Increasing the Pig Market Weight: World Trends, Expected Consequences and Practical Considerations

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ABSTRACT : The present report has been aimed at reviewing important factors which need to be closely analyzed or considered when increasing the market weight of finishing pigs. The pig market weight has increased worldwide during the past few decades, which is attributable primarily to an increased lean gain potential of finishing pigs. To increase the market weight, however, the acceptability of larger pigs by the packer as well as pork consumers should be met first. By increasing the market weight, total number of breeding stock, as well as the facility for them, necessary for producing a given weight of pork can be reduced, whereas more building space for finishing pigs and an additional nutrition program for the later finishing period are needed. Additionally, a more thorough disease prevention program especially against ileitis and mycoplasma pneumonia may also be needed, because outbreaks of these are known to increase with increasing body weight over 110 kg. Some larger finishing pigs may deposit excessive fat that may be reduced or prevented by using hormonal and/or nutritional agents. Backfat thickness increases linearly with increasing body weight between 110 and 130 kg, whereas intramuscular fat content does not change significantly. With increasing live weight within this range, the ratios of belly and loin to carcass weight also are known to increase. Some physicochemical characteristics related to fresh and cooked meat quality including color, firmness, juiciness, etc. are known to be unaffected or slightly changed following an increase of slaughter weight. In conclusion, ratios of primal cuts and pork quality characteristics are not significantly affected by increasing the market weight. Moreover, increasing the market weight of lean-type pigs approximately up to 130 kg is normally profitable to producers, as long as packers and consumers accept larger pigs. ***(Asian-Aust. J. Anim. Sci. 2005. Vol 18, No. 4 : 590-600)***

Key Words : Pig, Market Weight, Lean, Fat, Pork

INTRODUCTION

Market weight is an important economic factor in swine production, influencing the meat quality as well as profit. Pig market weight has increased worldwide during the past few decades and is still in the increasing trend mainly thanks to an increased lean gain potential of new genetic lines. The following criteria need to be considered, however, to increase the pig market weight in a given country or society. First of all, consumer acceptability of larger finishing pigs has to be met in terms of meat quality characteristics. Obviously, there exists more room for increasing the market weight in countries such as Korea where consumers prefer high-fat belly and shoulder to lean cuts than in countries where lean cuts such as loin and ham are preferred. Secondly, growth efficiency of larger finishing pigs needs to be considered. In general, the rate of lean gain decreases after 80- to 90-kg body weight whereas the rate of fat gain increases linearly up to approximately 150 kg body weight (Shields, Jr., et al., 1983; Gu et al., 1992). This results in a substantially reduced lean vs. fat percentage in carcass composition with increasing live weight between 110 and 130 kg. The reciprocal lean vs. fat gain of the finishing pigs also causes a decreased growth rate and a reduced feed efficiency during the later finishing period. These disadvantages of larger finishing pigs thus limit the market weight and also necessitate the selection of lean-type breeding lines if the market weight is to be increased. Thirdly, total production cost per unit weight of pork also needs to be considered. In general, pork production cost decreases with increasing market weight to a certain point mainly due to savings in the piglet production cost.

The present review will focus on world trends of pig slaughter weight and expected changes in carcass and meat quality by increasing pig market weight followed by what needs to be carefully considered when increasing the market weight. Also included in this review are some methods of growth manipulation that are potentially useful when producing larger finishing pigs.

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WORLD TREND OF MARKET PIG WEIGHT

Pig market weights vary depending on regions and cultural backgrounds (Table 1). European countries including Denmark and the Netherlands who are traditionally strong pig producers market pigs at between 105- and 125-kg live body weight, while in the US pigs are

Table 1. Average pig market weight in selected countries (DARD, 2002; MLC, 2003; NASS, 2003)

Country	Market weight (kg)	Country	Market weight (kg)
Canada	115-125	Italy	150-160
China	90-105	Korea	100-110
Denmark	100-110	Netherlands	110-125
France	110-120	Spain	110
Germany	115-125	United Kingdom	95-100
Irish republic	95-100	USA	120-130

marketed at slightly higher weights between 120 and 130 kg (NASS, 2003). Pig market weight in Ireland Republic is near 95 kg, which is significantly lower than those in other European countries (MLC, 2003). This low market weight in Northern Ireland is due to traditional preference of small pigs by the processors to suit the bacon market even though it is now slightly increasing due to the changes in consumer preference for pork (DARD, 2002). Market weight in Italy, which is greater than 150 kg, is exceptionally high. This is mainly for producing cured meats that are demanded in large quantities in this country. Pig market weights in Asian countries are lower than those in Europe and North America. Market weights in Korea and China are averaging 100 to 110 kg and 90 to 105 kg, respectively. One of the reasons for the low market weight in China is because genetic lines used in this country are different from the high-lean types commonly used in the US and Europe. Pork producers in South America market pigs at about the same weight as in Europe.

Globalization in pork production demands standardization for the feasible export and import of fresh or processed pork. Improvement in genetic potential for lean gain allows the pork producers to keep pigs at higher body weights without excess fat deposition. Thus pig market weight favors to the higher body weights globally. Pig market weight in the US has increased by 12% during the last two decades (NASS, 2003). This continuous increase in pig market weight is attributable to several factors including genetic improvement for high lean gain, improved nutritional management to support high lean gain, novel feed additives such as carcass modifiers, etc. It is true that these factors contributed to higher financial benefits to pork producers by high-lean production with increased market weight. In the following sections, details of each factor related to heavy market weight will be discussed.

RELATIONSHIPS BETWEEN PIG SLAUGHTER WEIGHT AND CARCASS CHARACTERISTICS

Because of the significant change in the relative rate of fat and protein accretion during the finishing period of pigs, a substantial change in carcass composition occurs by increasing the slaughter weight of pigs. The weight of lean continues to increase in later stage of finishing period, but at a much slower rate than that of carcass fat gain. As a result, increasing the slaughter weight is expected to influence pig carcass characteristics and pork quality in addition to the general increase in carcass fat content.

Effects of market weight on carcass characteristics

On backfat thickness, loin eye area and intramuscular fat content: Some earlier studies reported a quadratic relationship between the backfat thickness and body weight (Noffsinger et al., 1959), suggesting an accelerated backfat deposition at heavier slaughter weight. However, others reported a linear relationship between the backfat thickness and body weight (Quijandria and Robinson, 1971). Recent studies with heavier slaughter weights (at around 130 kg) also support the linear relationship between the two variables (Gu et al., 1992; Cisneros et al., 1996; Latorre et al., 2004), indicating that increasing slaughter weight does not necessarily accelerate the rate of backfat deposition at least in a certain weight range. The slope of the linear relationship, which is variable depending on the location of backfat measurement in different studies, ranges from 1.4 mm to 2.4 mm per 10-kg weight gain (Gu et al., 1992; Cisneros et al., 1996; Latorre et al., 2004). Given that the increase in chemical body fat content has a curvilinear relationship to body weight (Shields, Jr., et al., 1983; Tess et al., 1986; Gu et al., 1992), fat present in other parts of the body appears to increase at a greater rate in later stage of growth than in earlier stage of growth.

Studies generally indicate that there exists a linear relationship between the loin eye area and the slaughter weight (Gu et al., 1992). Most studies reported that the lipid content of loin eye is not affected by slaughter weight at least up to 137 kg (Martin et al., 1980; Monin et al., 1999). However, the lipid content of loin eye probably increases if pigs are slaughtered at a much heavier weight (Cisneros et al., 1996).

On the yield of primal cuts: Since the values of different cuts of pig carcasses are different, information on the changes of the proportion of primal cuts at different slaughter weight can be important in analyzing pig production to optimize profit. With swine lines selected for high lean growth, Martin et al. (1980) reported that with the increase of market weight, the yield of untrimmed ham and shoulder decreased, whereas the yield of untrimmed belly and loin increased when expressed as a percentage of untrimmed side (Table 2). Cisneros et al. (1996) reported a similar result. Differences in response were noted between gilts and barrows (Martin et al., 1980), with significantly greater increase of belly and greater decrease of ham percentages in barrows than in gilts (Table 2). However,

Table 2. Lean cut percentage at various slaughter weight (Martin et al., 1980)

		Weight class (kg)						Regression coefficient	
		73	85	100	112	126	137	Gilts (G)	Barrows (B)
Shoulder	(G+B)	29.9	29.0	28.2	28.6	27.4	26.6	-0.047	-0.043
Belly	(G+B)	15.9	16.7	17.2	17.7	18.5	19.3	0.044	0.057*
Ham	(G+B)	25.5	25.4	25.1	24.4	24.6	24.4	-0.010	-0.030*
Front loin	(G+B)	9.64	9.49	9.92	10.1	10.5	10.8	0.020	0.021
Back loin	(G+B)	12.0	12.1	12.6	12.5	12.8	12.6	0.012	0.010

* p<0.05 between sexes.

when the yield of the trimmed wholesale cuts as a percentage of untrimmed side were studied in pig carcasses of various ranges of fatness and weight, the yields of the trimmed wholesale cuts remained constant within a given fatness class in the range of carcass weights between 60 and 100 kg (Martin et al., 1980). As expected, carcass fatness was a significant factor affecting the yield of trimmed wholesale cuts. Similarly, other studies found that genotype and sex are more significant factors affecting the yield of trimmed wholesale cuts rather than carcass weight (Fortin, 1980; Cisneros et al., 1996).

Effects of market weight on meat quality characteristics

On fresh meat quality: The effect of slaughter weight on meat color is not consistent: some reported a slight increase in darkness in longissimus dorsi (LD) muscle (Martin et al., 1980; Garcia-Macias, 1996; Leach et al., 1996), but others reported a slight increase in paleness in LD muscle (Cisneros et al., 1996). Cisneros et al. (1996) reported a reduction in firmness score and lower 24-h pH in association with increasing slaughter weight. As a result, they suggested that heavier pigs might be more prone to the development of the pale, soft and exudative (PSE) condition. They postulated that the increased incidence of PSE might be related to the decreased cooling rate of carcasses resulting from heavier carcass weights. However, others reported limited effects of the carcass weight on fresh meat qualities including drip loss (Martin et al., 1980; Piao et al., 2004). Differences among studies in the effect of slaughter weight on fresh meat quality are probably due to differences in genotype, sex and (or) pre- and post-slaughter handling (Gu et al., 1992; Friesen et al., 1994).

On cooked meat quality: The results regarding the effects of slaughter weight on cooked meat quality are not consistent among studies. This is probably due to the interactions among sex, genotype, nutrition and cooked meat quality. In some studies, tenderness decreased with the increase in slaughter weight (Leach et al., 1996; Cisneros et al., 1996; Unruh et al., 1996), but the magnitude was generally small. Most studies found that slaughter weight does not affect cooking loss, juiciness and off-flavor. It is interesting to note, however, that pigs slaughtered at a heavier weight have a lower percentage of polyunsaturated fatty acid (PUFA) in subcutaneous fat (Virgili et al., 2003). Cathepsins and aminopeptidase activities were also affected by the slaughter weight. While the effect of changes in fatty acid composition and protease activities on fresh and cooked meat quality is not well understood, Virgili et al. (2003) reported that the changes incurred by increasing slaughter weight positively affected the muscle and fat quality of dry-cured ham.

PRACTICAL CONSIDERATION FOR LARGER FINISHING PIGS

Economics

Cost for producing a given amount of pork reduces as pig market weight increases. This is mainly due to a decreased marginal production cost accompanying the increased market weight, because costs for sow management, nursery management and genetic premiums for sows per market pig decreases following an increase in market weight. In other words, as pig market weight increases, producers can maintain the total pork production with fewer numbers of sows. Altered growth rate and carcass composition following an increased market weight, of course, will affect the actual profit. Thus, genetic potential of pigs will affect the overall profit level. Meat and Livestock Commission estimated that the cost of increasing market weight of gilts from 100 to 120 kg would be $12.50 for feed (2.9 kg/d), utility, veterinary cost, etc. for 26 additional days to slaughter (MLC, 2003). However, reduced costs related to fewer numbers of sows exceed this additional cost for increasing the market weight. An additional 20-kg gain per pig can reduce 15% of the number of pigs to be slaughtered, implicating that the number of sows also can be reduced by 15%. Reduced number of sows will decrease the costs related to purchasing gilts and feeding sows during gestation and lactation, etc. The MLC (2003) estimated that the net profit would be about $0.90 per pig when the market weight increased from 100 to 120 kg (MLC, 2003). However, most of all, access to a secure market for heavier pigs is important to guarantee the profit.

Genetics

One of the key things which need to be considered prior to increasing the market weight is the selection of a proper genetic line. Fat gain accelerates and lean gain decelerates

Table 3. Effects of restricted feeding on growth performance of finishing pigs

Items	Chung et al. (1988)[1]					Lee et al. (2002)[2]		
	Unrestricted	Restricted from 50-kg BW		Restricted from 70-kg BW		Restricted from 60-kg BW		
		10%	20%	10%	20%	0%	20%	SE
Initial wt (kg)	N/A	N/A	N/A	N/A	N/A	59.5	58.9	1.3
Final wt (kg)	125.8	125.4	125.0	125.2	125.4	109.7	102.3	1.1
ADG (g)	745[a]	717[a]	660[b]	739[a]	700[b]	861[c]	704[d]	20
ADFI (kg)	2.56	2.47	2.17	2.48	2.40	3.14[c]	2.48[d]	0.09
Gain:feed	0.291	0.291	0.304	0.287	0.294	0.278	0.285	0.007
Backfat thickness (cm)	4.23[a]	4.07[a]	3.68[b]	4.09[a]	4.01[a]	1.85	1.72	0.07

[1] Data are means of a total of nine gilts and barrows.
[2] Data are means of 32 barrows. Backfat thickness was adjusted for 105-kg live weight.
N/A: not applicable. [a, b] $p<0.05$. [c, d] $p<0.01$.

when pigs reach their genetic potential. It is thus almost imperative to use lean-type pigs to increase the market weight. Fortunately, pigs have been genetically selected for a high lean gain and thus modern lean-type pigs possess higher efficiency for the lean gain than traditional ones.

Nutrition

Sound nutrition program should support the maximal lean gain potential of heavier pigs. Increasing market weight from 105- to 130-kg body weight requires some five more weeks to reach the target weight. However, as pigs get heavier or older, their fat gain accelerates and their lean gain decelerates (de Lange et al., 2001). As lean gain decreases along with increasing body weight, crude protein (amino acids) percentages of diets for heavier pigs should be adjusted at lower levels (Han et al., 1998; Cline and Richert, 2001). Provision of excess protein would not improve the lean gain but rather cause increased oxidation of absorbed dietary amino acids, increased fat gain, increased feed cost, and increased nitrogen excretion to manure. Thus more attention should be given to protein quality rather than quantity. Amino acid profiles in the diet should target an ideal ratio needed for the pig growth and maintenance (Baker et al., 1993). When this ratio ideally matches with pig's needs, lean gain will be most efficient. Readers are referred to papers published by Baker et al. (1993) and Boisen (2003) for the ideal dietary amino acid ratios suggested for growing and finishing pigs.

Facility and transportation

Increasing market weight also requires or may require modification of existing facilities. Size of pens should be recalculated for larger pigs according to space allowance for each pig (FASS, 1999). A pig with 105-kg body weight requires 0.78 m^2, whereas a pig with 130-kg body weight requires 0.90 m^2 (FASS, 1999). Drinker height should also be adjusted for the heavier pigs. Pen height also needs to be checked to prevent possible escape of pigs. Overall pig flow or management program needs to be modified to accommodate the pigs approximately five more weeks up to marketing. A close interaction with packers is also an essential element because processing facility should also be able to handle larger pigs. Total number of pigs produced will be reduced because of increased market weight. Even though larger pigs occupy more truck space per head, they require a less truck space per unit body weight than smaller pigs. Accordingly, cost of transportation of larger pigs to the packing plant is less than that of smaller ones. However, people responsible for transportation should well be aware of increased market weight not to exceed the maximum weight limit of the vehicle.

Animal health

With increasing body weight above 110 kg, risks of outbreaks of ileitis and mycoplasma pneumonia increase. Especially the former is primarily seen in the USA in 110-kg and larger finishing pigs. As such, a more thorough sanitation program is imperative to increase the market weigh beyond 110 kg.

MODULATION OF GROWTH OF LARGER FINISHING PIGS

With increasing slaughter weight, some finishing pigs may gain excess fat depending on their genetic backgrounds or nutritional programs for them. Following are methods presently available for reducing excess fat deposition of larger finishing pigs.

Restricted feeding

As has been aforementioned, pigs deposit fat at an increased rate with increasing body weight. Moreover, barrows gain more fat than gilts or boars resulting from a relatively excessive feed intake of the former (Field, 1971). In castrated males, gonadal steroid hormones that suppress feed intake in the male pig are not secreted. Obviously, unwanted fat deposition of larger finishing pigs can be reduced by limiting the feed intake, although weight gain also can be reduced by restricted feeding (Table 3; Leymaster and Mersmann, 1991). Feed efficiency is slightly improved (Leymaster and Mersmann, 1991) or unaffected (Table 3) by restricted feeding in barrows. Moreover, fat

Table 4. Effects of digestible energy level on growth performance of growing-finishing pigs

Items	Chung et al. (1981)[a]									Lee et al. (2002)[b]		
	3.1 (Mcal/kg)			3.3 (Mcal)			3.5 (Mcal)			2.95 (Mcal)	3.5 (Mcal)	SE
Initial wt (kg)	24.1			24.4			24.8			58.5	59.9	1.1
Days on feed	70	100	130	70	100	130	70	100	130	62.2	58.9	1.3
Final wt (kg)	76.8	97.2	116.5	81.8	104.2	121.2	85.6	108.6	128.0	104.9	107.1	1.1
ADG (kg)	0.75	0.73	0.71	0.82	0.80	0.74	0.87	0.83	0.79	0.76	0.81	0.02
ADFI (kg)	2.59	2.69	3.13	2.76	2.90	2.99	2.67	2.83	2.97	3.00*	2.62	0.09
Gain:feed	0.291	0.253	0.227	0.295	0.275	0.248	0.326	0.295	0.267	0.254**	0.309	0.07
Dressing (%)	74.4	76.3	78.2	76.3	76.7	78.0	77.0	77.3	78.6	71.3	73.3	0.5
Lean (%)	51.0	52.2	54.4	46.6	51.5	47.6	51.5	49.4	47.4	N/A	N/A	N/A
Backfat thickness (cm)	3.30	3.20	4.34	3.60	4.00	4.62	3.50	3.70	4.30	1.65**	1.97	0.08
Backfat (105 kg-adjusted)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.65**	1.92	0.07

[a] Data are means of two female and three male pigs. [b] Data are means of 32 barrows.
N/A: data are not available. * p<0.05 under the same study. ** p<0.01 under the same study.

Table 5. Effects of somatotropin on pig growth performance and carcass composition (NRC, 1994)

	Percentage difference from control
Average daily gain	+10 to +36% (Avg 15.2%)
Feed/gain ratio	-4 to -32% (Avg -21.1%)
Carcass fat	-18 to -68% (Avg backfat, -24.8%)
Carcass protein	+6 to +62% (Avg loin eye, +18.5%)

deposition or growth rate may also be modulated by the extent of feed restriction. This practice, however, requires additional labor for weighing feed in the manual-type feeding facility, which limits its usefulness in swine production. It also needs to be noted that an unavoidable competition for feed among pigs within a pen can result in inconsistent feed intakes and accordingly inconsistent growth rates of the animals regardless of the type of feeding facility, unless all the animals housed within a pen can get an equal access to the feed.

Use of a low-energy diet

The potentially excessive fat deposition of larger finishing pigs can also be reduced by feeding a low-energy diet (Table 4; Chang and Chung, 1985; Hale et al., 1986; Lee et al., 2000, 2002). Use of a low-energy diet, however, usually results in an increase in feed intake accompanied by a decrease in gain:feed. Growth rate also can be reduced by feeding a low-energy diet apparently resulting from a decreased energy intake or absorption. Feeding a low-energy diet has a practical advantage over restricted feeding, because extra labor or feeding facility necessary in the latter practice is not required in the former. However, use of a low-energy has following disadvantages, which limits its usefulness in the production of larger finishing pigs. First, total energy intake of pigs fed a low-energy diet is not reduced to the extent equal to that of the relatively reduced dietary energy level, because animals increase feed intake to compensate for the reduced energy content of the diet. The effect of the low-energy diet on energy intake or the excessive fat deposition thus can be only marginal or insignificant. Moreover, depending on the dietary energy level or environmental temperature, inconsistent responses to the low-energy diet have been reported. For instance, according to a study of Coffey et al. (1982), use of a low-energy diet (3.14 vs. 3.34 or 3.54 Mcal ME/kg for control diet) was effective for decreasing backfat thickness in summer, but not in winter.

Use of growth promotants

Somatotropin: Numerous studies during the 1980's have demonstrated that administration of recombinant porcine somatotropin (pST) improves feed efficiency, increases protein deposition and decrease lipid content of pork carcasses, resulting in a larger size of loin eye area and thinner backfat. Table 5 summaries the effects of pST on pig growth performance and carcass composition (NRC, 1994). It is apparent that pST dramatically increases carcass protein deposition and decreases carcass fat accretion. The magnitude of response is variable due to differences in experimental design including initial body weight, length of administration, sex, breed, dose and diet composition. Between the pigs in growing and finishing phases, pigs in finishing phase responded to the pST treatment with a greater magnitude than pigs in growing phase (NRC, 1994).

Regarding the effects of pST on pig meat quality, studies have generally indicated that pST treatment has no deleterious effects on various meat quality characteristics including 24-h pH, cooked meat shear force, panel tenderness, juiciness, aroma and overall acceptability (Thornton and Shorthose, 1989; Nieuwhof et al., 1991). However, sex and pST interaction was noted on cooked meat quality (D'Souza and Mullan, 2002): in gilts, no significant effect of pST treatment was observed on cooked meat quality (tenderness, juiciness and overall acceptability), but the cooked meat quality was deteriorated in barrows by the pST treatment. Minimal effect of pST treatment on muscle color was reported (Thornton and Shorthose, 1989; Nieuwhof et al., 1991). While many reported no effect of pST on marbling (Thornton and Shorthose, 1989; Nieuwhof et al., 1991), in some studies

Table 6. Growth performance, carcass composition, carcass and fresh meat characteristics of pST-treated pigs slaughtered at 105 or 127 kg (Johnston et al., 1993)

Parameters	Control		4 mg/d pST		Effect of pST
	59-105 kg	59-127 kg	59-105 kg	59-127 kg	
Growth performance					
ADG (kg)	0.83	0.83	0.96	1.01	S
ADFI (kg)	3.06	3.17	2.69	2.82	S
G/F	0.27	0.26	0.37	0.36	S
Carcass composition (%)					
Protein	15.5	14.5	17.8	18.1	S
Lipid	28.0	27.8	22.3	19.6	S
Moisture	50.2	47.8	55.5	55.3	S
Carcass characteristics					
Backfat (cm)	3.40	3.71	2.72	2.92	S
LD area (cm^2)	33.16	35.42	35.16	44.45	S
Hot carcass wt (kg)	77.25	92.58	75.84	88.50	S
Dressing (%)	73.9	74.6	72.6	71.8	S
Color, firmness and marbling score[a]					
Ham color	2.8	2.8	2.4	2.8	S, NS
Ham firmness	2.4	2.4	2.0	2.0	S
Ham marbling	1.6	2.0	1.0	1.6	S
Loin color	1.6	1.7	1.6	1.7	NS
Loin firmness	2.4	2.6	2.4	2.2	NS
Loin marbling	1.7	2.2	1.2	1.2	S

[a] The scale is as follows. Color; 1=extremely pale, 5=dark. Firmness; 1=soft and watery, 5=very firm and dry. Marbling; 1=trace, 5=abundant.

Table 7. Effects of beta-adrenergic agonists on pig growth performance and carcass composition (NRC, 1994)

Items	Swine	Ruminant
Average daily gain	+0 to 10%	+0 to 20%
Feed/gain ratio	+0 to 15%	+0 to 20%
Carcass fat	-5 to -25%	-15 to -40%
Carcass protein	+4 to 15%	+5 to +25

marbling was reduced with no change in the acceptability (Bechtel et al., 1988). It is likely that a high dose of pST administration deleteriously affects the carcass and meat quality by excessive reduction of fat accretion in the carcass (Beerman et al., 1988). According to the results by Mourot et al. (1992), polyunsaturated fatty acid composition in some intermuscular and subcutaneous adipose tissue was significantly increased by the pST treatment.

Johnston et al. (1993) examined the growth performance, carcass composition and fresh meat characteristics of pST-treated pigs slaughtered at 105 or 127 kg. Table 6 summarizes the results. As expected, pST treatment significantly improved growth performance and carcass composition, decreased backfat thickness and increased LD area regardless of the slaughter weight. In the pST-treated group, extending the finishing weight to 127 kg did not significantly change the growth performance, including average daily gain and feed efficiency. Carcass composition appeared to be slightly improved with an increase in protein content and a decrease in lipid content by extending the finishing period of pST-treated pigs. Backfat thickness was slightly increased by extending the finishing period of pST-treated pigs, but the pST-treated pigs had a lower backfat thickness at 127-kg slaughter weight than non-treated ones at 105-kg slaughter weight. Ham and loin marbling and firmness were decreased by pST treatment. In the pST-treated group, extending the finishing period slightly increased ham marbling, but not loin marbling. Ham and loin colors were not affected significantly by the pST treatment. The results indicate that using pST may allow pigs to be marketed at heavier weights while maintaining growth efficiency and carcass characteristics similar to those of lighter weight market pigs.

While the commercial use of somatotropin is approved in dairy cattle to increase the milk production in a lot of countries of the world, the commercial use of pST in swine production is not currently approved in most countries, including Europe and North America.

Beta-adrenergic agonists (BAA): Beta-adrenergic agonists are synthetic compounds that share similarity in structure and some physiological functions with naturally occurring catecholamines such as epinephrine, norepinephrine and dopamine. Studies from the early 1980's have shown that some BBAs including cimaterol, clenbuterol, L-644, 969 and ractopamine (RAC) promote skeletal muscle growth and reduce fat accretion in animal carcasses. Unlike the somatotropin, beta-agonists are orally active. Currently, ractopamine is approved for use in commercial pig production in the United States.

The extent of improvement in growth performance and carcass composition is smaller in pigs than in ruminants (Table 7). The magnitude of response appears to depend on factors including different BAAs, time of administration,

Table 8. Effects of ractopamine on fresh and cooked meat quality

	Study 1 (60-90 kg, 20 ppm)			Study 2 (64-100, 20 ppm)		
	Control (G/B)[a]	RAC (G/B)[a]	Effect	Control (mixed)[a]	RAC (mixed)[a]	Effect
Backfat						
10th rib (cm)	2.34/3.10	2.25/2.78	S	2.25	2.07	S
Last rib (cm)	2.94/2.97	2.97/3.44	NS			
LD area (cm^2)	30.3/29.1	31.9/31.4	NS	40.62	44.63	S
LD color						
L value	52.2/54.4	54.8/55.5	NS	46.32	45.48	NS
a value	5.8/6.7	5.8/5.2	NS	7.59	6.48	S
b value	4.4/5.8	5.3/4.6	NS	3.14	2.42	S
Drip loss (%)	6.59/5.83	7.43/5.92	NS	6.45	4.31	NS
Cooking loss (%)				25.73	24.36	NS
Shear force (kg)	4.81/3.39	4.17/4.00	NS	4.23	4.72	S

[a] G: gilts; B: barrows; mixed: barrows and gilts were mixed.
Studies 1 and 2 are from Dunshea et al. (1993) and Uttaro et al. (1993), respectively.
NS: non-significant; S: significant (p<0.05).

Table 9. Growth performance, carcass compostion, carcass and fresh meat characteristics of ractopamine-treated pigs slaughtered at 107 or 125 kg (Crome et al., 1996)

Parameters	Control		RAC		Effect of RAC
	68-107 kg	85-125 kg	68-107 kg	85-125 kg	
Growth performance					
ADG (kg)	0.81	1.84	0.93	0.93	S
ADFI (kg)	2.84	3.26	2.76	2.84	S
G/F	0.28	0.26	0.34	0.32	S
Carcass composition (%)					
Protein	15.5	14.5	17.8	18.1	S
Lipid	28.0	27.8	22.3	19.6	S
Moisture	50.2	47.8	55.5	55.3	S
Carcass characteristics					
Backfat (cm)	2.62	3.21	2.43	2.55	S
LD area (cm^2)	34.75	35.20	42.20	45.83	S
Hot carcass wt (kg)	76.82	91.02	82.17	95.57	S
Dressing (%)	76.8	77.6	78.6	79.0	S
Color, firmness and marbling score[a]					
Loin color	2.25	2.08	2.27	1.90	NS
Loin firmness	2.17	2.00	2.27	1.73	NS
Loin marbling	2.00	1.92	2.10	1.55	NS

[a] The scale is as follows. Color; 1=extremely pale, 3=extremely dark.
Firmness; 1=very soft, 3=very firm. Marbling; 1=very little marbling, 5=heavily marbled.
NS: non-significant; S: significant (p<0.05).

administration period, drug concentration, sex, genotype and nutrition. The effects of ractopamine (RAC) and other BAAs on average daily gain and feed intake have been inconsistent, but most studies have found improvement in gain:feed (see Dunshea et al., 1993). Much of the variability is probably due to the interactions between RAC, genotype, administration and nutritional regimen.

It is well demonstrated that the responsiveness of the animals to BAAs including RAC is attenuated with prolonged administration. The greatest response to RAC in pigs occurs during the first 14 days and declines slowly thereafter (reviewed by Schinckel et al., 2001). The temporal response of RAC appears to be due to receptor desensitization. When the density of beta-adrenergic receptor in skeletal muscle was measured at various times during a BAA treatment in rats (Kim et al., 1992), the number of receptor gradually decreased with the increase in treatment time. The reduction in receptor density preceded the attenuation of muscle weight gain, supporting the role of receptor desensitization on diminished response. Sainz et al. (1993) observed a decrease in beta-receptor density in skeletal muscles of RAC-fed pigs. As a way to sustain the capability of BAA to enhance skeletal muscle growth, increased amount of BAA was administered in rats during the desensitized period (Kim et al., 1995). The results demonstrated that increased concentration of BAA could partially restore the growth-promoting effect of BAA, suggesting a potential application of the stepwise application of RAC in swine production in order to extend the growth-promoting effect of RAC.

Table 10. Effects of implantation of estradiol with or without trenbolone acetate on growth performance of finishing pigs

Items	Estradiol-17β[a]		Estradiol-17β+trenbolone acetate[b]			
	Barrows		Barrows		Gilts	
	Control	Implanted	Control	Implanted	Control	Implanted
Initial wt (kg)	71.1±1.1	71.3±1.2	63.0±3.0	61.3±2.9	59.6±3.1	59.5±3.1
Final wt (kg)	108.2±1.0	106.6±1.1	100.8±1.1	99.7±1.2	96.6±1.3	100.1±1.6
ADG (kg)	0.83±0.03	0.77±0.02	0.855±0.035	0.822±0.025	0.705±0.037	0.830±0.036*
ADFI (kg)	2.71±0.06	2.40±0.05**	3.18±0.10	2.57±0.11**	2.66±0.11	2.96±0.14
Gain:feed	0.278±0.007	0.289±0.003	N/A	N/A	N/A	N/A
Feed/gain	N/A	N/A	3.75±0.16	3.12±0.09**	3.82±0.15	3.58±0.14
Backfat (cm)	2.17±0.08	1.80±0.09**	3.4±0.1	3.1±0.1	3.1±0.1	3.3±0.2

[a] Compudose® containing 24 mg estadiol-17β. Backfat thickness was adjusted for 110 kg live weight. Data are unpublished results of C. Y. Lee et al.
[b] Revalor H containing 20 mg estradiol-17β and 140 mg trenbolone acetate. Data are from De wilde and Lauwers (1984).
N/A, data are not available.
* p<0.05 within a given 'Control' vs. 'Implanted' under the same study and sex.
** p<0.01 within a given 'Control' vs. 'Implanted' under the same study and sex.

Table 8 shows the effects of RAC on fresh and cooked meat quality summarized from selected studies. Most trials reported an increase in the size of loin eye and a decrease in backfat thickness by RAC treatment. Most studies generally indicate that RAC has no significant effect on fresh pork quality including color, marbling and firmness (Dunshea et al., 1993; Uttaro et al., 1993; Stites et al., 1994; Crome et al., 1996). No significant effect of RAC on 24-h pH and drip loss was also reported. The effect of RAC on meat tenderness is not consistent: while many studies reported no significant effect on shear value or sensory tenderness (see Schinckel et al., 2001), some studies reported an increase in shear value after RAC treatment (Aalhus et al., 1990; Uttaro et al., 1993). Stites et al. (1994) suggested that the discrepancy was probably due to a difference in cooking temperature. The juiciness, pork-flavor and off-flavor intensity were not affected by the RAC treatment (Stites et al., 1994).

Crome et al. (1996) examined the growth performance, carcass composition and carcass and fresh meat characteristics of RAC-treated pigs slaughtered at 107 or 125 kg. Ractopamine (RAC) was fed for the last 40 kg of gain. The results are summarized in Table 9. Similar to the effect of pST, RAC-treatment significantly improved growth performance, decreased backfat thickness and increased LD area regardless of slaughter weight. Under RAC-treatment, extending the finishing period to 125 kg did not significantly change the growth performance including average daily gain and feed efficiency. Under RAC-treatment, backfat thickness was slightly increased by extending the finishing period, but the RAC-treated pigs had a lower backfat thickness at 125-kg slaughter weight than non-treated ones at 107-kg slaughter weight. Loin color, marbling and firmness were not affected by the RAC-treatment. The results indicate that RAC administration may allow pigs to be marketed at heavier weights while maintaining growth efficiency and carcass characteristics similar to those of lighter weight market pigs.

Anabolic steroids

Animal growth can also be modulated by use of anabolic steroids which include naturally occurring and synthetic estrogens, androgens and progestins. These agents, alone or in combination, have been used for a long time in beef cattle to improve the growth rate and feed efficiency. Of commercially available anabolic steroids, estradiol-17β, a fungal estrogen zeranol, testosterone and a synthetic androgen trenbolone acetate [androst-4,9(10),11 trien-3-one, 17β acetate; TBA] have been approved for use in cattle by Food and Drug Administration (FDA). Studies in cattle indicated that these steroids enhance nitrogen retention, with lesser effects on suppression of fat deposition, resulting in an increase in weight gain and feed efficiency (NRC, 1994). Effects of estrogen with or without androgen in pigs, however, are somewhat different from those in cattle. Whereas estrogen and androgen additively enhance growth rate without significantly affecting feed intake in castrated male cattle (Galbraith and Topps, 1981), effects of these anabolic steroids on these growth efficiency variables have not been consistent in finishing barrows for unknown reason(s). In early studies (Grandadam et al., 1975; van Weerden et al. 1976), Revalor implant containing estradiol plus TBA has been reported to enhance growth rate without affecting feed intake in finishing barrows. In later studies (de Wilde and Lauwers, 1984; Lee et al., 2002; Table 10), by contrast, both Revalor and an estradiol-17β implant Compudose suppressed feed intake resulting in a decrease in weight gain. As in cattle, however, backfat thickness was consistently reduced in response to Revalor or Compudose implant in these studies. Moreover, feed efficiency also has been reported to be improved even in the face of reduced feed intake following Revalor implantation in finishing barrows (Lee et al., 2002). These results are thus interpreted to suggest that, in contrast to the preferential effect of anabolic steroids on protein vs fat metabolism in cattle, the two metabolic effects of estrogen and androgen, i.e.

Table 11. Effects of carcass modifiers as feed additives

	Improvement		Source
	Growth rate	Lean gain	
Chromium	Yes	Yes	Page et al. (1992a,b)
	N/A	Yes	Page et al. (1993)
	Yes	N/A	Van Heugten and Spears (1997)
	Yes	Yes	Lindemann et al. (1993)
	No	Yes	Mooney and Cromwell (1997)
	No	Yes	Boleman et al. (1995)
Carnitine	Yes	Yes	Owen et al. (1996)
	No	Yes	Owen et al. (2001)
	Yes	Yes	Heo et al. (2000)
Betaine	No	Yes	Cromwell et al. (1999)
	Yes	No	Siljander-Rasi et al. (2003)
	No	Yes	Matthews et al. (2001)

N/A: data are not available.

enhancement of *N*-retention and suppression of fat deposition, in barrows (van Weerden et al., 1976) may be comparable in their magnitudes. Both estrogen and androgen are thus potentially useful growth modifiers in larger finishing pigs, although use of these steroid implants in the pig has not been approved yet. It needs to be noted, however, that exogenous androgen can induce masculinization of implanted barrows including mounting as a sexual behavior and an undesirable development of external genitalia (Lee et al., 2002).

Other growth modifiers

Lean gain can also potentially be further improved by using feed additives that affect nutrient metabolism. Some examples and their effects are shown in Table 11. However, detailed mechanisms of action will not be described in this text. Trivalent chromium has been shown to improve lean gain and reduce fat gain of finishing pigs. Commonly used chromium products are (tri-)picolinate, chromium yeast, etc. L-carnitine has also been shown to be effective in reducing fat gain (relative increase in lean gain). Betaine, chemical name of which is trimethylglycine, has also been shown to be effective in reducing body fat of pigs. Proper use of some of these feed additives may be beneficial in increasing market weight by suppressing excess fat gain.

CONCLUSIONS

Pig market weight has increased worldwide during the past few decades mainly thanks to an increased lean gain potential of finishing pigs. Although backfat thickness increases linearly with increasing market weight between 110 and 130 kg, ratios of the primal cuts and physicochemical characteristics of the pork are unaffected or insignificantly changed by an increased slaughter weight. Production cost per unit weight of pork is normally reduced by increasing the pig market weight, as long as lean-line pigs are available and packers and consumers accept larger finishing pigs.

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