A second look at the influence of birth weight on carcass and meat quality in pigs

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Abstract

To re-examine the relationship of birth weight with carcass and meat quality of pigs at market weight, offspring ($n = 378$) of 63 sows were assigned to three birth weight groups; 25% low weight (LW), 50% middle weight (MW), and 25% heavy weight (HW), with runts (<800 g) being excluded. LW pigs exhibited the lowest postnatal growth performance, the lowest lean mass and the greatest degree of fatness in terms of perirenal fat compared with MW and HW pigs. Only in females, but not in male castrates, the lean percentage was highest in HW pigs. Characteristics of *longissimus* muscle technological quality declined either in LW (pH, drip loss) or HW (conductivity, lightness) compared with MW pigs. In contrast, intramuscular fat percentage (IMF) was highest in LW pigs. The results suggest that the most desirable carcass composition is obtained with HW pigs, whereas optimum technological pork quality, except for IMF, is achieved with MW pigs.

Keywords: Birth weight; Carcass quality; Pork quality; Fat; Lean meat

1. Introduction

Birth weight and within-litter variation in birth weight are important economic traits in pig production. Genetic selection for large litters during the last decades has lowered mean birth weight, which mainly results from a higher competition of the foetuses *in utero* reflected also by an inverse correlation of birth weight and litter size (e.g. Milligan, Fraser, & Kramer, 2002; Quiniou, Dagorn, & Gaudre, 2002). Low birth weight, however, is associated with decreased survival and lower postnatal growth rates (e.g. Herpin, Damon, & Le Dividich, 2002; Milligan et al., 2002; Pond & Mersmann, 1988; Quiniou et al., 2002; Ritter & Zschorlich, 1990). In addition, pigs at market weight originating from piglets of low birth weight develop a lower carcass quality in terms of higher fat deposition and lower lean accretion compared with their middle or heavy weight littermates (Bee, 2004; Gondret et al., 2006; Hegarty and Allen, 1978; Kuhn et al., 2002; Poore & Fowden, 2004; Powell and Aberle, 1980, 1981; Rehfeldt and Kuhn, 2006). Low birth weight results from intrauterine growth retardation during gestation. It has been shown previously that small piglets form a lower total number of skeletal muscle fibres during prenatal development compared with their larger littermates (Gondret et al., 2006; Handel & Stickland, 1987; Wigmore & Stickland, 1983). From recent studies, it has been suggested that it is the low number of muscle fibres, which restricts the potential of postnatal lean growth and therefore allows to deposit increased amounts of fat (Rehfeldt & Kuhn, 2006). In addition, tendencies towards lower meat quality in terms of tenderness and water holding capacity have been observed at slaughter, when the piglets were small at birth (Gondret et al., 2005; Gondret et al., 2006; Rehfeldt & Kuhn, 2006), which may be associated with accelerated muscle fibre hypertrophy because of low fibre number. The studies on the influence of birth weight mentioned above have in common, that

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the number of animals used in the experiments were not very large (5–32 pigs per birth weight group born to 13–16 sows) and the variation in the traits of interest caused by the dam/litter has not always been considered in the statistical models. Therefore, this study was conducted using a larger set of pigs from 63 litters in total to re-examine the consequences of birth weight for ultimate carcass and meat quality.

2. Materials and methods

2.1. Experimental design

This experiment was conducted at the experimental station of the FBN Dummerstorf, Germany, under controlled environmental conditions. Sixty-three litters from German Landrace sows (bred by artificial insemination to German Landrace boars; 1st to 5th parity) in a total of seven temporally successive replicates were used. Birth weight was recorded, and runts exhibiting less than 800 g were excluded from this study. The mean litter size was 13.6 ± 3.1. In 6 of 7 replicates 2–3 piglets were removed from each litter for other studies. The remaining piglets ($n = 378$ in total) stayed with their dams, which received increasing amounts of a commercial diet for lactating sows (Trede & Pein GmbH & Co. KG, Itzehoe, Germany). Male piglets were castrated at five days of age, and all piglets were weaned at 28 days of age. During the whole growing-finishing period the offspring was fed *ad libitum* with a starter mixture from d 28 to 70, and with a universal mixture throughout finishing (Trede & Pein). The pigs were kept on flat-decks from d 28 to 70 and thereafter housed in groups. The pigs were weighed at 28, 70, 133 days of age, and before slaughter at approximately the same age (180 ± 8 days).

All procedures were in accordance with the guidelines set by the Animal Care Committee of the State Mecklenburg-Vorpommern, Germany, based on the German Law of Animal Protection.

2.2. Carcass and meat quality

At slaughter, the weights of the heart and of the perirenal fat were recorded. Muscle meat percentage, length and perimeter of the ham, loin muscle area, and back fat thickness were determined on the left carcass half. The length of the ham was taken as the straight distance from the cut of the pubic symphysis to the distal end of the ham cut; the perimeter was measured at the largest width of the ham. Muscle meat percentage was estimated by the FOM device (Fat-o-Meat'er, SFK-Technology A/S, Søborg, Denmark). Loin muscle area and back fat thickness were measured manually at the level of 13th/14th ribs. At the same position the following characteristics of meat quality were determined in the *longissimus* muscle: pH values (pH_{45}; pH_{24}) and conductivity (at 45 min and 24 h *postmortem*), impedance, colour, drip loss, and chemical composition (at 24 h *postmortem*). The pH_{45} and pH_{24} values were measured by electrode (pH-Star, Matthäus, Pöttmes, Germany). Likewise, for measurements of conductivity and impedance manual devices were used such as LF- Star (Matthäus, Pöttmes, Germany) or Meat Check 150 (Sigma electronic GmbH, Erfurt, Germany). Meat colour (lightness, L^*; redness, a^*; yellowness, b^*) was measured with the CR-200 (Minolta AG, Langenhagen, Germany). Drip loss was defined as the weight loss of a meat sample (50 g), placed on a flat plastic grid and wrapped in foil, after a storage time of 24 h (24–48 h *postmortem*) in a refrigerator (4 °C). The composition of *longissimus* muscle by water/dry matter, lipid, and ash was analysed according to standard methods (AOAC, 1990), and protein was estimated by difference (Kuhn, Ender, & Nürnberg, 1994).

2.3. Statistical analysis

All pigs were assigned to three birth weight groups: 25% to low weight (LW $\leqslant$ 1.22 kg), 50% to middle weight (MW); and 25% to heavy weight (HW $\geqslant$ 1.54 kg) according to the quantiles of frequency distribution with $n = 102$, $n = 180$, and $n = 96$, respectively. Birth weight ranged from 0.80 to 2.17 kg (1.37 ± 0.25 kg on average). The data set included 172 males (LW = 47; MW = 73; HW = 52) and 206 females (LW = 55, MW = 107, HW = 44). Data were subjected to analyses of variance, using the mixed classification model of SAS (SAS System for Windows Release 8 e; SAS Institute Inc., Cary, NC 27513, USA) including sex, replicate, birth weight group and corresponding interactions as fixed factors and sow within replicate as random factor. Data given in the tables are least squares means ± SE. Significance of differences between least squares means was tested by multiple *t*-test ($P < 0.05$).

3. Results

3.1. Growth and carcass composition

The LW pigs grew clearly slower than MW pigs, and the latter grew still slower than HW pigs (Fig. 1A). Following live weight development from birth to slaughter, weights were significantly different among LW, MW and HW pigs at all stages of age ($P < 0.05$) with the same ranking maintained from birth to slaughter. Though, before slaughter (d 180) live weight only tended to be different between MW and HW ($P = 0.07$). These differences in growth were also reflected by significant differences in live weight gain at all stages of age examined (Fig. 1B).

At slaughter, carcass weight differed correspondingly among LW, MW and HW pigs (Table 1). Absolute measures of lean mass, such as loin area or ham length and perimeter were lower ($P < 0.05$) in LW as compared to MW and HW piglets. Meat percentage measured by the FOM device was only numerically but not significantly lowest in LW piglets. However, there was a birth weight group by sex interaction ($P = 0.07$) in that a ranking by birth weight was apparent in females, but not in male castrates (Fig. 2). Apart from higher lean percentage in females than in castrates, LW and MW females exhibited a lower lean percentage than HW females. Absolute measures of fat deposition, such as back fat thickness and perirenal fat weight showed no differences among the birth weight groups. However, the percentage of perirenal fat was clearly higher in LW pigs as compared with MW and HW pigs.

The weight of the heart differed significantly among all birth weight groups with lowest weight exhibited by LW and highest weight exhibited by HW pigs. The relative heart weight was numerically lowest in LW pigs ($P = 0.31$).

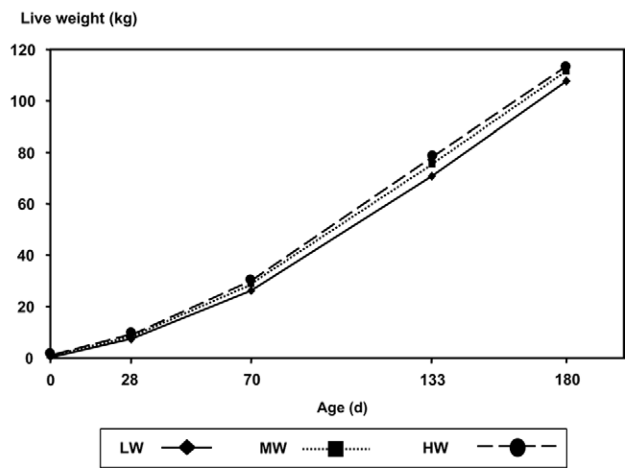

Fig. 1A. Live weight development of pigs originating from piglets of low (LW), middle (MW) and heavy (HW) birth weight. Data are least squares means; the maximum SE is 0.01, 0.14, 0.45, 1.03, and 1.02 kg at d 0, 28, 70, 133, and 180, respectively. The differences between LW, MW and HW are significant at all stages of age ($P < 0.01$) with the exception of the difference between MW and HW at d 180 ($P = 0.07$).

Apart from birth weight and weight of the heart all carcass traits were highly dependent on sex in that male castrates showed higher live and carcass weights, but a lower degree of leanness and higher fat deposition than females (data not shown).

3.2. Meat quality

Meat quality characteristics were determined in *longissimus* muscle (Table 2). Comparing the pigs by birth weight groups, LW pigs showed a lower pH_{45} value and a higher value for drip loss ($P < 0.05$) and tended to lower impedance values ($P < 0.10$) than MW pigs with HW pigs exhibiting intermediate values. Lightness (L^*) and conductivity were higher ($P < 0.05$) in HW than in

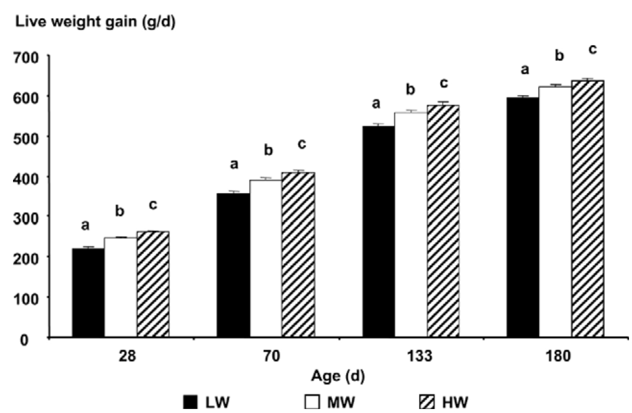

Fig. 1B. Daily live weight gain calculated cumulatively at different stages of age for pigs originating from piglets of low (LW), middle (MW) and heavy (HW) birth weight. Columns represent least squares means ± SE. Different letters indicate significant differences within days of age ($P < 0.05$).

Table 1
Carcass characteristics of pigs at market weight (d 180 of age) originating from piglets of low (LW), middle (MW) and heavy (HW) birth weight (least squares means ± SE)

Item	Birth weight group (B)[d]			P-values <		
	LW	MW	HW	B	Sex	B × Sex
Number of pigs	102	180	96			
Birth weight (kg)	1.08 ± 0.01[a]	1.37 ± 0.01[b]	1.67 ± 0.01[c]	–	0.62	0.77
Final live weight (kg)	107.7 ± 0.93[a]	111.6 ± 0.80[b]	113.6 ± 1.02[b]	0.0001	0.0001	0.83
Daily gain (g/d)	594 ± 5.58[a]	621 ± 4.68[b]	637 ± 6.11[c]	0.0001	0.0001	0.89
Carcass weight (kg)	85.1 ± 0.77[a]	88.1 ± 0.67[b]	89.8 ± 0.84[c]	0.0001	0.0001	0.93
Lean meat (FOM) (%)	54.88 ± 0.29	55.15 ± 0.24	55.36 ± 0.32	0.47	0.0001	0.07
Loin muscle area (cm^2)	45.51 ± 0.57[a]	47.95 ± 0.48[b]	48.79 ± 0.62[b]	0.0001	0.0001	0.66
Ham length (cm)	29.65 ± 0.14[a]	30.01 ± 0.12[b]	30.16 ± 0.15[b]	0.01	0.15	0.78
Ham perimeter (cm)	71.75 ± 0.26[a]	73.05 ± 0.22[b]	73.55 ± 0.29[b]	0.0001	0.01	0.80
Back fat thickness (cm)	2.22 ± 0.03	2.25 ± 0.03	2.22 ± 0.04	0.59	0.0001	0.30
Heart (g)	369.8 ± 7.5[a]	387.2 ± 6.3[b]	403.6 ± 7.7[c]	0.001	0.61	0.25
Heart[e] (%)	0.44 ± 0.01	0.45 ± 0.01	0.45 ± 0.01	0.31	0.01	0.42
Perirenal fat (g)	1667 ± 63.0	1593 ± 50.4	1550 ± 64.8	0.28	0.0001	0.69
Perirenal fat[e] (%)	1.96 ± 0.06[a]	1.82 ± 0.05[b]	1.71 ± 0.06[b]	0.01	0.0001	0.60

[a,b,c] Least squares means bearing a letter in common are not significantly different ($P > 0.05$).
[d] Pigs were allocated to birth weight groups according to the quantiles of frequency distribution (25% LW; 50% MW; 25% HW).
[e] Related to cold carcass weight.

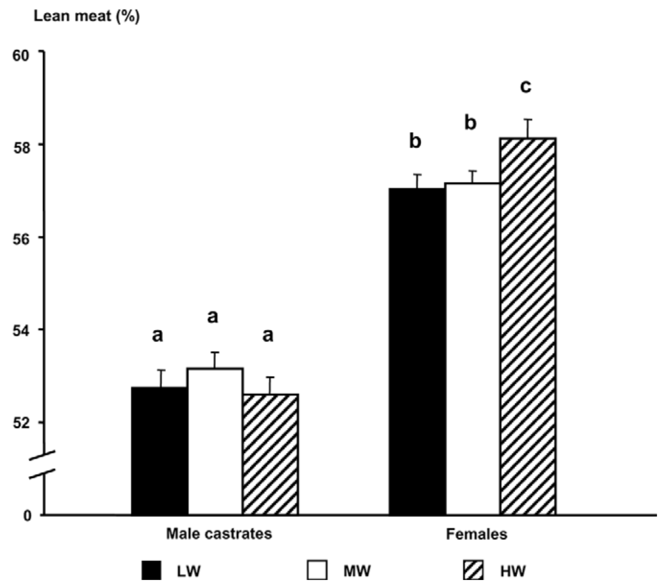

Fig. 2. Lean meat percentage (FOM) of male and female pigs at market weight (d 180 of age) originating from piglets of low (LW), middle (MW) and heavy (HW) birth weight. An interaction between birth weight group and sex has been observed ($P = 0.07$). Columns represent least squares means ± SE. Different letters indicate significant differences ($P < 0.05$).

MW pigs with being intermediate in LW pigs. No significant differences among the groups were observed in the ultimate pH_{24}, redness (a^*), and yellowness (b^*) of the meat. Looking at all quality traits mentioned so far, it is apparent that the MW pigs exhibited values indicating the better quality of meat compared with LW and HW pigs, both of which decline from MW in selected traits. Differently, the intramuscular fat content was significantly higher in LW pigs compared with MW and HW pigs. With the exception of lighter meat colour in males than in females, male castrates exhibited a higher meat quality in terms of pH_{45}, $conductivity_{45}$, drip loss and intramuscular fat (details not shown).

4. Discussion

Carcass and meat quality have been determined in pigs at market weight originating from as much as 63 litters to verify the results on the influence of birth weight on these important economic trait complexes that have been reported previously using lower number of animals. Dividing the pigs into three birth weight groups such as low (LW), middle (MW) and heavy (HW) our results confirm that the ranking at birth is maintained during postnatal growth resulting from different initial weights and different growth rates, which has been observed in former studies (Gondret et al., 2005, 2006; Powell & Aberle, 1981; Rehfeldt & Kuhn, 2006). At a fixed age at market weight the inferiority of LW pigs and the superiority of HW pigs becomes clearly apparent in carcass weight. Furthermore, LW pigs show a lower lean mass than MW and HW pigs, but a comparable increase in back fat thickness and perirenal fat. This results in a greater relative body fatness of low birth weight pigs at market weight in terms of perirenal fat, which is indicative of lower carcass quality. On the other hand, the differences in absolute measures of lean mass between LW, MW, and HW pigs were not sufficiently high to cause clear differences in average lean (FOM) percentage. In principle, the obtained results substantiate those obtained with smaller numbers of pigs (Bee, 2004; Gondret et al., 2006; Kuhn et al., 2002; Poore & Fowden, 2004a; Rehfeldt & Kuhn, 2006).

While the higher relative fatness of LW pigs in terms of perirenal fat is apparent in both females and male castrates, there seems to be a sex-specific dependency of birth weight in lean meat percentage. In females, the proportion of lean meat was lower in LW and MW than in HW pigs, whereas no differences were apparent within male castrates that ranged ca. 5%-units on average below females. For this trait, sex revealed to be more important than the originating birth weight of the pig. Consistent with our results, the lean meat percentage of LW pigs was found to be lower than

Table 2
Meat quality of *longissimus* muscle of pigs at market weight (d 180 of age) originating from piglets of low (LW), middle (MW) and heavy (HW) birth weight (least squares means ± SE)

Item	Birth weight group (B)[e]			*P*-values <		
	LW	MW	HW	B	Sex	B × Sex
Number of pigs	$n = 102$	$n = 180$	$n = 96$			
pH_{45}-value	6.15 ± 0.03[a]	6.25 ± 0.03[b]	6.18 ± 0.04[ab]	0.02	0.02	0.68
pH_{24}-value	5.49 ± 0.01	5.49 ± 0.01	5.49 ± 0.01	0.88	0.11	0.56
$Conductivity_{45}$ (m S/cm)	4.30 ± 0.10[ab]	4.15 ± 0.08[a]	4.41 ± 0.10[b]	0.09	0.06	0.75
$Conductivity_{24}$ (m S/cm)	4.46 ± 0.17	4.23 ± 0.14	4.48 ± 0.18	0.33	0.92	0.89
Impedance (Py)	47.12 ± 1.47[c]	49.93 ± 1.21[d]	47.27 ± 1.61[cd]	0.14	0.49	0.72
Lightness (L^*)	47.69 ± 0.31[ab]	47.27 ± 0.25[a]	48.06 ± 0.34[b]	0.11	0.06	0.88
Redness (a^*)	7.94 ± 0.15	7.74 ± 0.14	7.84 ± 0.16	0.30	0.94	0.81
Yellowness (b^*)	1.12 ± 0.09	1.00 ± 0.08	1.17 ± 0.10	0.29	0.09	0.98
Drip loss (%)	5.66 ± 0.23[a]	5.13 ± 0.19[b]	5.48 ± 0.25[ab]	0.09	0.01	0.77
Intramuscular fat (%)	1.14 ± 0.04[a]	0.99 ± 0.04[b]	0.93 ± 0.05[b]	0.001	0.0001	0.64

[a,b] Least squares means bearing a letter in common are not significantly different ($P > 0.05$).
[c,d] Least squares means bearing a letter in common are not significantly different ($P > 0.10$).
[e] Pigs were allocated to birth weight groups according to the quantiles of frequency distribution (25% LW; 50% MW; 25% HW).

that of HW pigs, when only females were used (Gondret et al., 2006). When both sexes were included, it tended to be lower in LW pigs (Rehfeldt & Kuhn, 2006) or it was equal in LW and HW pigs (Bee, 2004) as seen in the present study. Thus, the inconsistency may results from the influence of gender on lean meat percentage. Poore and Fowden (2004a) also observed stronger effects of birth weight for females than for entire males, but in terms of adult fatness, which was most pronounced in female low birth weight pigs.

A number of possible mechanisms, by which poor foetal growth leads to altered body composition in favour of fat, are under discussion. The low number of muscle fibres formed prenatally in LW piglets could be the reason for attaining the plateau of postnatal lean growth earlier (Rehfeldt & Kuhn, 2006). In this case, nutritional energy can no longer be used for muscle accretion, but is mainly used to deposit fat. The excess of nutrients may also change the hormonal status and related metabolism. Thus, differences in insulin/glucose and fat metabolism have been reported to depend on birth weight (Gondret et al., 2006; Poore, Forhead, Gardner, Giussani, & Fowden, 2002; Poore & Fowden, 2004a, 2004b). Another possibility is that changes in the intrauterine programming of the endocrine system (e.g. Poore & Fowden, 2003) could have long-term consequences for postnatal growth and metabolism. Furthermore, changes in metabolism may be related to the capacity of the cardiovascular system. Low birth weight has been shown to correlate with a higher incidence of cardiovascular diseases in human and in animals (e.g. Barker, 2004; Poore et al., 2002; Wu, Bazer, Cudd, Meininger, & Spencer, 2004). One clue in this respect could be the lower heart weight that has been found in pigs of low birth weight in this study confirming previous data (Rehfeldt & Kuhn, 2006).

Novel aspects can be derived from this study in terms of the relationship of birth weight with pork quality. The few results, which were available so far, referred to lower water holding capacity (Rehfeldt & Kuhn, 2006) and less tenderness scores (Gondret et al., 2006) in LW compared with HW pigs. The results of this study with a larger set of animals suggest, however, that there is an optimum in MW pigs, since there is a decline in meat quality in LW pigs with respect to pH_{45}, drip loss, and impedance and in HW pigs with respect to conductivity 45 min *postmortem* and lightness. Thus, it is not surprising that only a few or no differences have been observed in these traits when comparing the extremes, LW with HW pigs (Gondret et al., 2005, 2006; Rehfeldt & Kuhn, 2006). In the case of LW pigs the impaired quality has been related to excessive fibre hypertrophy and formation of giant fibres, which are known to correlate inversely with good pork quality (Fiedler, Dietl, Rehfeldt, Wegner, & Ender, 2004). With respect to HW pigs, intensive (lean) growth as it is obtained in response to genetic selection or with special feeding regimes has been reported earlier to correlate with poor meat quality that may be related to accelerated fibre type conversion towards fast twitch glycolytic fibres (Bee, 2004; Fiedler et al., 2004; Karlsson, Klont, & Fernandez, 1999; Larzul et al., 1997). However, no significant effects of birth weight on fibre type composition in market weight pigs have been observed in previous studies (Bee, 2004; Gondret et al., 2005; Rehfeldt & Kuhn, 2006), wherefore other, unknown, factors may play a more important role. On the other hand, our results are consistent with the fact that poor meat quality occurs with both extreme number and size of myofibres and that an optimum is reached with a balanced relation of moderate size and number (Rehfeldt, Fiedler, & Stickland, 2004). With respect to intramuscular fat showing the highest values in LW pigs, there is a consistency with the highest degree of fatness in these pigs as well as with the results of former experiments (Gondret et al., 2006; Powell & Aberle, 1981; Rehfeldt & Kuhn, 2006). In the case of intramuscular fat, pork quality of LW pigs exceeded that of MW and HW pigs, however, the overall values were very low.

5. Conclusions

In pigs, foetal growth retardation resulting in low birth weight cannot be compensated for during postnatal growth. Pigs of low birth weight exhibit the lowest lean mass and the highest degree of fatness compared with pigs of middle and heavy birth weights, which is more pronounced in females than in male castrates, and which reflects the intrauterine programming of adult obesity. Pork quality, however, appears to be optimal in pigs of middle birth weight, but declines, albeit with respect to different traits, both with low and heavy birth weights. Exceptionally, the intramuscular fat content is highest in pigs of low birth weight. The production of balanced litters with middle-ranged birth weights could help to optimize carcass and meat quality in pigs.

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