement.