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Genetic parameters and selection strategies for female fertility and litter quality traits in organic weaner production systems with closed breeding systems

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ABSTRACT

The increase of litter sizes in conventional weaner production systems in the past 30 years is associated with decreasing piglet birth weights, and in further consequence, with increasing piglet mortality. The aim of this study was the implementation of practicable litter quality recording schemes in six participating organic herds, in order to record new litter quality traits for the estimation of genetic parameters and breeding values. The litter quality traits were “Average Piglet Birth Weight” (ABW), “Litter Evenness” (LE), and “Piglet Vitality” (PV). Litter quality traits were recorded on a scale from 1 to 4, whereas score 4 indicated the desired performance value. A further female fertility trait was the “number of live born piglets” (LBP). The dataset included 2602 recorded litters from 1102 German Landrace x German Large White crossbred sows (rotational crossing system) from the birth years 2007 to 2015. For the estimation of genetic (co)variance components, univariate and bivariate animal models were applied. Heritability estimates for the litter quality traits were 0.09 for LE, 0.14 for PV and 0.21 for ABW. Genetic correlations among litter quality traits were throughout large and favourable, i.e., 0.90 between LE and ABW, 0.90 between LE and PV, and 0.75 between ABW and PV. Genetically, all new litter quality traits were negatively correlated with LBP (genetic antagonistic relationship). Estimated genetic (co)variance components were input parameters in selection index calculations. The aim was the identification of an optimal selection strategy for organic weaner production systems, i.e., an optimised breeding goal for the selection of replacement sows from the own herd. Using a desired gain approach, we focussed on the maximisation in genetic gain for litter quality traits, while keeping the status quo for LBP. The optimal index scenario included the phenotypic information from all four traits from the selection candidate (sow) from two litters. At the same time, three litters from the dam of the sow, and one litter from 10 half sibs, were available as information sources. For such a design of information sources and genetic relationships, optimal economic weights were 7.50 € for LBP and 20 € for all litter quality traits LE, ABW and PV. The correlation between the index and the aggregated genotype from this scenario was 0.60. Genetic gain per year considering a generation interval of 2.80 years for organic weaner production systems was larger than 0.04 points for all litter quality traits.

1. Introduction

Since the early 1990´s, breeding goals in conventional pig production systems mainly focused on increasing litter size, in order to maximise the number of live born and weaned piglets per sow and year (Biermann et al., 2014). Conventional and organic weaner production in medium sized farms is organised very similar. The main differences from a breeding perspective are the length of generation intervals, utilised breeds and sow replacement strategies. Since decades, commercial pig breeding companies focussed on the advantages of hybrid-breeding programs, and achieved huge progress in reproduction traits, especially for the number of live born piglets (Kaufmann et al., 2000; Zhang et al., 2000). For organic piglet producers, there is no specific breeding programme available. Hence, organic farmers purchase their replacement gilts from commercial pig breeding companies. High fertile hybrid sows with large litter sizes require an optimised and highly professional herd management, in order to keep piglet losses during the suckling period as low as possible (Biermann et al., 2014). However, such herd management strategies including specific feeding concepts and husbandry conditions, are difficult to implement in organic pig production systems. Furthermore, the amount of replacement gilts from commercial breeders in organic production is restricted, and only an

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exception by regulations. Thus, as a breeding alternative, organic farmers often use rotational crossing systems with semen from dam line boars from commercial breeding organisations, in order to produce their own replacements.

Along with the increased number of live born piglets per litter, the average birth weight of piglets decreased, with detrimental impact on piglet losses (Brandt, 2015; Hermesch et al., 2001a; Täubert and Henne, 2003; Roehe, 1999). Heritabilities for piglet birth weight were quite small, only in the range from 0.02 to 0.09, when the trait was analysed as trait of a piglet (Engblom et al., 2015; Kaufmann et al., 2000; Roehe, 1999). The same authors identified larger heritabilities in the range from 0.21 to 0.26 when assigning the trait to the dam. Brandt (2015) showed that piglets with birth weighs lower than one kilogram had survival rates lower than 50%. In the study by Brandt (2015), the average birthweight from all weaned piglets was significantly larger than the average birthweight from piglets not surviving the suckling period.

Increasing suckling losses due to increased litter size also refers to the teat number limitations of the sow, with the number of teats often being smaller than the number of suckling piglets. Feeding of milk supplements or the use of nurse sows is a standard management procedure in commercial farms (Brandt, 2015), but not allowed under all currently available organic pig production labels (Bioland, 2016). Due to stagnating or even decreasing pork prices and rising production costs (AMI, 2016), as well as public animal welfare discussions (Hinrichs, 2016), adjustments of pig breeding goals or fertility indices towards more sustainability, are imperative. This is also true from an economic perspective, because farm economy strongly depends on production costs per weaned piglet, and not only on the number of life born piglets per sow and year (Täubert and Henne, 2003). Täubert and Henne (2003) evaluated alternative breeding strategies for female fertility traits, i.e., aiming on reduced piglet losses while still improving litter size. They developed a selection index scenario, which included the traits LBP and piglet birth weight. Considering repeated records from the dam and grand dams, and an economic value of 60 € per weaned piglet, prediction accuracy (i.e., the correlation between index and aggregate genotype) was 0.48.

Aims of the present study were two fold. First, we estimated genetic parameters for new female litter quality traits based on a novel on-farm recording scheme. In a second step, estimated genetic (co)variance components were the basis for the development and evaluation of different selection index scenarios aiming on improvements in litter quality traits while keeping the status quo for litter size. Selection index scenarios for the selection of replacement gilts, i.e., the available information sources, generation intervals and selection intensities, reflected a closed organic nucleus scheme with rotational crossing, using sow replacements from the own herd.

2. Materials and methods

2.1. Data

We developed and implemented a practical on-farm recording system for litter quality traits. Traits of interest were “Live Born Piglets (LBP)”, “Litter Evenness (LE)”, “Average Piglet Birthweight (ABW)” and “Piglet Vitality (PV)”. Trait recording was included in the daily routine service, implying trait recording at the farrowing date within an acceptable time span. Recording of LE, ABW and PV based on a linear scoring system (scores 1, 2, 3, or 4), with score 4 indicating the desired classification. Score 2 reflected trait performances slightly below the farm average. In analogy to scores 1 and 2, score 3 reflected trait performances slightly above the farm average, and score 4 represented a trait performance way above the farm average. The intention of the four-class scoring system was to avoid too many litters classified as average. In the chosen scoring range, the classifier was forced to decide if the particular litter was rather worse or better than the average. Litter evenness classifying considered piglet uniformity, independent from the actual size or weight of the piglets, and based on the subjective impression for LE averages from the respective herd. Similarly, the herdsmen scored ABW, without weighing the piglets. The piglet's ability in finding teats, taking part in suckling and showing active behaviour, were characteristics for subjective PV scoring. Also PV was scored as litter average, meaning that the better the uniformity of piglet's vitality indicating behaviour within the litter, the better was the scoring in this trait for a particular sow. In order to guarantee trait recording from an identical observer perspective, always the same person from the herd classified the litters.

Data basis were 2602 litters from 1102 different sows (German Landrace x German Large White in a rotational cross using artificial insemination), born between 2007 and 2015. None of the participating farms had a purebred nucleus herd. All farms once purchased conventional crossbred restocking gilts and inseminated them with German Landrace/German Large White boars in rotation, for producing restocking litters. All conventional gilts purchased by the participating farms came from the same German breeding organisation. Genetic connectedness among farms is given via utilisation of the dam line boars from the same breeding company. Litter numbers ranged from one to 13. For genetic statistical modelling, litters from 5 to 13 were combined into one litter class. The litter dataset contained 472 parity-one litters, 533 parity-two litters, 437 parity-three litters, and 1160 litters of parity four or higher. Sows were kept on six participating farms located in the German federal states of Lower Saxony and North-Rhine Westphalia.

2.2. Estimation of genetic parameters

Genetic parameters for LBP, LE, ABW and PV were estimated using the REML methodology as implemented in the software package VCE 6 (Groeneveld et al., 2010). The statistical model was defined as follows:

$$y_{ijkl} = \mu + \text{farm}_i + \text{litternumber}_j + \text{animal}_k + \text{pe}_l + e_{ijkl}$$

$$y_{ijkl} = \text{traitscore(forLE, ABW, andPV)orno. ofpiglets(forLBP)}$$

$$\mu = \text{overallmeaneffect}$$

$$\text{farm}_i = \text{fixedfarmeffect}(i = 1 - -6)$$

$$\text{litternumber}_j = \text{fixedlitternumbereffect}(j = 1 - -5 with 5 combining all parities > 5)$$

$$\text{animal}_k = \text{randomadditive} - \text{geneticeffect}$$

$$\text{pe}_l = \text{randompermanentenvironmentaleffect}$$

$$e_{ijkl} = \text{randomresidualeffect}$$

Heritabilities, variance components and repeatabilities were estimated from univariate animal models. Bivariate animal models were applied to all trait combinations in order to estimate covariances, phenotypic and genetic correlations. Permanent environmental variances were close to zero in all univariate models for litter quality traits LE, ABW and PV, and in consequence, excluded from bivariate modelling.

2.3. Selection index scenarios

Selection index calculations were accomplished using the SIP software package (Wagenaar et al., 1995). The general strategy was the evaluation of indices and breeding goals depicting current on-farm pig breeding practice as realistic as possible. Because of the lacking economic values calculated under organic conditions, economic weights for LBP were in analogy to values as used in conventional German pig breeding goals, i.e., in the range from 7.50 € to 9.00 € per piglet

Table 1
Breeding scenarios (BS) as evaluated in the current study (IS = information source; GI = generation interval; HS = Half Sibs). Traits: litter evenness (LE), average piglet birth weight (ABW), piglet vitality (PV) and the number of live born piglets (LBP).

BS	IS	Measurements per IS	Economic weights				
			LE (€)	ABW (€)	PV (€)	LBP (€)	GI (Years)
A1	1 Sow	2 LBP	–	–	–	7.5	2.66
	1 Dam	3 LBP					
	10 HS	1 LBP					
A2	1 Sow	2 LBP LE ABW PV	1.0	1.0	1.0	7.5	2.66
	1 Dam	3 LBP LE ABW PV					
	10 HS	1 LBP LE ABW PV					
B1	1 Sow	2 LBP LE ABW PV	10	10	10	8.0	2.66
	1 Dam	3 LBP LE ABW PV					
	10 HS	1 LBP LE ABW PV					
B2	1 Sow	2 LBP LE ABW PV	20	20	20	8.5	2.66
	1 Dam	3 LBP LE ABW PV					
	10 HS	1 LBP LE ABW PV					
B3	1 Sow	2 LBP LE ABW PV	30	30	30	9.0	2.66
	1 Dam	3 LBP LE ABW PV					
	10 HS	1 LBP LE ABW PV					
B4	1 Sow	2 LBP LE ABW PV	20	20	20	7.5	2.66
	1 Dam	3 LBP LE ABW PV					
	10 HS	1 LBP LE ABW PV					
C1	1 Dam	2 LBP LE ABW PV	20	20	20	7.5	1.33
	2 HS	1 LBP LE ABW PV					
C2	1 Sow	1 LBP LE ABW PV	20	20	20	7.5	2.25
	1 Dam	3 LBP LE ABW PV					
	5 HS	1 LBP LE ABW PV					
D1	1 Sow	2 LBP LE ABW PV	20	20	20	7.5	2.80
	1 Dam	3 LBP LE ABW PV					
	10 HS	1 LBP LE ABW PV					

(Table 1). The true economic values for the traits are not so meaningful in the present study, because we focussed on the desired gain for litter size and litter quality traits. Marginal variations in economic weights for LBP in different breeding scenarios were due to fixations in desired gains for LBP. Economic values for LE, ABW and PV varied in different breeding scenarios, but were always identical for all three traits. The intention was to treat all litter quality traits equally, following the suggestions of practical organic pig breeders. Breeding scenario evaluation criteria were the correlation between the index and the aggregate genotype (= accuracy of prediction) for the selection candidate (sow), and genetic gain in single traits.

The basic breeding scenario (Scenario A1) reflected the current practical situation, considering only litter size in the breeding goal as well as in the index. It is the aim of the farmer to select the best sows as dams for replacement gilts. The farmer himself is not selecting on the sire side, here he relies on the genetic progress reached by the breeding organisations. Hence, records for litter size were available from the selection candidate (sow), the dam of the selection candidate, and from 10 half sibs of the selection candidate. The second breeding scenario (A2) was an extension of scenario A1. Again, the only trait in the index was LBP with the same information sources as defined in A1, but additional breeding goal traits were LE, ABW and PV. The intention for evaluating the A2 scenario was a first approach towards litter quality improvements without recording litter quality traits, just considering these traits with a small economic value (1 €) in the breeding goal. Breeding scenarios B reflected a desired gain index approach, i.e., aiming on the identification of optimal economic weights for litter quality traits in relation to economic weights for LBP with two intentions: First, the maximization of genetic gain in litter quality traits, while, secondly, keeping the genetic gain in LBP on the current level. In this regard, economic weights for litter quality traits were altered in several B sub-scenarios. Generally, B scenarios considered the same traits in the breeding goal as defined for the A scenarios. B1 was the first approach for a substantial improvement of litter quality traits, i.e., consideration of LE, ABW and PV as index as well as breeding goal traits (economic value: 10.00 € for all litter quality traits). In scenarios B2 and B3, economic values for litter traits increased to 20.00 € and 30.00 €, respectively—plus an adjustment of the economic weight for LBP up to 9.00 € (B3)—while keeping remaining settings in analogy to B1. In scenario B4, economic values were adjusted to 20.00 € for litter quality traits, and to 7.50 € for LBP. The intention of breeding scenarios C was the reduction of generation intervals. In scenario C1, the generation interval was 1.33 years, instead of 2.66 years in A and B scenarios. A reduction of the generation interval in C1 was possible, because in C1, the sow's estimated breeding value only based on early records from related animals (the dam and two half sibs). The C2 scenario was a compromise considering both intentions, i.e., the reduction of generation intervals, but also achieving moderate prediction accuracies. Hence, in C2, the own performance of the sow was considered, but only from one lactation instead of two repeated measurements as modelled in scenarios A and B. The generation interval in C2 comprised 2.25 years. The optimal organic breeding scenario D1 (maximal genetic gain in litter quality traits, selection response equal to zero for LBP) considered the index traits and information sources as defined in A and B scenarios, with economic values of 20.00 € per unit for LE, ABW and PV, and an economic value of 7.50 € for LBP (based on the desired gain from scenario B4). The only difference when comparing D1 with B4 was the slightly longer generation interval in D1 due to an extended organic suckling period (minimum of 42 days). Furthermore, organic farms are not allowed to apply reproduction synchronisation techniques, e.g., via hormone treatments (Koopmann et al., 2008), implying consideration of natural sow reproduction cycles with possible impact on longer generation intervals.

3. Results

3.1. Genetic parameters

Frequencies for the litter quality trait scores are depicted in Fig. 1. Live born piglets averaged at 14.02 piglets per litter with a standard deviation of 3.27 piglets.

Estimated genetic parameters for the quality traits and LBP are shown in Table 2. Heritabilities for LE (0.09) and PV (0.14) were quite small, but moderate genetic variances allow accumulation of genetic gain. Low heritabilities for LE and PV were mainly due to the substantial residual component (Table 2). The litter quality trait with the largest heritability was ABW (0.21). The repeatability for LBP was 0.25, but repeatabilities for litter quality traits were identical with their heritability estimates. Hence, only a very small permanent environmental component (very close to zero) contributed to litter quality traits. Heritability standard errors for the litter quality traits were in a moderate range, representing 15%—25% of the corresponding heritability estimate.

Phenotypic and genetic correlations among all litter quality traits were positive (Table 3). The strongest genetic correlation was 0.90 (between LE and ABW, and 0.90 between LE and PV). In addition, the strong positive genetic correlation between ABW and PV (0.75) underlines the general importance of ABW for the improvement of litter quality. The antagonistic relationship between litter size and litter quality traits is very obvious, because LBP was negatively correlated with all litter quality traits at genetic and phenotypic scales (Table 3). Low standard errors for genetic correlations underline the data quality from the on-farm recording system.

3.2. Evaluation of breeding scenarios: genetic gain and prediction accuracy

Genetic gain per generation for LBP in the status quo (A) scenarios was 0.64 piglets (A1) and 0.63 piglets (A2) (Table 4). With a small economic weight in the breeding goal, and without direct trait recording, genetic gain for all litter quality traits was negative, in the

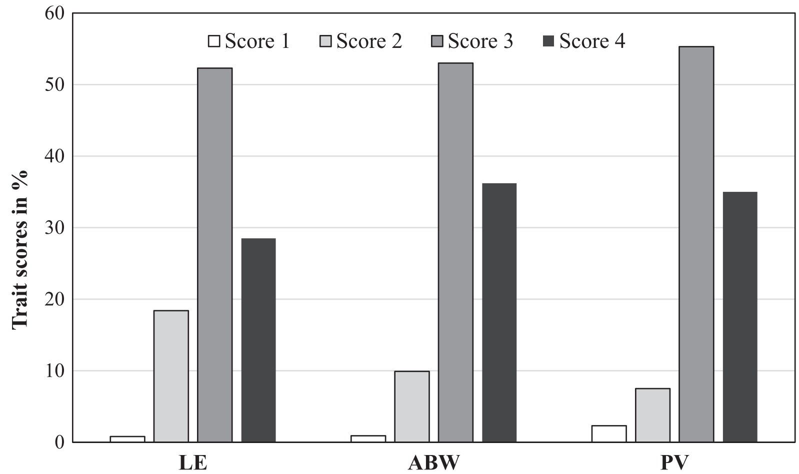

Fig. 1. Percentages for the assigned scores for litter quality traits litter evenness (LE), average piglet birth weight (ABW) and piglet vitality (PV).

Table 2
Variance components (σ^2_a = additive genetic variance, σ^2_{pe} = permanent environmental variance, σ^2_e = random residual variance), heritability (h^2) with corresponding standard error (se) and repeatability for litter evenness (LE), average piglet birth weight (ABW), piglet vitality (PV) and for the number of live born piglets (LBP).

Trait	σ^2_a	σ^2_{pe}	σ^2_e	h^2 (se)	Repeatability
LE	0.04		0.43	0.09 (0.02)	0.09
ABW	0.08		0.32	0.21 (0.03)	0.21
PV	0.05		0.87	0.14 (0.03)	0.14
LBP	0.99	1.56	7.58	0.10 (0.05)	0.25

Table 3
Genetic (above diagonal) and phenotypic (below diagonal) for all trait combinations litter evenness (LE), average piglet birth weight (ABW), piglet vitality (PV) and for the number of live born piglets (LBP). (Standard errors in brackets).

	LE	ABW	PV	LBP
LE		0.90 (0.01)	0.90 (0.10)	−0.30 (0.15)
ABW	0.55		0.75 (0.07)	−0.40 (0.13)
PV	0.50	0.50		−0.35 (0.16)
LBP	−0.23	−0.25	−0.14	

Table 4
Genetic gain per generation for litter quality traits litter evenness (LE), average piglet birth weight (ABW), piglet vitality (PV) and for the number of live born piglets (LBP), prediction accuracy and generation interval for the different breeding scenarios.

Scenario	Genetic gain LE (Points)	ABW (Points)	PV (Points)	LBP (Number)	Accuracy (%)	GI (Years)
A1	–	–	–	0.64	56	2.66
A2	−0.04	−0.07	−0.05	0.63	56	2.66
B1	0.07	0.08	0.06	0.38	55	2.66
B2	0.12	0.16	0.12	0.07	59	2.66
B3	0.13	0.18	0.13	−0.05	61	2.66
B4[a]	0.12	0.17	0.12	0.01	60	2.66
C1	0.10	0.13	0.10	−0.01	45	1.33
C2[a]	0.11	0.15	0.10	0.01	50	2.25
D1[a]	0.12	0.17	0.12	0.01	60	2.80

[a] Desired gain scenarios, i.e., selection response close to zero (but stilly slightly positive) for LBP.

range from −0.04 points for LE to −0.07 points for ABW (scenario A2). Prediction accuracies (also depicted in Table 4) from the A scenarios were quite low (56%).

Scenario B1 with small economic values of 10 € for all litter quality traits still contributed to marginal breeding progress in LBP (0.38 piglets). With an increase of economic values for litter quality traits in B2, genetic gain in LBP was close to zero (0.07 piglets). B3 was the first scenario showing negative selection response for LBP, because high economic values of 30 € were used for all litter quality traits. Breeding progress in all three litter quality traits increased from scenario B1 (0.06–0.08 points) to B3 (0.13–0.18 points). Breeding progress for litter quality traits in the B4 scenario was almost identical with breeding progresses in B3. In scenario B4, we achieved our desired gain intention, because selection response for LBP was very close to zero, but still positive (0.01 piglets).

Prediction accuracies from the B- scenarios ranged from 55 to 61 percent. The reduced information content due to a reduced number of related animals with observations in the C- scenarios was associated with lower prediction accuracies in C1 (45%) and C2 (50%). Accordingly, also genetic gains per generation for litter quality traits were lower in scenario C1, compared to scenarios B2, B3 or B4.

Aiming on a constant genetic level for LBP, and at the same time achieving maximum breeding progress for litter quality, the most effective set of economic values included 20 € for all litter quality traits, and 7.50 for LBP (scenarios B4 and D1). An increase of economic values for litter quality traits larger than 20 € was associated with undesired negative selection response for LBP. In this regard, the best prediciton accuracy was achieved when classifying three litters of the sow's dam, considering single measurements of ten half sibs, and recording two litters of the selection candidate (sow) itself.

A conventional piglet production system utilizing hormonal gilt synchronisation, and focussing on a short suckling period of only 21 days, implies an average generation interval of 2.66 years. The impact of reduced generation intervals on genetic gains per year is depicted in Fig. 2. Breeding progress per year is maximised when choosing the breeding scenario with the shortest generation interval. On the other side, we know from discussions with practical organic breeders that they do not accept breeding values with low accuracies. In this regard, also in the genomic era, König et al. (2009) defined an "acceptance threshold", i.e., prediction accuracys of at least 0.60. The results for breeding scenario D1 differ only in genetic gains per year and trait from those in B4, but not in prediction accuracies or in genetic gains per generation. Exactly the same breeding program structure was considered in both scenarios D1 and B4, but it is imperative to account for the longer generation interval (2.80 years) in organic weaner production systems.

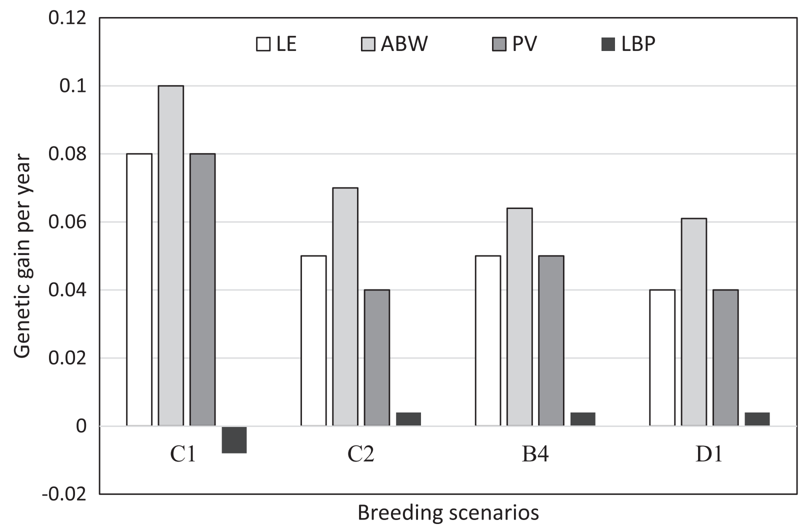

Fig. 2. Annually genetic gain for each trait (litter evenness (LE), average piglet birth weight (ABW), piglet vitality (PV), and the number of live born piglets (LBP)) and accuracy of prediction (= correlation between index and aggregate genotype) for selected breeding program scenarios.

4. Discussion

4.1. Genetic parameters

The moderate heritability for LBP in the present study (0.10) is in agreement with previous estimates from different pig populations (Gernand et al., 2010; Heusing et al., 2005; Täubert and Henne 2003; Hanenberg et al., 2000). The relatively broad range in heritability estimates for LBP and ABW may result from the altering trait definitions, the utilised breeds and varying population sizes in different studies. In the present study, LBP was defined as the number of alive piglets at the time point of first litter registration, by neglecting piglet losses during the time span from birth until the first piglet count. In our study, the maximal value for this time span was only one day, implying only minor bias for the LBP trait.

The estimated heritability of 0.21 for ABW is in agreement with estimates from studies basing on the average birth weight of the litter. In these studies, e.g., Rydhmer (2000), Hermesch et al. (2001b), Täubert and Henne (2003), Grandinson et al. (2005) and Kapell et al. (2011), heritabilities were in the range from 0.15 to 0.40. Heritabilities for ABW and PV were larger than for LBP, suggesting moderate genetic gain for litter quality traits when applying direct selection strategies. Piglet vitality is a complex trait, with varying definitions in previous studies. Randall (1971) and Zaleski and Hacker (1993) investigated heart rate and muscle tone of piglets immediately after birth and related those data to the viability during the suckling period. Recording of physical parameters during the first minutes after birth as an indicator for PV is a very accurate phenotyping strategy, but is difficult to implement in commercial weaner production systems (Muns et al., 2014). In consequence, Muns et al. (2014) developed a practical linear vitality scoring method, in order to create an index including vitality traits and birth weight. This index was used as a practical on-farm selection tool for management decisions. Four natural piglet behaviour pattern, including movement capacity, udder stimulation, number of completed circles around enclosure, and screaming, were scored in order to validate PV (Muns et al., 2014). In the present study, in analogy with the scoring method by Muns et al. (2014), PV was determined via observing typical piglet behaviour. Even though PV scoring was accomplished within one day after farrowing, some of the weakest piglets might have been dead before litter quality assessments. This means that potential bias in trait recording was not avoidable. These circumstances might contribute to lower heritability estimates for PV, because of an increased residual variance component. In theory, also covariances and trait correlations can be biased. However, under the prerequisite of integrating the trait recording into the daily routine without being too time consuming for the farmer, there was no more precise trait recording possibility, and a certain risk of bias had to be accepted.

In a combined breeding goal with LBP, genetic gain for litter quality is hampered due to the genetic antagonistic relationship between LBP with ABW ($r_g = -0.40$), and between LBP with PV ($r_g = -0.35$). The generally antagonistic genetic relationship between LBP with all three litter quality traits explains the decline in litter quality in conventional weaner production systems during the last decades (Beaulieu et al., 2010; Milligan et al., 2002).

4.2. Evaluation of breeding scenarios

From a commercial perspective, breeding goals for organic and for conventional piglet production are very similar. The commercial success of both production systems relies on weaned piglets per sow and year. The main difference in organic piglet production is that suckling losses of piglets are of a higher relevance, due to the limited technical solutions available, e.g., utilisation of a farrowing crate (Biermann et al., 2014). Due to the higher risk of piglet crushing in a free farrowing system, especially PV and ABW are important traits regarding mobile and robust piglets. Paying attention to the fact, that so far no economic weights for litter quality traits out of commercially used organic breeding programmes are available for comparison, we decided to keep the economic weights for all litter quality traits equal in this study's first approach. Such approach also reflects the demand of organic pig breeders, as identified in a survey conducted in the local pig breed “Bunte Bentheimer” (Biermann, 2015).

The development of an optimal organic breeding strategy, with the aim of litter quality improvements, associated with a constant genetic level for LBP, strongly depends on the genetic and phenotypic correlations between litter size and litter quality. Dwyer et al. (1994) carefully elaborated the negative effects of uterus-undernutrition on piglet's birth weights. In addition to uterus capacity and nutritional supply during pregnancy, the average embryo growth-rate significantly influenced survival-rates (Ford, 1997). The antagonistic relationship between birth weight and litter size was also observed in other species, such as in sheep and rabbits (Poigner et al., 2000; Yapi et al., 1992). Reasons for the lower average birthweight of twin lambs in comparison to single lambs are a reduced nutrition supply and a declined removal of metabolic products, even though the placental enlargement was proportional to the lamb number (Dwyer et al., 2005; Kaulfuß et al., 2000). Hence, physiological mechanisms explaining the antagonistic associations between birth weight and litter size in multiparous species seem to be very similar.

For the practical implementation of an organic on farm breeding program, the rotational crossbred sows represent the active breeding population, being the basis for on-farm selection strategies. This approach is possible, because of the consequently altering insemination rhythm between Large-White and Landrace sows for restocking litters on all farms in this study. The implementation of purebred nucleus herds within organic farms is not feasible, due to the quite small number of sows per herd. Selection on litter quality traits is impossible on the male pathway, because the organic herds use commercially semen doses for restocking litters as well as for terminal sires, without any information about boar-side litter quality. In such breeding system, she selection candidates are all sows in the herd (rotational crosses, being potential dams to produce replacement gilts. For the female selection side, it was the major goal to identify a selection scenario, which keeps the level for LBP constant and maximises the genetic gain for the litter quality traits.

The realistic generation interval following the common breeding conditions for conventional piglet production is 2.66 years, and 2.80 years for organic piglet production due to a longer suckling period and due to the less intensive reproduction management (Biermann et al., 2014). Such timeframe allows consideration of the first two litters of the selection candidate. At the same time, at least three litters from her dam are available as well for genetic evaluations. The combination of own performance and dam records with performance data of ten half sibs in selection index calculations was associated with moderate prediction accuracy (60%) in scenarios B4 and D1. An accuracy of 60% is large enough to achieve moderate breeding progress for fertility traits without changing common restocking rhythms. The theoretically shortest generation interval being possible under organic conditions (prerequisite: a minimum of 42 day suckling period) comprises 2.80 years. However, the slightly longer generation interval compared to typical conventional production systems only marginally decreased breeding progress per year. In organic or extensive production systems, and simultaneously utilizing local endangered breeds, generation intervals exceeded a three-year time span. For example in the "Bunte Bentheimer" pig population, Biermann et al. (2014) identified an average generation interval of 3.07 years. Hence, breeders have to make a compromise regarding losses in annual genetic gain or in prediction accuracy increases due to generation interval extensions. Gernand et al. (2010) favoured longer generation intervals in pigs to enlarge prediction accuracies, because they additionally found increasing heritabilities for fertility traits with increasing parities.

Almost 40 years ago, Kroes and Van Male (1979) critically discussed the decline in functional trait levels (e.g., vitality, conformation traits, longevity) of female selection candidates, being a potential basis for intra-herd replacements. Hence, Kroes and Van Male (1979) suggested improvements and more intensive selection among females, implying the development of innovative intra-herd replacement strategies. Accordingly, also König et al. (2007) identified potential to accumulate genetic gain when intensifying the female pathway of selection.

4.3. Practical implementation of routinely on-farm trait recording

Implementation of routine on-farm recording systems for litter quality traits is imperative when developing farm specific selection indices, especially when aiming on replacement strategies for gilts from the own herd. Van Steenbergen (1989) compared and evaluated linear trait scoring systems, especially against the background of classifying strategies. The linear scoring is a common method for the classification of conformation traits in livestock species, generally involving a large pool of trained classifiers for across-herd classifications (Janssens and Vandepitte, 2004; Van Bergen and Van Arendonk, 1993; Van Steenbergen, 1989). Kristensen et al. (2006) emphasised the improved data quality from linear recording schemes for body condition scoring in cattle when only one trained person is involved. Our trait recoding approach is unbiased from individual classifier opinions, because the herd average is the "fixed-point" for score assessments. The applied linear trait recording scheme during the routinely daily litter management considers all three traits ABW, PV and LE simultaneously, implying a short recording time (only one minute per litter) when involving an experienced herd manager.

However, it is imperative for future improvements that observers use the full range of possible trait scores. As outlined in Fig. 1, trait scores one and two are underrepresented, and classifiers should be trained or motivated to use poorer trait scores to a larger extent. Haberland et al. (2012) evaluated horse-breeding programs. One identified crucial point contributing to low genetic gain was the low percentage of observation for trait scores at the extreme ends of the linear scoring scale. A further alternative is the creation of binary data, i.e., assigning a score = 0 for "below average herd performance", and a score = 1 for "above average herd performance". Afterwards, for the estimation of variance components, threshold methodology (Gianola and Foulley, 1983) can be applied, with assumed larger heritabilities on the underlying liability scale compared to linear model applications (e.g., König et al., 2008). Especially for functional traits reflecting health, growth or vitality, genetic analyses on a liability scale might be a proper alternative.

5. Conclusions

It was possible to implement a practicable litter quality scoring system in participating organic weaner production herds. Data recording spanned a maximum period of one day after farrowing, and generated a reliable database for genetic evaluations. Heritabilities for the new litter quality traits ABW, LE, and PV were in a moderate range from 0.09 to 0.21, allowing the inclusion of these traits into overall breeding goals. For all three litter quality traits, we identified pronounced genetic antagonistic relationships with LBP. Based on the estimated genetic (co)variance components, the optimal breeding scheme for intra-herd selection of sows was a breeding goal including all four traits LBP, ABW, LE, and PV simultaneously. Additionally, it is imperative to consider all traits as information sources, i.e., two litters from the selection candidate (sow), three litters from the dam of the sow, and one litter from 10 half-sibs. With an economic value of 7.50 € for LBP, and 20 € for all litter quality traits, genetic gain in litter quality traits was maximised while keeping the status quo for the genetic level in LBP.

Conflicts of interest statement

We confirm that we have no conflicts of interest.

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References

AMI, 2016. AMI Agrarmarkt Informations – Gesellschaft mbH. https://www.ami-informiert.de/ami-maerkte.html.

Beaulieu, A.D., Aalhus, J.L., Williams, N.H., Patience, J.F., 2010. Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition, and eating quality of pork. J. Anim. Sci. 88 (8), 2767–2778.

Biermann, A.D.M., Pimentel, E.C., Tietze, M., Pinent, T., König, S., 2014. Implementation

of genetic evaluation and mating designs for the endangered local pig breed 'Bunte Bentheimer'. J. Anim. Breed. Genet. 131, 36–45.
Biermann, A.D.M., 2015. PhD-thesis. University of Kassel.
Bioland, 2016. Bioland Richtlinien stand 22.11.2017. http://www.bioland.de/fileadmin/dateien/HP_Dokumente/Richtlinien/Bioland_Richtlinien_22_Nov_2016.pdf.
Brandt, H.R., 2015. Sauenremontierung im ökologischen Landbau. Bioland Naturland Schweinetagung 15, 1–3.
Dwyer, C.M., Stickland, N.C., Fletcher, J.M., 1994. The influence of maternal nutrition on muscle fiber number development in the porcine fetus and on subsequent postnatal growth. J. Anim. Sci. 72, 911–917.
Dwyer, C.M., Calvert, S.K., Farish, M., Donbavand, J., Pickup, H.E., 2005. Breed, litter and parity effects on placental weight and placentome number, and consequences for the neonatal behaviour of the lamb. Theriogenology 63, 1092–1110.
Engblom, L., Calderon Diaz, J.A., Nikkilä, M., Gray, K., Harms, P., Fix, J., Tsuruta, S., Maybry, J., Stalder, K., 2015. Genetic analysis of sow longevity and sow live time reproduction traits using consored data. J. Anim. Breed. Genet. 133, 138–144.
Ford, S.P., 1997. Embryonic and fetal development in different genotypes in pigs. J. Reprod. Fert. 52, 165–176.
Gernand, E., Müller, U., Mäurer, H., Müller, S., Bergfeld, U., 2010. Optimierung der Zuchtwertschätzung für lebend geborene Ferkel hinsichtlich der Wurfnummerdifferenzierung und Herdensaison. Züchtungskunde 82, 205–216.
Gianola, D., Foulley, J.L., 1983. Sire evaluation for ordered categorical data with a threshold model. Genet. Sel. Evol. 15, 201–223.
Grandinson, K., Rydhmer, L., Strandberg, E., Solanes, F.X., 2005. Genetic analysis of body condition in the sow during lactation, and its relation to piglet survival and growth. Anim. Sci. 80, 33–40.
Groeneveld, E., Kovač, M., Mielenz, N. (2010): VCE User's guide and reference manual version 6.0.
Haberland, A.M., König von Borstel, U., Simianer, H., König, S., 2012. Integration of genomic information into sport horse breeding programs for optimization of accuracy of selection. Animal 6, 1369–1376.
Hanenberg, E.H.A.T., Knol, E.F., Merks, J.W.M., 2000. Estimates of genetic parameters for reproduction traits at different parities in Dutch Landrace pigs. Livest. Prod. Sci. 69, 179–186.
Hermesch, S., Luxford, B.L., Graser, H.U., 2001a. Genetic parameters for piglet mortality, within litter variation of birth weight, litter size and litter birth weight. In: Association for the Advancement of Animal Breeding and Genetics. 14. pp. 211–214.
Hermesch, S., Luxford, B.L., Graser, H.U., 2001b. Estimation of variance components for individual piglet weights at birth and 14 days of age. In: Association for the Advancement of Animal Breeding and Genetics. 14. pp. 207–210.
Heusing, M., Hamann, H., Distl, O., 2005. Genetische Analyse von Lebensleistungs- und Fruchtbarkeitsmerkmalen bei Sauen der Rasse Deutsches Edelschwein, Deutsche Landrasse und Pietrain. Züchtungskunde 77, 15–34.
Hinrichs, A., 2016. Umsetzung des Tierwohlkonzeptes. In: Willers, C. (Ed.), CSR Und Lebensmittelwirtschaft. Management-Reihe Corporate Social Responsibility. Springer Gabler, Berlin, Heidelberg, pp. 179–186.
Janssens, S., Vandepitte, W., 2004. Genetic parameters for body measurements and linear type traits in Belgian Bleu du Maine, Suffolk and Texel sheep. Small Ruminant Res. 54, 13–24.
Kaufmann, D., Hofer, A., Bidanel, J.P., Künzi, N., 2000. Genetic parameters for individual birth and weaning weight and for litter size of Large White pigs. J. Anim. Breed. Genet. 117, 121–128.
Kapell, D.N.R.G., Ashworth, Ch.J., Knap, P.W., Roehe, R., 2011. Genetic parameters for piglet survival, litter size and birth weight or its variation within litter in sire and dam lines using Bayesian analysis. Livest. Sci. 135, 215–224.
Kaulfuß, K.H., Schramm, D., Bertram, M., 2000. Der Einfluß von Genotyp, Alter, Wurfgröße, Wurfgewicht und Vatertier auf morphologische Parameter der Plazenta beim Schaf. Dt. Tierärztliche Wochenschrift 107, 269–275.
König, S., Lessner, S., Simianer, H., 2007. Application of controlling instruments for improvements in cow sire selection. J. Dairy Sci. 90, 1967–1980.
König, S., Wu, X., Gianola, D., Heringstad, B., Simianer, H., 2008. Exploration of relationships between claw disorders and milk yield in Holstein cows via recursive linear and threshold models. J. Dairy Sci. 81, 395–406.
König, S., Simianer, H., Willam, A., 2009. Economic evaluation of genomic breeding programs. J. Dairy Sci. 92, 382–391.
Koopmann, R., Ganter, M., Link, M., 2008. Veterinary treatment in organic husbandry. In: 16th IFOAM Organic World Congress, Modena, Italy, June 16-20. Archived at. http://orgprints.org/11643.
Kristensen, E., Dueholm, L., Vinl, D., Andersen, J.E., Jakobsen, E.B., Illum-Nielsen, S., Petersen, F.A., Enevoldsen, C., 2006. Within- and Across-Person Uniformity of Body Condition Scoring in Danish Holstein Cattle. J. Dairy Sci. 89 (9), 3721–3728.
Kroes, Y., Van Male, J.P., 1979. Reproductive lifetime of sows in relation to economy of production. Livest. Prod. Sci. 6, 179–183.
Milligan, B.N., Fraser, D., Kramer, D.L., 2002. Within-litter birth weight variation in the domestic pig and its relation to pre-weaning survival, weight gain, and variation in weaning weights. Livest. Sci. 76, 182–192.
Muns, R., Manzanilla, E.G., Sol, C., Manteca, X., Gasa, J., 2014. Piglet behaviour as a measure of vitality and its influence on piglet survival and growth during lactation. J. Anim. Sci. 91, 1838–1843.
Poigner, J., Szendrö, Zs, Lévai, A., Radnai, I., Birnó-Németh, E., 2000. Effect of birth weight and litter size on growth and mortality in rabbits. World Rabbit Sci. 8 (1), 17–22.
Randall, G.C.B., 1971. Relationship of arterial blood pH and pCO2 to viability of newborn piglet. Can. J. Comp. Med. 35, 141–146.
Roehe, R., 1999. Genetic determination of individual birth weight and its association with sow productivity traits using Bayesian analyses. J. Anim. Sci. 77, 330–343.
Rydhmer, L., 2000. Genetics of sow reproduction, including puberty, oestrus, pregnancy, farrowing and lactation. Livest. Prod. Sci. 66, 1–12.
Täubert, H., Henne, H., 2003. Große Würfe und wenig Ferkelverluste – ein erreichbares Zuchtziel beim Schwein? Züchtungskunde 75, 442–451.
Van Bergen, H.M.J.M., Van Arendonk, J.A.M., 1993. Genetic parameters for linear type traits in Shetland Ponies. Livest. Prod. Sci. 36, 273–284.
Van Steenbergen, E.J., 1989. Description and evaluation of a linear scoring system for exterior traits in pigs. Livest. Prod. Sci. 23, 163–181.
Wagenaar, D., Van Arendonk, J., Kramer, M., 1995. Selection Index Program (SIP). Wageningen Agricultural University, Wageningen.
Yapi, C.V., Boylan, W.J., Robinson, R.A., 1992. Heritability and repeatability estimates and the correlations of lamb mortality with birth weight and litter size. World Rev. Anim. Prod. 27, 55–60.
Zaleski, H.M., Hacker, R., 1993. Comparison of viability scoring and blood-gas analysis as measures of piglet viability. Can. J. Anim. Sci. 73, 649–653.
Zhang, S., Bidanel, J.P., Burtot, T., Legault, C., Naveau, J., 2000. Genetic parameters and genetic trends in the Chinese x European Tiameslan composite pig line. I. Genetic parameters. Genet. Sel. Evol. 32, 41–56.