GxE interactions for growth and carcass leanness: Re-ranking of boars in organic and conventional pig production

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The objective of this study was to evaluate genotype by environment interactions for growth rate and carcass leanness in organic and conventional pig production environments. Organic breeding values for fattening traits were estimated for 37 Hampshire AI-boars based on slaughter records registered for 1805 crossbred offspring raised in an organic environment. The offspring were born and raised in herds certified for organic production. The statistical model included the fixed effects of sex, litter size at 2 weeks and herd. It also included the random effects of herd-year-season, birth litter and animal. Conventional breeding values for the same boars were captured from the breeding organization’s genetic evaluation. In the organic environment \( h^2 \) was estimated to 0.30 and 0.37 for growth rate and carcass leanness, respectively (\( r_g = -0.11 \)). Spearman rank correlations between organic and conventional breeding values, based on 29 boars with ≥20 progenies, were 0.48 for growth rate and 0.42 for carcass leanness. Both correlations were significantly different from 0 and 1. In conclusion, the results of the present study indicate weak genotype by environment interactions for both growth rate and carcass leanness in organic and conventional pig production environments, and there is some re-ranking of boars’ breeding values between environments.

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1. Introduction

The genetic material used in organic pig production is normally the same as that used in conventional pig production. These animals are bred for high performance in a conventional production environment. Presently there are no separate organic breeding programs for commercial pig breeds, which mean that organic producers have few alternatives when choosing genetic material.

As a result of differences in ethical values and the rules governing production, the environments in organic and conventional pig production differ. In Europe these differences are determined by regulations covering organic production set out by the EU (1999) and certification organizations. These regulations principally affect three areas: housing, feeding and medical care (Boelling et al., 2003).

To devise an organic breeding strategy it is necessary to investigate genotype by environment (GxE) interactions in conventional and organic production systems (Boelling et al., 2003). Where GxE interactions occur, the trait is partly influenced by different genes in different environments. Weak GxE interactions result in non-identical differences between animals’ breeding values but little or no re-ranking of animals within the studied environments (Fig. 1a). Strong GxE interactions result in significant re-ranking of animals’ breeding values in the differing environments (Fig. 1b). GxE interactions that result in re-ranking are of considerable economic importance to producers if the genetic evaluation is based on information from only one of the environments. Strong GxE interactions result in large over-prediction of economic outputs if these interactions are not accounted for in the breeding program (Dominik and Kinghorn, 2008).

To our knowledge, no studies of GxE interaction in organic and conventional pig production environments based on estimated breeding values have been published. However, Werner et al. (2007) found significant GxE interactions when...
investigating growth rate and carcass leanness in seven different breeds and breed-crosses in organic and conventional environments. Kelly et al. (2007) found no significant GxE interactions when comparing a traditional breed, a modern breed, and a cross between the two, in outdoor and indoor organic environments.

The objective of this study was to investigate GxE interactions for fattening pig traits in organic and conventional pig production environments.

2. Materials and methods

The study was performed in accordance with Swedish regulations governing animal use in experiments.

2.1. Organic animals and herds

2750 crossbred offspring of 37 Hampshire AI-boars and 174 sows were marked with a litter and sex identity. The sows were in most cases Swedish Landrace x Yorkshire crosses and in some cases purebred Swedish Landrace or Yorkshire. Individual slaughter records from 1805 of these offspring were collected at the slaughter plants.

The organic fattening pigs included in the study were raised in 3 commercial organic piglet producing herds and 6 different commercial organic fattening herds. One herd was a farrowing to finishing herd and 5 herds were specialized fattening herds. All the herds were located in the central and southern parts of Sweden. All were organically certified. There was no mixing of piglets from different piglet producing herds in the fattening herds. The fattening pigs were slaughtered at one of two slaughter plants (Fig. 2). The piglet producing herds had on average 77 sows (55–96) in production and the fattening herds sent on average 993 (700–1600) pigs to slaughter every year. In two of the piglet producing herds, the sows farrowed indoors in individual farrowing pens without crates. Sows and their litters were group-housed 2–7 weeks post partum (pp) indoors in pens with deep straw bedding and with outdoor access on concrete flooring. In one of these two herds, sows and their litters had additional access to pasture during the vegetative season (approximately May to September). In the other of the two herds where sows farrowed indoors, sows and their litters were kept in huts on pasture 2–7 weeks pp during the vegetative season. In the third piglet-producing herd sows farrowed outdoors in huts throughout the year. In this herd sows and their litters were kept in groups on pasture with access to individual farrowing huts and family huts. Family groups consisted of 5–10 sows and their litters. In the fattening herds the pigs were kept in buildings with deep straw bedding and outdoor access on concrete floor. The fattening pigs were fed restrictively following the SLU-norm, according to weight (Simonsson, 1994) and had access to pasture during the vegetative season. Both slaughter plants were certified by KRAV to slaughter organic pigs (KRAV, 2005).

KRAV is the largest certification organization for organic production in Sweden. It is accredited by, and follows, the standards of IFOAM (International Federation of Organic Agriculture Movements). The herds included in the present study were organically certified by KRAV. The main differences between conventional and organic pig production required by KRAV are given in Table 1 (KRAV, 2005).

2.2. Identification and registrations

Sows were inseminated with semen from Hampshire Al-boars from February 2003 to August 2004. AI-doses were provided by the breeding organization Quality Genetics. Hampshire Al-boars are continuously exchanged at the boar station, thus AI-doses from each individual boar are available for approximately 12 months. To ensure that the boars were used evenly across the three herds and over time, herdsmen were instructed to follow an insemination scheme designed for this study. When the study began, 15 Hampshire Al-boars were selected for the insemination scheme. New boars were added to

Fig. 1. a. Schematic presentation of weak genotype by environment interaction, no re-ranking of boars. b. Schematic presentation of strong genotype by environment interaction, re-ranking of boars.

Fig. 2. Herd structure of piglet producing herds (P.H.), fattening herds (F.H.) and slaughter plants.
### Table 1
Environmental differences between organic and conventional pig production (KRAV, 2005).

<table>
<thead>
<tr>
<th>Issue</th>
<th>Organic (KRAV)</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feeding period</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated live weight at slaughter (kg)</td>
<td>1791</td>
<td>86.3</td>
</tr>
<tr>
<td>Backfat thickness at 100 kg (mm)</td>
<td>1759</td>
<td>10.8</td>
</tr>
<tr>
<td>Lean meat content (%)</td>
<td>1799</td>
<td>57.9</td>
</tr>
<tr>
<td>Growth rate until 100 kg (g/day)</td>
<td>1753</td>
<td>578</td>
</tr>
<tr>
<td><strong>Grazing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During the vegetative period</td>
<td>No grazing</td>
<td></td>
</tr>
<tr>
<td><strong>Weaning age</strong></td>
<td>≥ 7 weeks</td>
<td>≥ 4 weeks</td>
</tr>
<tr>
<td><strong>Housing, minimum space allowance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nursing period (per sow and litter)</td>
<td>Single housed first 2 weeks</td>
<td>Single housed from farrowing to weaning, 6.0 m² indoor</td>
</tr>
<tr>
<td>Fattening period (per pig 85 kg)</td>
<td>1.2 m² indoor and 0.8 m² outdoor</td>
<td>0.83 m²</td>
</tr>
<tr>
<td>Medical care</td>
<td>No preventive medical care</td>
<td>Withdrawal period x 1</td>
</tr>
<tr>
<td>Withdrawal period x 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Differs from 1805 because offspring to boars with less than 20 offspring were excluded, litters with only one pig registered at slaughter were excluded, and because of missing values.

### 2.5. Statistical analysis

SAS software (version 9, SAS Institute Inc., Cary, NC) was used to edit data. Data from litters with only one pig registered at slaughter were excluded from the statistical analyses. The DMU package (Madsen and Jensen, 2008) was used to estimate genetic variance and covariance components and to estimate organic breeding values. All 37 Hampshire Al-boars were included in the genetic analysis. Spearman rank and Pearson correlations between organic and conventional breeding values were calculated using PROC CORR. Only boars with more than 20 offspring (29 boars, range 20–110 offspring) were included in the rank correlation calculations.

To make the organic breeding values comparable to the conventional breeding values, growth rate and backfat thickness were pre-adjusted to performance at 100 kg. The pre-correction formulas were used adapted from Lundeheim (2002):

\[
GR100 = ((\text{LW} - (\text{LW} - 100) - 1.5) * 1000) / (\text{SA} - (\text{LW} - 100) / 0.950)
\]

and

\[
BF100 = BF - (\text{LW} - 100) * 0.1
\]

where GR100 = Growth rate until 100 kg (g/day), BF100 = Backfat thickness at 100 kg (mm), LW = Live weight at slaughter (kg), SA = Slaughter age (days), BF = Backfat thickness (mm). Assumptions: average growth rate = 950 g/day and backfat deposition = 0.1 mm/kg when the pig weighs around 100 kg; piglet weigh at birth = 1.5 kg. Normality was tested for the two dependent variables, growth rate and backfat thickness, using PROC UNIVARIATE, applying the Shapiro–Wilks test and a normal probability plot.

A genetic bivariate analysis was performed for growth rate until 100 kg and backfat thickness at 100 kg. The animal model included the fixed effects of sex (2 classes), litter size 2 weeks (3 classes: <10, 10–12, >12) and fattening herd (6 classes), and the random effects of herd-year-season, birth litter and animal. The pedigree included the sires’ pedigree over two generations. The identities of the fattening pig dams were

### Table 3
Correlations between organic and conventional breeding values for 29 boars. Confidence interval (95%) and p-values for the hypotheses that the correlation is 0 or 1.

<table>
<thead>
<tr>
<th></th>
<th>Correlation</th>
<th>p-values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Confidence interval)</td>
<td>H0: r = 0</td>
</tr>
<tr>
<td><strong>Spearman rank correlation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growth rate</td>
<td>0.48</td>
<td>0.09</td>
</tr>
<tr>
<td>Backfat thickness</td>
<td>0.42</td>
<td>0.022</td>
</tr>
<tr>
<td><strong>Pearson correlation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growth rate</td>
<td>0.45</td>
<td>0.015</td>
</tr>
<tr>
<td>Backfat thickness</td>
<td>0.37</td>
<td>0.045</td>
</tr>
</tbody>
</table>
included but their pedigree was unknown. Thus all dams were regarded as unrelated.

3. Results

Of the 2750 ear-tagged and tattooed piglets from the organic piglet producing herds, 1805 (66%) were identified at the slaughter plant and included in the genetic evaluation. The 29 boars included in the re-ranking evaluation had an average 59.8 offspring (median 55, range 20–105), from an average 8.0 litters (median 8, range 2–15). Standard statistical data on slaughter records and pre-adjusted parameters are given in Table 2.

Based on the performance of boars’ offspring in organic herds, heritability \( (h^2) \) was estimated to 0.30 ± 0.01 and 0.36 ± 0.01 for growth rate until 100 kg and backfat thickness at 100 kg, respectively. The genetic correlation \( (r_g) \) between the two traits was estimated to −0.11 ± 0.24. Litter effect \( (c^2) \) was estimated to 0.15 and 0.11 for growth rate and backfat thickness, respectively.

Spearman rank and Pearson correlations between organic and conventional breeding values for the 29 boars are presented in Table 3. All differ significantly from 0 and 1.

The distribution of conventional and organic breeding values for the two traits are presented in Fig. 3a and b. Differences in the ranking of boars’ breeding values in the two environments are presented in Fig. 4a (growth rate) and Fig. 4b (backfat thickness). These show that some re-ranking of the boars’ breeding values did occur.

4. Discussion

The estimated correlations between organic and conventional breeding values for growth rate and carcass leanness in the present study were positive and significantly different from both 0 and 1. The positive correlations mean that boars that are ranked highly on conventional breeding value are in many, but not all, cases also ranked highly on organic breeding value. The significant difference from 1 indicates that GxE interactions exist for growth rate and carcass leanness in the organic and conventional production environments included in this study. However, the significant difference from 0 indicates that these interactions are weak. We expected GxE interactions, since they have been reported previously in connection with commercial herds and other environments. Merks (1989) reported GxE interaction for carcass leanness, but not for growth rate in conventional nucleus and commercial herds. Werner et al. (2007) found GxE interactions for both growth rate and carcass leanness when comparing different breeds in organic and conventional environment, but they observed no re-ranking of breeds.

The rank correlations of boars’ breeding values estimated in the present study are assumed to be in close relationship to the corresponding genetic correlations. McLaren et al. (1985) showed that genetic and boar rank correlations are closely related when they investigated purebred and two-crossbred offspring of Hampshire, Duroc and Yorkshire raised in the same environment. The genetic and rank correlations were 0.67 and 0.69 respectively for growth rate and 0.86 and 0.82 respectively for backfat thickness. The accuracy of rank correlations is dependent on the accuracy of both ranks included. In the present study, the conventional breeding values were based on much more information and many more relatives leading to a high accuracy of boars’ rank compared with the organic breeding values that were based on less information and fewer relatives, leading to a relatively lower accuracy of boars’ rank. By using as much information as possible in the ranks included in the rank correlation the overall accuracy of the correlation was increased.

The rank correlations estimated in the present study are influenced by crossbreeding since the organic breeding values are based on the performance of crossbred offspring and the conventional breeding values are based on the performance of the boars and their purebred relatives. Brandt and Taubert (1998) estimated genetic correlations between purebred Duroc and their crossbred (Duroc x (Landrace x Large White)) relatives raised in the same environment to 0.97 for growth rate and 0.98 for backfat thickness. Zumbach et al. (2007) reported genetic correlations between purebred Duroc from nucleus herds and their crossbred (Duroc x (Landrace x Large White)) relatives in commercial herds for growth rate (0.60 and 0.79 for two different Duroc lines) and for backfat thickness (0.83 and 0.89). Since the correlations found in the present study are considerably lower than what has been reported in previous studies between purebred and crossbred relatives, the correlations found in the present

![Fig. 3.](image-url)
study does indicate GxE interactions between organic and conventional production environment.

In our study some re-ranking of boars did occur (Fig. 4a and b). This could be important when it comes to choosing breeding animals for organic pig production. Boelling et al. (2003) argue that if there are weak GxE interactions in organic and conventional production systems, it is possible to combine data from both systems and operate a shared breeding program. If there are strong GxE interactions, information from one system would be of little value in connection with the other and separate breeding programs should be preferred. Our results indicate that with regard to growth rate and carcass leanness, an organic breeding index, based on conventional data, using alternative economic weights would be possible. Nauta et al. (2006) reported moderate GxE interactions for yield traits in organic and conventional dairy production environments. Alternative breeding indices with economic weights suitable for organic production are provided for dairy bulls in Switzerland (Bapst, 2001). The relative weights of traits in organic and conventional pig breeding indices would probably differ (Boelling et al., 2003). Robustness, disease resistance and maternal traits are examples of traits prized in organic production (Hirt et al., 2001). Growth rate and carcass leanness are less highly valued in organic production than they are in conventional pig production, and often they have unfavourable genetic correlations with other traits of greater importance to organic producers (Clutter and Brascamp, 1998). Consequently, their relative weights would be lower in an organic breeding index than they would be in a conventional one. If organic breeding indices are applied in conventional pig breeding.

Fig. 4. a. Differences in ranking of breeding values for growth rate, based on offspring performance in organic and conventional environments (N = 29). Interpretation: the best boar in the conventional environment (boar A) is ranked 11 in the organic environment. One of the two lowest ranked boars in the conventional environments (boar D) is ranked approximately the same as boar A (number 13) in the organic environment. Boar B has a high rank, and boar C has a low rank, in both environments. b. Differences in ranking of breeding values for backfat thickness, based on offspring performance in organic and conventional environments (N = 29).
programs, it is essential that traits of importance in the organic pig production environment are recorded in the conventional breeding program. Further research to determine which traits are most important in organic pig production, including investigation of GxE interactions in organic and conventional pig production environments for these traits, is necessary before organic breeding programs or indices can be developed.

Organic pig production environments vary depending on the certification organization, region and herd. Robust animals with the ability to adapt to a variety of environments are sought in organic production (Hirt et al., 2001). A reaction norm describes the phenotype as a function of the environment where the environment is described, or quantified, on a continuous scale (de Jong, 1995). Protein level in the feed and stocking density are parameters that could be relevant on the environmental scale when reaction norms for fattening pigs are estimated. Robust animals show plasticity and have flat reaction norms, meaning that they produce equally well in various environments (Knap, 2005). Breeding values for the slope of the reaction norm in different traits could be of high value in organic breeding programs. In the present study the classification of the environment was based on whether the herds were certified as organic or not. The two environments give just two measuring points, but it is clear that the slope and level of the lines differ between boars. For example (Fig. 4a), the highest and lowest ranked boars in the conventional environment (boars A and D, respectively) are ranked in approximately the same way in the organic environment. Boar A, which appears to be sensitive to the environments, is a bad choice for organic farmers. Boar B, with a flat line, seems to be a good choice in either environment. Highly ranked boars, with good results in several environments, like boar B, will be considered robust and suitable for organic production.

Slaughter weight and carcass leanness averages in the organic herds were close to the average level in Swedish pig production, but average daily gain in the studied organic herds was slightly lower than the Swedish average. Average lean percentage and slaughter weight were 57.9% and 86.3 kg, respectively. The corresponding averages for all pigs slaughtered in 2005 by the largest slaughter organization in Sweden, Swedish Meats, were 57.4% and 85.7 kg for organic pigs and 57.7% and 86.0 kg for conventional pigs (Åkerfeldt, 2006). The estimated growth rate in the present study, 578 g/day, is lower than the growth rate of approximately 670 g/day for conventional pigs reported in the pig production herd monitoring system PigWin provided by the breeding organization Quality Genetics. However, that growth rate is not adjusted to 100 kg.

To our knowledge, genetic parameters for fattening traits in organic environment have not been reported previously. The heritability of growth rate and backfat thickness estimated in the organic environment in the present study, 0.30 and 0.36 respectively, is in line with previous reports of heritability estimates for both crossbred and purebred animals in conventional environments. Heritability of growth rate based on crossbred relatives has been reported to range from 0.16 to 0.42 (mean = 0.27) and of backfat thickness from 0.31 to 0.57 (mean = 0.39) (McLaren et al., 1985; Brandt and Taubert, 1998; Zumbach et al., 2007). According to a review by Clutter and Brascamp (1998) the heritability of backfat thickness is often moderate (mean = 0.31) when the pigs are restrictively fed, as in the present study. In accordance with earlier studies, a favourable but weak genetic correlation (−0.11) between growth rate and backfat thickness was estimated. Brandt and Taubert (1998) estimated this genetic correlation to −0.09 based on crossbred pigs. According to the review by Clutter and Brascamp (1998), this relationship is often reported weak when pigs are fed restrictively (mean = −0.16).

Continuing identification of slaughter pigs was a central issue in the practical work of this study. As it turned out, links between slaughter records from commercial slaughter plants and AI-boars were relatively successfully tracked, and 66% of the ear tags and tattooed piglets were identified at the slaughter line. This shows that genetic studies of this size, involving data from thousands of commercial pigs recorded at slaughter plants, can be performed. However, identification methods with electronic chips would make this kind of study much easier in the future.

In conclusion, our results indicate weak GxE interactions for both growth rate and carcass leanness in organic and conventional pig production environments. With regard to these traits, an organic breeding index within a conventional breeding program is a better option than a separate organic breeding program. However, further research on GxE interactions for other traits prized in organic production is needed.

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References


