Lean and fat development in the whole body and hams of hybrid pigs studied by magnetic resonance tomography

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ABSTRACT: The aim of this study was to determine the influence of MHS-genotype and feeding regime on the growth and development of muscle and fatty tissue in the whole body as well as in hams of hybrid pigs. The experiment was carried out on 72 barrows that were divided into 4 groups regarding the MHS-genotype (NN and Nn) and feeding regime (standard and intensive). Data necessary to determine the volume of examined tissues were obtained by means of magnetic resonance tomography. During the fattening period there were no statistically significant differences between pig groups with respect to total lean content of the body although the feeding regime effect in the finishing fattening phase was on the margin of statistical significance ($P = 0.057$). Differences between investigated groups with respect to the lean content in hams were not significant either. Results of this research lead to a conclusion that different feeding regimes and MHS genetic status of pigs do not have a significant influence on the growth of muscle and fatty tissue in hams.

Keywords: BHZP; MHS genotype; tissue growth; feeding regime

Animal growth is a complex biological process, determined by different genetic and environmental factors. Animal genotype defines the maximal level to what this process can be developed, and environmental factors affect the level to what the genetic potential can be manifested. Defining the connection between genetic and environmental factors is of vital importance for the setting up of strategies and models that will best determine the maximum growth potential. In order to determine the growth potential in a faster, cheaper and more precise way, techniques have been developed to measure the body composition as well as the size of tissues and organs *in vivo*. Magnetic resonance (MRT) is a noninvasive diagnostic method which has recently been used in researches on domestic animals. The basic principle of this method relies on the properties of atomic nuclei with an odd number of protons or neutrons (or both), which absorb and reemit radio waves when placed in a powerful magnetic field (Baulain, 1997). MRT is frequently applied to determine the body composition of pigs at their particular live weights (Baulain, 1997; Kastelic, 1997; Mitchell et al., 2001; Berg et al., 2002; Kušec et al., 2006). Their studies proved that MRT offered numerous possibilities for an *in vivo* noninvasive analysis of the body composition of pigs, being based on volumetric measurements of specific tissues and organs, with the aim to predict the composition of total fat and muscles as well as their growth. Based on the analysis of images obtained by the scanning of the whole body and by comparing these results with the results of total dissection, Mitchell et al. (2001) stated that the highest match was achieved with larger organs and tissues. He claimed that the accuracy of volumetric analysis could be affected by connection of distances between measurement spots as well as by the amount of tissue, and that the measurement of the fat and muscle volume of well defined back and ham area provided data for precise prediction of the overall composition of pigs. Baulain and Henning (2001)

referred to the MRT technique as being very precise in the volume measurement of tissues or specific organs in live animals or in carcasses, on the basis of which growth models could be developed. The authors stated that NMR considerably lowered research costs as it required much fewer animals in an experiment, and the expensive dissection of carcasses was no longer necessary. Moreover, the precise resolution of soft tissues enables to apply this technique as a reference method to improve rearing systems of domestic animals and carcass classification. Vangen and Jopson (1996) described MRT as a technique allowing relatively fast and accurate evaluation of the body composition of live animals. It is possible to save images over a longer period of time, which makes a reanalysis possible if a new hypothesis appears. Databases of scanned images are created and made available whenever needed. Investigations of Tholen et al. (2003), Baulain et al. (2004), Collewet et al. (2005) and Monziol et al. (2006) showed that lean content could be predicted accurately by the acquisition of a series of cross-sectional images covering the whole carcass or primal cuts.

Besides all advantages, there are also some restrictions of the *in vivo* body determination that are usually referred to as difficulties in measurements of particular organs or intestine content and insufficient automation of image analysis. Moreover, the size of magnet and the frequency of radio waves can significantly restrict the usage of MRT in researches on animals. Animals larger than humans cannot be scanned without prior alteration of the equipment; which complicates the measurement procedure and raises expenses. On the other hand, costs of MRT equipment are too high and are therefore a limiting factor in using this method more frequently in researches on domestic animals.

MATERIAL AND METHODS

Data needed to analyze the growth of muscle and fatty tissue in pigs were obtained by means of magnetic resonance tomography. A tomograph used for measurements had a magnetic field of 1.5 Tesla. It is a Medspec BMT 15/100 model produced by BRUKER Biospin GmbH (Figure 1). Just before scanning, the pigs were given Ursotamin tranquilizer (app. 40 mg/kg of weight). Scanning lasted on average 1.5 hours per pig.

Research was carried out on 72 male castrates that were divided into 4 groups according to their genotype and feeding regime. The investigated pigs were four-way crossbreeds of Piétrain (Pi) × Hampshire (Ha) in the sire line, and Large White (LW) × German Landrace (GL) in the dam line (BHZP – Bundes Hybrid Zucht Program – Scheme 1). The MHS (malignant hyperthermia syndrome) genetic status of pigs was determined by the DNA testing of tissue samples, by PCR (polymerase chain reaction) and RFLP method (restriction fragment length polymorphism). Based on the genotyping, piglets were divided into two genotype groups, one with carriers of the MHS gene (heterozygote, Nn) and the MHS gene negative piglets (homozygote, NN). During the experiment, pigs were kept in two different feeding regimes. A standard feeding re-

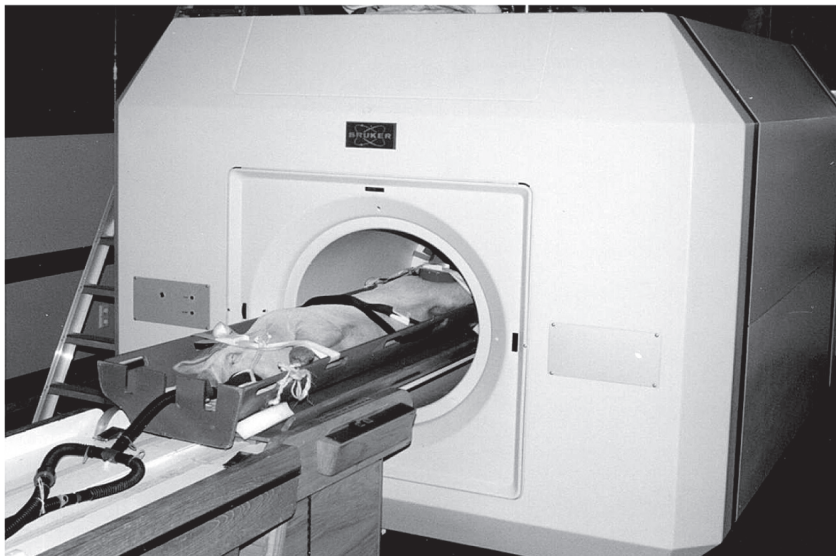

Figure 1. BRUKER Biospin GmbH tomograph, Medspec BMT 15/100 model

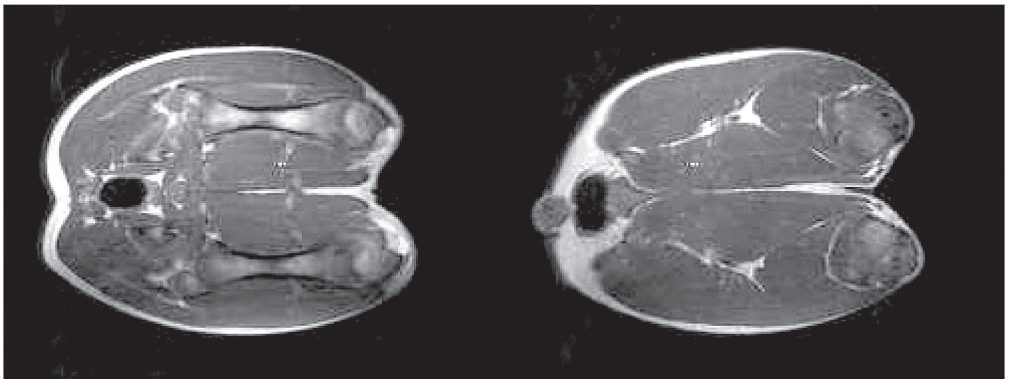

Figure 2. MR image of carcass cross-section in the ham area

gime was set up according to the currently valid BHZP recommendations (standard diet), which are applied in market production of fattening pigs. Intensive feeding was experimental and designed to manifest the full genetic potential of muscle and fatty tissue growth in pig carcass in the given conditions. Pigs from the standard feeding regime were fed *ad libitum* in the first fattening phase; in the finishing phase they were fed standard diets. Pigs kept under the intensive feeding regime were fed *ad libitum* during the whole fattening period.

Measurements of pigs by magnetic resonance tomography were carried out every 4 weeks, starting at the age of 10 weeks up to the finishing weight of app. 120 kg. During the scanning process, a set of parallel images of pig body cross-sections was obtained. One sequence consisted of 50–60 images of the whole pig body, and a distance between images depended on the size of the animal and varied from 16 to 32 mm. Scanning of ham provided usually 9–12 images, depending on the age and size of the pig (Figure 2).

Images obtained by scanning were screened on a computer and analyzed. The images of body parts that were not subject to this investigation (bones, organs) were manually removed by Silicon Graphics Workstation Program using the IDL software package (IDL Research System Inc., 1994). The remain-

Table 1. Total growth of muscle tissue (dm^3) in investigated groups of pigs

Measurement	Statistical indicators	Standard feeding		Intensive feeding		Statistical significance
		NN	Nn	NN	Nn	
1st	$\bar{x}$	10.56	9.98	10.63	9.99	$P_1 = 0.430$ $P_2 = 0.524$ $P_3 = 0.528$
	sd	1.94	1.94	1.42	2.01	
	cv	19.26	19.38	13.37	20.18	
	$s_{\bar{x}}$	0.47	0.47	0.34	0.52	
2nd	$\bar{x}$	20.65	19.81	21.16	20.13	$P_1 = 0.210$ $P_2 = 0.578$ $P_3 = 0.893$
	sd	2.90	3.63	1.98	3.41	
	cv	14.05	18.31	16.94	9.33	
	$s_{\bar{x}}$	0.70	0.88	0.47	0.88	
3rd	$\bar{x}$	34.11	33.32	33.34	33.10	$P_1 = 0.536$ $P_2 = 0.551$ $P_3 = 0.741$
	sd	2.87	3.85	2.33	4.25	
	cv	8.41	11.56	7.00	12.84	
	$s_{\bar{x}}$	0.69	0.93	0.55	1.10	
4th	$\bar{x}$	46.16	45.14	47.03	48.10	$P_1 = 0.979$ $P_2 = 0.057$ $P_3 = 0.292$
	sd	3.23	3.90	3.38	5.45	
	cv	6.99	8.63	7.19	11.32	
	$s_{\bar{x}}$	0.78	0.95	0.79	1.41	

P_1 = genotype influence; P_2 = feeding influence; P_3 = interaction

ing parts, shown in pixels, were analyzed by so called cluster analysis in the SAS Software (SAS, 2000). Cluster analysis distinguishes muscle tissue from fatty tissue on the given images. Muscle and fat volumes were calculated by Cavalieri's mathematical method. This method was named after the Italian mathematician Bonaventura Cavalieri (1598–1647) as his principle forms a basis to evaluate volume and has been used until now (Roberts et al., 1993). Cavalieri's principle of tissue volume evaluation is simplified in the following equation:

$$estV = T \times (A_1 + A_2 + ... + A_n)\ \text{cm}^3$$

where:

$estV$ = the estimated tissue volume

T = the distance between the taken images (cm)

A_1 to A_n = numbers of pixels which correspond to the muscle and fat area on images analyzed by cluster analysis

Statistical analysis was performed by the SAS software (SAS, 2000) and STATISTICA for Windows 6.0 (StatSoft, 1996). Graphs and diagrams in this paper are prepared in STATISTICA for Windows 6.0 and Microsoft Excel 97 (Microsoft Corp., 1997). The differences in the fattening traits were tested by two-way ANOVA analysis from the SAS 6.12 GLM procedure. The differences between live weights and tissue proportions were tested by LSD-test of STATISTICA for Windows 6.0 Program Package (StatSoft, 1996).

RESULTS AND DISCUSSION

The development of total body muscle tissue across four measurements during the experimental period of fattening for investigated groups of pigs is presented in Table 1. As can be observed from the results presented above, during the fattening period there were no statistically significant differences ($P > 0.05$) between the experimental groups of pigs with respect to the growth of muscle tissue content in the whole body. These results correspond to those reported by Pommier et al. (1992) and Leach et al. (1996), who did not find any differences between halothane-resistant pigs and halothane carriers, which could affect production characteristics and carcass composition. On the contrary, Jensen and Barton-Gade (1985), as well as Schinckel (2001) stated that in the first fattening phase halothane-resistant pigs exhibited better leanness and superior carcass composition than halothane carriers. Nevertheless, many authors stated the opposite, i.e. that halothane carriers grew faster and had a higher portion of muscle tissue in carcass (Monin, 1999; Miller et

Table 2. Growth of muscle tissue in hams (dm^3) of investigated pigs

Measurement	Statistical indicators	Standard feeding		Intensive feeding		Statistical significance
		NN	Nn	NN	Nn	
1st	$\bar{x}$	3.17	3.17	3.36	3.17	$P_1 = 0.526$ $P_2 = 0.543$ $P_3 = 0.518$
	sd	0.56	0.69	0.52	0.65	
	cv	18.86	21.57	0.51	0.65	
	$s_{\bar{x}}$	18.86	21.57	15.31	20.63	
2nd	$\bar{x}$	6.52	6.17	6.71	6.49	$P_1 = 0.207$ $P_2 = 0.241$ $P_3 = 0.769$
	sd	0.86	0.97	1.08	0.65	
	cv	13.12	15.82	16.57	9.65	
	$s_{\bar{x}}$	0.21	0.24	0.15	0.28	
3rd	$\bar{x}$	10.28	10.13	9.93	10.12	$P_1 = 0.958$ $P_2 = 0.431$ $P_3 = 0.478$
	sd	0.95	1.08	0.53	1.17	
	cv	9.24	10.68	5.30	11.57	
	$s_{\bar{x}}$	0.23	0.26	0.12	0.30	
4th	$\bar{x}$	13.34	13.67	13.46	14.13	$P_1 = 0.145$ $P_2 = 0.400$ $P_3 = 0.609$
	sd	1.43	1.71	1.06	1.28	
	cv	10.75	12.54	7.86	9.03	
	$s_{\bar{x}}$	0.35	0.41	0.25	0.33	

P_1 = genotype influence, P_2 = feeding influence, P_3 = interaction

Tab le 3. Development of fatty tissue (dm^3) in the whole body of investigated pigs

Measurement	Statistical indicators	Standard feeding		Intensive feeding		Statistical significance
		NN	Nn	NN	Nn	
1st	$\bar{x}$	4.14	4.17	4.27	4.40	$P_1 = 0.740$ $P_2 = 0.447$ $P_3 = 0.837$
	sd	1.13	0.99	0.62	1.03	
	cv	27.30	23.83	14.60	23.40	
	$s_{\bar{x}}$	0.27	0.24	0.15	0.27	
2nd	$\bar{x}$	8.84	8.08	9.30	8.69	$P_1 = 0.065$ $P_2 = 0.128$ $P_3 = 0.836$
	sd	1.38	1.34	1.43	1.83	
	cv	15.58	16.64	15.37	20.99	
	$s_{\bar{x}}$	0.33	0.32	0.34	0.47	
3rd	$\bar{x}$	16.23	15.18	18.03	16.40	$P_1 = 0.025$ $P_2 = 0.012$ $P_3 = 0.624$
	sd	2.37	2.30	2.64	2.16	
	cv	14.59	15.14	14.66	13.17	
	$s_{\bar{x}}$	0.57	0.56	0.62	0.56	
	$LSD_{0.05} = 1.65$. $LSD_{0.01} = 2.19$					
4th	$\bar{x}$	21.88	21.10	28.43	26.99	$P_1 = 0.290$ $P_2 < 0.001$ $P_3 = 0.925$
	sd	3.14	2.10	3.07	2.61	
	cv	14.36	9.96	9.69	10.79	
	$s_{\bar{x}}$	0.76	0.51	0.72	0.67	
	$LSD_{0.05} = 1.92$. $LSD_{0.01} = 2.55$					

P_1 = genotype influence, P_2 = feeding influence, P_3 = interaction

al., 2000). Schinckel et al. (2001) and Sillence (2004) reported that the effect of genotype on the growth of muscle tissue was reduced as the finishing fattening phase approached. The present study opposes the results of Whang et al. (2003), who stated that an intensified feeding regime led to intensive development of muscle tissue in the particular growth phases. Although this study did not result in any statistically significant influence of feeding on the total lean development, differences between groups with respect to the feeding regime affecting the portion of muscle tissue during the last period of fattening were on the margin of statistical significance ($P = 0.057$), which points at the necessity of further research into this problem.

Referring to the development of lean (dm^3) in hams (Table 2), it is noticeable that neither genotype nor feeding regime had a statistically significant effect in the whole research period. This is contrary to the research of Holck et al. (1997), who pointed out a significant effect of environmental factors, mostly of feeding. On the other hand, Sillence (2004) emphasized genotype as a factor that significantly affects the growth of muscle tissue in hams as well as in the whole carcass in the starting growth phase. Monin (1999), Miller et al. (2000) and Rosner et al. (2003) also reported a higher portion of muscle tissue in pigs of Nn genotype when fed intensively. However, Aalhus et al. (1991) did not determine any significant differences between different pig genotypes with respect to lean content in the carcass parts, which corresponds to the results presented in this paper.

Referring to the deposition of fatty tissue in pigs (Table 3), the investigated genotypes and feeding regimes did not have a significant effect on the total growth of fatty tissue in the first and second fattening phase. In the third phase, pigs fed standard diets had less fatty tissue than pigs fed *ad libitum*. Effects of genotype and feeding regime in this period were statistically significant ($P = 0.025$ and $P = 0.012$). At the end, pigs fed standard diets had a significantly lower portion of fatty tissue. In the last fattening phase, the feeding regime affected the total deposition of fatty tissue in pigs highly significantly ($P < 0.001$). At the same time, the genotype influence was not statistically significant ($P = 0.290$). Results from the present study support the conclu-

Table 4. Growth of fatty tissue in hams (dm^3) of investigated pigs

Measurement	Statistical indicators	Standard feeding		Intensive feeding		Statistical significance
		NN	Nn	NN	Nn	
1st	$\bar{x}$	0.85	0.79	0.82	0.83	$P_1 = 0.738$ $P_2 = 0.897$ $P_3 = 0.541$
	sd	0.28	0.28	0.19	0.23	
	cv	32.72	28.68	23.75	27.28	
	$s_{\bar{x}}$	0.07	0.06	0.05	0.06	
2nd	$\bar{x}$	1.71	1.64	1.84	1.74	$P_1 = 0.348$ $P_2 = 0.220$ $P_3 = 0.881$
	sd	0.40	0.44	0.28	0.40	
	cv	23.43	26.66	15.17	22.84	
	$s_{\bar{x}}$	0.10	0.10	0.07	0.10	
3rd	$\bar{x}$	3.29	3.20	3.57	3.39	$P_1 = 0.373$ $P_2 = 0.125$ $P_3 = 0.749$
	sd	0.62	0.53	0.66	0.67	
	cv	18.83	16.50	18.51	19.91	
	$s_{\bar{x}}$	0.15	0.13	0.16	0.18	
4th	$\bar{x}$	4.32	4.31	5.56	5.44	$P_1 = 0.648$ $P_2 < 0.001$ $P_3 = 0.680$
	sd	0.46	0.58	0.83	0.82	
	cv	10.59	13.55	14.90	15.03	
	$s_{\bar{x}}$	0.11	0.14	0.19	0.21	
	$LSD_{0.05} = 1.35$. $LSD_{0.01} = 1.76$					

P_1 = genotype influence, P_2 = feeding influence, P_3 = interaction

sions of Pringle and Williams (2001), who found that an intensive feeding regime promoted an increase in fatty tissue in pig carcasses. Wood et al. (2004) reported that an increase in the feeding intensity of finishing phase affected an increase in the fatty tissue deposition, but these processes were also influenced by animal genotype. In the present study, animal genotype had a significant effect only in the third measurement. Results of our investigation correspond with the generally acknowledged thesis on greater deposition of fatty tissue in an intensive feeding regime (Ŏverland et al., 2000; Whang et al., 2003).

Development of fatty tissue in hams (dm^3) is overviewed in Table 4. In the first three fattening phases there were no statistically significant differences ($P > 0.05$) determined between groups, when considering the feeding regime and genotype influence on fatty tissue deposition in hams. In the first fattening phase, all pig groups exhibited equal portions of fatty tissue in hams. In that period, genotype ($P = 0.738$) and feeding ($P = 0.897$) did not have any significant effects on the deposition of fatty tissue in hams. In the second and third phase, pigs fed standard diets exhibited a lower portion of fatty tissue in hams than pigs fed *ad libitum*; however, these differences were not statistically significant ($P > 0.05$). The effect of genotype was neither relevant in the fourth phase of fattening ($P = 0.648$). Pigs fed standard diets had a lower portion of fatty tissue (NN = 4.32 dm^3 and Nn = 4.31 dm^3), when compared to pigs fed *ad libitum* (NN = 5.56 dm^3 and Nn = 5.44 dm^3). The effect of feeding regime on the deposition of fatty tissue in hams was statistically very highly significant ($P < 0.001$).

Sillence (2004) pointed out that in the finishing phase the genotype had a significantly lower effect on the fatty tissue deposition than the feeding regime. However, Wood et al. (2004) emphasized that the genotype influence was not to be neglected and that feeding intensity determined the genetic potential in animals to a certain extent. Significant influence of feeding regime on the fatty tissue content in hams during finishing is in accordance with the studies of Schinckel et al. (2001) and Whang et al. (2003).

CONCLUSION

No statistically significant differences ($P > 0.05$) in portions of muscle tissue between investigated

groups were obtained either in carcass or in hams, respecting both the feeding regime and genetic status during the whole period of fattening. When considering total fatty tissue deposition in pigs during the first and second period of fattening, no significant effect of fattening and MHS-genotype was observed. In the third fattening phase, pigs fed standard diet had a lower portion of fatty tissue than pigs fed *ad libitum* ($P = 0.012$). In this phase, the influence of genotype was also statistically significant ($P = 0.025$). In the fourth fattening phase, deposition of fatty tissue in pigs was highly significantly ($P < 0.001$) affected by the feeding regime alone. Under conditions of intensive feeding, pigs that carry the MHS gene exhibit better characteristics to some extent, while in conditions of more cost effective standard feeding MHS-negative pigs presented better results, which points out the fact that there is no necessity to keep pigs that carry this specific gene.

REFERENCES

Aalhus J.L., Jones W.M., Robertson W.M., Tong A.K.W., Sather A.P. (1991): Growth characteristics and carcass composition of pigs with known genotypes for stress susceptibility over a weight range of 70 to 120 kg. Anim. Prod., 52, 347 pp.

Baulain U. (1997): Magnetic resonance imaging for the *in vivo* determination of body composition in animal science. Comput. Electr. Agric., 17, 189–203.

Baulain U., Henning M. (2001): Studies of carcass and meat quality by means of MR tomography and MR spectroscopy. Arch. Tierz., 44, 181–193.

Baulain U., Wiese M., Tholen E., Hoereth R., Hoppenbrock K.H. (2004): Magnet-Resonanz-Tomographie: Referenztechnik zur Bestimmung der Körperzusammensetzung in der Leistungsprufung beim Schwein. Fleischwirtschaft, 84, 101–104.

Berg E.P., Asfaw A., Ellersieck M.R. (2002): Predicting pork carcass and primal lean content from electromagnetic scans. Meat Sci., 60, 1330–139.

Collewet G., Bogner P., Allen P., Busk H., Dobrowolski A., Olsen E., Davenel A. (2005): Determination of the lean meat percentage of pig carcasses using magnetic resonance imaging. Meat Sci., 70, 563–572.

Holck J.T., Schinckel A.P., Coleman J.L., Wilt V.M., Thacker E.L., Spurlock M., Grant A.L., Malven P.V., Senn M.K., Thacker B.J. (1997): Environmental effects on the growth of finisher pigs. J. Anim. Sci., *75*, 246 pp.

Jensen P., Barton-Gade P.A. (1985): Performance and carcass characteristics of pigs with known genotypes for halothane susceptibility. In: Proc. Commission on Animal Management and Health and Commission of Pig Production. Stress Susceptibility and Meat Quality in Pigs. EAAP, ed. Pudoc, Wageningen, Netherlands. 33, 80 pp.

Kastelic M. (1997.): Bestimmung der Wachstumsallometrie von Muskel- und Fettgewebe aus In-vivo-Messungen beim Schwein. Landbauforschung Vőlkenrode, Sonderheft, 172.

Kušec G., Baulain U., Kallweit E., Glodek P. (2006): Influence of MHSgenotype and feeding regime on allometric and temporal growth of pig assessed by magnetic resonance imaging. Livest. Sci., doi: 10.1016/j.livsci.2006.10.007

Leach L.M., Ellis M., Sutton D.S., Mc Keith F.K., Wilson E.R. (1996): The growth performance, carcass characteristics, and meat quality of halothane carrier and negative pigs. J. Anim. Sci., 74, 934–943.

Miller K.D., Ellis M., McKeith F.K., Wilson E.R. (2000): Influence of sire line and halothane genotype on growth performance, carcass characteristics and meat quality in pigs. Can. J. Anim. Sci., 80, 319–327.

Mitchell A.D., Scholz A.M., Wang P.C., Song H. (2001): Body composition analysis of the pig by magnetic resonance imaging. J. Anim. Sci., 79, 1800–1813.

Monin G. (1999): Effects of the halothane genotype and slaughter weight on texture of pork. J. Anim. Sci., 77, 408–415.

Monziol M., Collewet G., Bonneau M., Mariette F., Davenel A., Kouba M. (2006): Quantification of muscle, subcutaneous fat and intermuscular fat in pig carcasses and cuts by magnetic resonance imaging. Meat Sci., 72, 146–154.

Ŏverland M., Granli T., Kjos N.P., Fjetland O., Steien S.H., Stokstad M. (2000): Effect of dietary formates on growth performance, carcass traits, sensory quality, intestinal microflora, and stomach alterations in growing-finishing pigs. J. Anim. Sci., 78, 1875–1884.

Pommier S.A., Houde A., Rousseau F., Savoie Y. (1992): The effect of the malignant hyperthermia genotype as determined by a restriction endonuclease assay on carcass characteristics of commercial crossbred pigs. Can. J. Anim. Sci., *72*, 973–976.

Pringle T.D., Williams S.E. (2001): Carcass traits, cut yields and compensational end points in high-lean-yielding pork carcasses: effects of 10th rib backfat and loin eye area. J. Anim. Sci., *79*, 115–121.

Rosner F., Von Langerken G., Maak S. (2003.): The value of pig breeding herds in Germany and progress in im-

provement of meatiness and pork quality. Anim. Sci. Pap. Rep., 21, 153–161.

SAS (2000): SAS System for Windows, Version 9.0, Cary, NC, USA.

Schinckel A.P. (2001): Factors affecting swine lean growth. In: 2nd International Virtual Conference of Pork Quality. www.conferencia.uncnet.br/pork/programa.en.html

Schinckel A.P., Wagner, J.R., Forrest, J.C., Einstein, M.E. (2001): Evaluation of alternative measures of pork carcass composition. J. Anim. Sci., 79, 1093–1119.

Sillence M.N. (2004): Technologies for the control of fat and lean deposition in livestock. Vet. J., 167, 242–257.

StatSoft (1996): Statistica for Windows. Statsoft Inc., Tulsa.

Tholen E., Baulain U., Henning M., Schellander K. (2003): Comparison of different methods to asses the composition of pig bellies in progeny testing. J. Anim. Sci., 81, 1177–1184.

Vangen O., Jopson N.B. (1996): Research application of non-invasive techniques for body composition. In: 47th Annual Meeting of the European Association for Animal Production, Lillehammer, Norway.

Whang K.Y., Kim S.W., Donovan S.M., McKeith F.K., Easter R.A. (2003): Effects of protein deprivation on subsequent growth performance, gain of body components, and requirements in growing pigs. J. Anim. Sci., 81,705–716.

Wood J.D. et al. (2004): Effect of breed, diet and muscle on fat deposition and eating quality in pigs. Meat. Sci., 67, 651–667.

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