Implications of Biotechnology: Meat Quality and Value

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Introduction

Biotechnology is the implementation of biological techniques to produce or modify products and to manipulate cell genome and function. Use of science for the improvement of muscle foods has involved natural selection of dominant traits, selection of preferred traits by crossbreeding, the use of endogenous and exogenous growth factors and ultimately gene manipulation and cloning to produce desirable changes in meat/carcass quality and yield.

Until recently, improvements in the quality of meat products that reached the market place were largely the result of postharvest technologies. Extensive postharvest efforts have been implemented to improve or to control the tenderness, flavor and juiciness. Tenderness, flavor, and juiciness are the sensory attributes that make meat products palatable and are often the attributes which consumers consider when making their selection to purchase meat products.

Consumers have not only been interested in the quality (palatability) but have been concerned with the nutritional value, safety and wholesomeness of the meat they consume. The public has been inundated with warnings about the health risks of consuming certain types or classes of foods (in particular fat profile). Consumers became more health and weight conscious in the '80s desiring fewer calories in their diet. In fact, the '80s was considered the decade of "nutrition." Consumers appear to prefer traditional and familiar foods they have always eaten. New technologies (e.g., biotechnology) appear to hold great promise for improving the quality and yield attributes of animal products.

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Development of recombinant DNA technology has enabled scientists to isolate, characterize, modify and amplify single genes, make copies of these isolated genes, and transfer copies into the genomes of livestock species. Such direct manipulation of genetic composition is referred to as "genetic engineering," and the term "transgenic animal" denotes an animal whose genome contains recombinant DNA.

A tremendous amount of variation in carcass components, such as muscle development, fat content distribution, tenderness and flavor, exists among and within breeds of each species. Animal breeders have successfully utilized selection from this genetic variation to improve farm animals for many years. Unfortunately, the quantitative genetic approach has yielded few clues regarding the fundamental genetic changes that accompanied the selection of animals for superior carcass attributes. Few single genes have been identified that have major effects on carcass composition. A national effort to map the genes of meat animals is underway. In cattle, the double-muscle gene is responsible for both muscle hyperplasia and hypertrophy and enhanced lean tissue deposition. In sheep, the callipyge mutated gene is responsible for muscle hypertrophy and enhanced lean tissue accretion. In pigs, the halothane sensitivity gene (Hal) is associated with increased yield of lean meat and porcine stress syndrome. Pigs homozygous for "Hal" are susceptible to stress and have a high incidence of pale-soft-exudative (PSE) meat. These genes offer considerable potential for investigation of carcass composition in meat producing animals. However, except for the Hal gene, which has been identified as a single mutation in the ryanidine receptor gene, the specific product of each gene remains to be identified.

Swine with Growth-Related Transgenes

Transgenic Pigs Expressing Somatotropin Genes

A number of transgenic pigs containing various somatotropin (ST) transgenes have been raised (Pursel and Rexroad, 1993). Production of excess ST in transgenic animals caused multiple physiological affects, but did not result in "giantism" as was expected based on the earlier production of "super" mice as described by Palmiter et al., 1982. However, transgenic pigs that have excess ST levels exhibited numerous unique carcass traits. Reduced carcass fat, alteration of muscle fiber profiles, thickening of the skin, enlargement of bones, and redistribution of major carcass components oc-

TABLE 1. Comparison of total carcass and lean tissue lipid and cholesterol content and longissimus muscle characteristics for transgenic (T) and control pigs.

Item	T-control	T-bST	T-oST	SEM	Significance, T
Carcass					
Total lipid, g/100g	27.00	4.49	4.82	1.7	*
Cholesterol, mg/100g	68.71	77.18	67.87	2.5	*
Lean					
Total lipid, g/100g	2.89	1.38	.96	.5	*
Cholesterol, mg/100g	48.64	55.58	49.33	1.5	NS
Longissimus muscle					
10^{th} rib backfat, mm	24.8	2.2	2.4	1.5	*
Area, cm^2	33.91	32.37	33.17	3.1	NS
Shear force, kg/1.3 cm	3.32	3.46	3.88	.5	NS
Fiber type, %					
SO	12.4	7.2	13.3	3.9	*
FOG	20.0	24.2	22.9	2.4	*
FG	67.6	68.6	63.8	2.8	NS
Fiber area, μm^2					
SO	3053	2694	3166	226	*
FOG	3669	1979	2180	225	*
FG	4359	2749	4356	407	*
Giant fiber					
Number	0	0	0		
Area, μm^2					

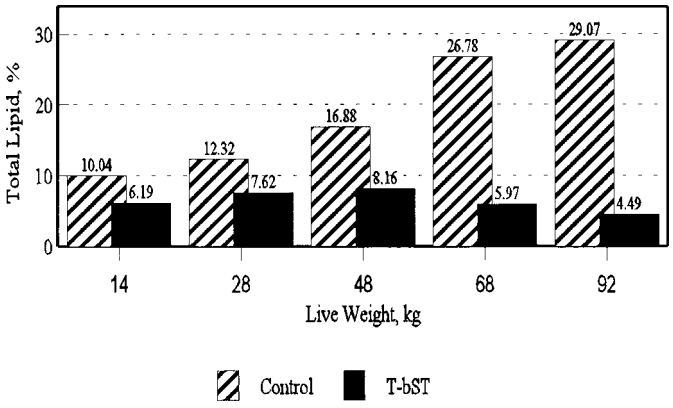
[a]Wet weight basis.
[b]T-control = control boars for transgenics; T-bST = transgenics (boars) with bovine somatotropin gene; T-oST = transgenics (boars) with ovine somatotropin gene; average live wt. at slaughter 93 kg.
[c]NS = not significant (P > .05); * = P < 05.
Solomon et al. (1991b; 1994).

curred in transgenic pigs. Some of these effects are similar to those observed after daily injection of porcine ST , while others are considerably different (Table 1). Possibly, these differences are the consequence of continual presence of excess ST in the transgenics while injections of pST provide a daily pulse of excess ST.

Carcass composition and meat tenderness. The first transgenic animals for which carcass and meat quality was evaluated were the transgenic (T) pigs expressing a bovine ST (bST) gene at the USDA-ARS-Beltsville, MD research facility. Carcass fat was dramatically reduced (Figure 1) in transgenic pigs that expressed a bST transgene at five different live weights (Solomon et al., 1994). This difference in fat became greater among transgenic and non-transgenic littermates as the pigs approached market weight. As body weight increased beyond 48 kg live weight in T-bST pigs, carcass fat dramatically decreased (by as much as 88%).

Comparing T-bST and T-oST (ovine somatotropin gene) with littermate control pigs at 93 kg body weight as much as a 83% (T-bST) and 82% (T-oST) reduction, respectively, was observed for total carcass lipid (Table 1; Figure 2). A similar pattern in lipid content reduction was observed for the lean tissue from T-bST and T-oST pigs compared to control pigs. Carcass tissue from T-bST pigs had 12% more cholesterol content than controls with no difference found for T-oST pigs. The lean tissue from these pigs followed a similar pattern (as the carcass) for cholesterol content. Carcass and lean tissue

FIGURE 1.



Carcass lipid accretion in control and transgenic pigs from 14 to 92 kg.

FIGURE 2.

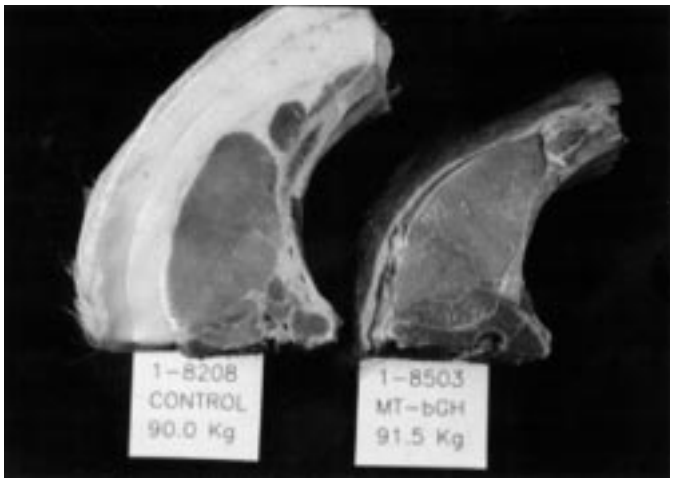


Illustration of rib sections from control (left) and transgenic (T-bST= right) showing the differences in subcutaneous fat and lean tissue.

from transgenic pigs had near the optimum ratio of 1:1:1 for SFA:MUFA:PUFA as recommended (NRC, 1988). Some underlying health-related problems were observed in these transgenic pigs. These included: ulcers, pneumonia, arthritis, cardiomegaly, dermatitis, and renal disease.

When carcasses were separated into the four primal (pork) cuts (Table 2), the hams of the bST transgenic pigs were significantly larger and the loins were significantly smaller than those of the sibling control pigs (Solomon and Pursel, 1994). The intramuscular fat for each primal cut (lean portion only) showed large differences between bST transgenic pigs and the controls (Table 3). Table 4 illustrates the dollar value for the individual cuts using the weight of each primal cut and price/pound (March 2000, USDA National Carlot Pork Report) for control and T-bST pigs described in Tables 2 & 3. Also included in Table 4 are the quantities of separable lean and fat for each cut. The dollar value for T-carcasses is $89 compared to $91 for the control carcasses. However, when taking into account the $89 for the T-carcasses, these carcasses would consist of 97 pounds of edible lean and 26 pounds of waste fat plus connective tissue compared to 78 pounds of edible lean with 45 pounds of waste fat for the $91 value for control carcasses. The monetary worth strongly favors the carcasses from the T-pigs. Thus, the dramatic decrease in waste fat which concomitantly results in an increase in lean tissue would have major economic impact on the meat (pork) industry. In spite of the dramatic reductions of fat throughout the carcasses of transgenic pigs (T-bST and T-oST) evaluation of tenderness by shear-force determination indicated there were no significant differences between the transgenic and control pigs for the longissimus (loin) muscle shear values (Table 1). All samples were below 3.88 kg/1.3 cm shear force suggesting there was no problem in meat tenderness.

TABLE 2. Primal cuts as a percentage of the carcass[a].

Component	Control	T-bST	SEM	Significance, P<
Primal cuts				
Shoulder	26.8	28.3	.7	NS[c]
Loin	28.7	24.8	.9	.01
Ham	25.4	28.5	.7	.01
Belly	19.0	18.7	1.3	NS

[a]Average live weight at slaughter 93 kg.
[b]kg/1.27 cm core
[c]NS = nonsignificant.
Solomon and Pursel (1994).

TABLE 3. Separable components and intramuscular lipid within each untrimmed primal cut.

Components	Control	T-bST[a]	SEM	Significance, P<
Separable lean, %				
Shoulder	56.1	65.9	1.4	.01
Loin	49.6	60.1	2.4	.01
Ham	62.0	74.5	1.5	.01
Belly	48.3	61.7	3.0	.01
Separable fat, %				
Shoulder	29.6	16.5	1.8	.01
Loin	31.1	17.2	2.8	.01
Ham	27.1	13.7	1.9	.01
Belly	38.1	23.7	3.8	.01
Separable bone, %				
Shoulder	14.3	17.6	.9	.01
Loin	19.3	22.7	1.4	.05
Ham	10.9	13.1	.6	.01
Belly	13.6	14.6	1.8	NS[b]
Intramuscular lipid, %				
Shoulder	11.7	2.6	1.8	.01
Loin	10.1	1.6	.8	.01
Ham	5.7	1.6	1.3	.01
Belly	16.7	3.1	2.6	.01

[a]Average live weight at slaughter 93 kg.
[b]NS = nonsignificant.
Solomon and Pursel (1994).

Muscle morphology. Morphological evaluation (Table 1) of bST transgenic-pig skeletal muscles revealed bST T-pigs had fewer SO fibers and more FOG fibers than control pigs. The population of FG was similar between the transgenic and controls; however, the classical porcine fiber arrangement with SO fibers grouped in clusters surrounded by FOG and FG fibers was less evident (Figure 3) in the transgenic muscle (Solomon et al., 1991). Morphological fiber profiles for T-bST pigs resembled that of bovine muscle rather than porcine muscle (Figure 2). Hypertrophied (giant) fibers (Figure 4), that have been identified in pST-injected pigs (Solomon et al., 1988, 1989, 1990,1994; Ono et al., 1995), were not observed in

TABLE 4. Weights of primal cut, price/pound, dollar values and quantities of lean and fat for control and TbST carcasses.

	Weight of cut, lb			Value, $		Lean, lb		Fat, lb	
Cut	Control	T-bST	Price/lb[a]	Control	T-bST	Control	T-bST	Control	T-bST
Ham	36	42	$.51	18.36	21.42	22	32	10	6
Loin	42	36	$.86	36.12	30.96	21	22	13	6
Shoulder	39	40	$.34	13.26	13.60	22	26	12	7
Belly	27	27	$.86	23.22	23.22	13	17	10	7
Total	144	145	$2.57	90.96	89.20	78	97	45	26

[a]Prices from March 2000 USDA National Carlot Pork Report.

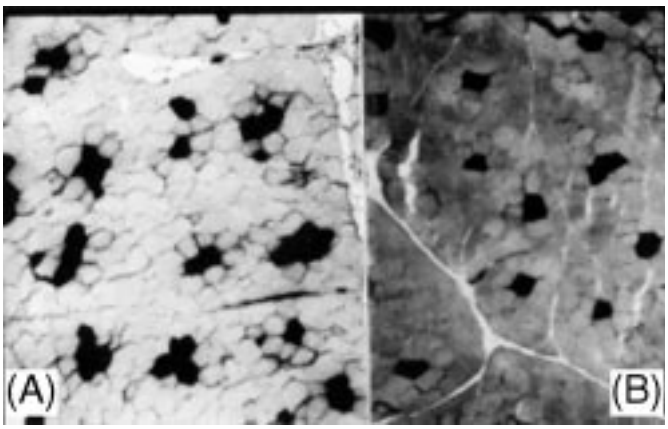
bST transgenic pigs (Table 1). The shift in the percentage of SO fibers to FOG fibers in the T-bST pigs has not been identified in pigs that have received daily injections of pST.

Muscle fiber growth patterns in bST and oST transgenic pigs differ markedly from that seen in muscle of pigs injected daily with pST. All three fiber types are enlarged in pST-treated pigs whereas in bST transgenic pigs, only SO fibers appear to hypertrophy during growth compared to controls. In the T-oST pigs both the SO and FG fibers hypertrophy similar to controls during growth, whereas the FOG fibers remain much smaller than controls (Table 3). No giant fibers were observed in muscle tissue from bST transgenic pigs. Even though ST transgenic pigs were highly stress sensitive, there were no signs of pale, soft, exudative muscle/meat tissue.

Transgenic Pigs Expressing cSKI Gene

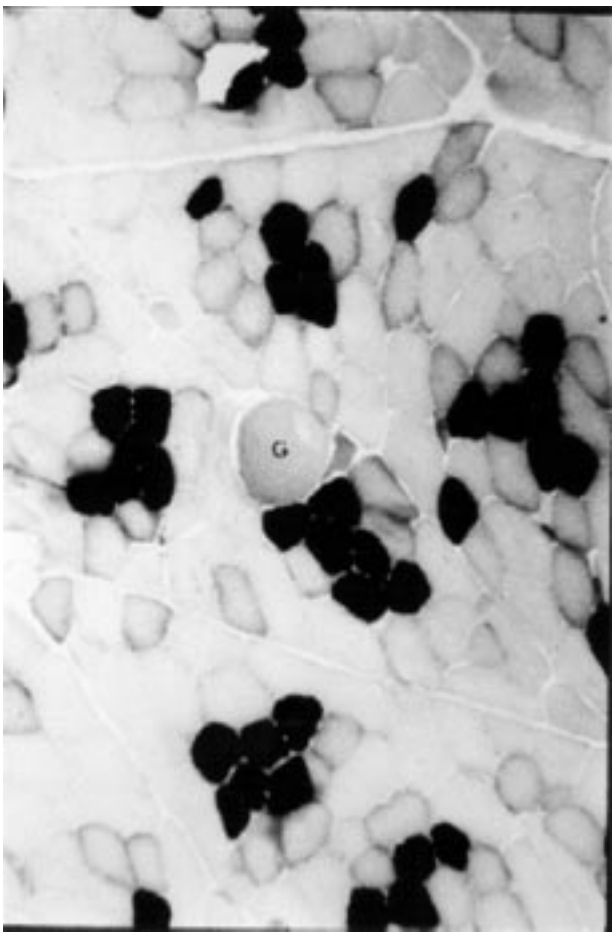
The cSKI transgene has also been investigated for potential stimulation of muscle development in swine and cattle. Initially, Sutrave et al. (1990) transferred the cSKI transgene into mice where expression was found to produce extensive hypertrophy of skeletal muscles and reduced body fat. A single transgenic calf was produced that exhibited considerable muscle hypertrophy at about two months of age, which was followed by progressive muscle degeneration over several weeks to the point where euthanasia was necessary (Bowen et al., 1994). Expression of the cSKI transgene in swine resulted in a wide range of phenotypes among animals (Pursel et al., 1992). Five transgenic pigs exhibited varying degrees

FIGURE 3.



Cross-section of longissimus muscle illustrating the fiber type profiles for control (A) and transgenic (T-bST= B) pigs.

FIGURE 4.



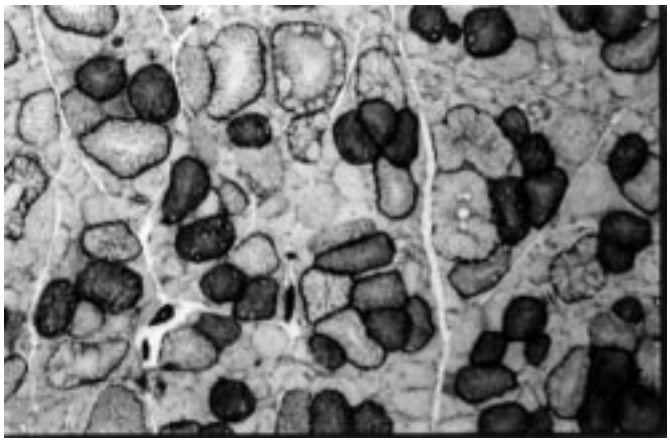
Cross-section of longissimus muscle illustrating the fiber type profile for pST treated pigs and the G denotes "giant" fiber.

of muscular hypertrophy, while five other cSKI transgenic pigs exhibited muscular atonia and weakness in both the front and rear legs. Skeletal muscles from these pigs had high levels of cSKI mRNA, while cardiac muscle contained low levels, and no transgene mRNA was detected in any other tissue.

Carcass composition and meat tenderness. Carcass composition did not exhibit any noticeable differences between cSKI transgenic pigs compared to controls (Table 5). Nor were there any major differences in shear force tenderness between the cSKI transgenic pigs and controls. When the cSKI transgene was transmitted to subsequent generations none of the transgenic pigs developed muscle hypertrophy without also simultaneously exhibiting considerable myofiber degeneration. Consequently, no line of cSKI transgenic pigs has been developed with commercial potential.

Muscle morphology. Histological examination of skeletal muscles from the cSKI myopathic pigs revealed that muscle fibers contained large vacuoles and exhibited degenerative pathological characteristics for individual muscle fibers from various muscles of the carcass (Figure 5).

FIGURE 5.



Cross-section of longissimus muscle illustrating the fiber type profile for cSKI transgenic pigs.

Transgenic Pigs Expressing IGF-I Gene

Although somatotropin is considered the primary growth-promoting hormone in mammals, many of its effects are thought to be mediated (Zapf et al., 1984) by insulin-like growth factor-I (IGF-I). Coleman et al. (1995) reported on a myogenic vector expression of insulin-like growth factor I that stimulated muscle cell differentiation and myofiber hypertrophy in transgenic mice. The fusion of a gene composed of avian skeletal alpha-actin regulatory sequence to direct expression of an IGF-I gene directed high levels of expression specifically to striated muscle in transgenic mice and elicited myofiber hypertrophy.

Carcass composition and meat tenderness. In a series of studies founder T-pigs were produced with a fusion gene composed of avian skeletal alpha-actin regulatory sequences and the cDNA encoding IGF-I. Founder transgenic boars were mated to non-transgenic gilts to produce G1 transgenic and sibling control progeny. The underlying rationale was to initiate a paracrine response with IGF-I to enhance muscle development without altering the general physiology that might occur from an endocrine response. Neither daily gain nor feed efficiency differed for T- or control pigs in the different studies. In marked contrast to previous experiences with somatotropin transgenic pigs, definitive phenotypes for the IGF-I T-pigs were not detected, and no gross abnormalities, pathologies, or health-related problems were encountered. Dual-energy x-ray absorptiometry (DXA) was used to estimate (non-invasive technology) total carcass fat, lean, and bone. Physical measurements of the carcasses were taken. In some of the studies one side of each carcass was used for determination of individual muscle weights.

In the first study (Pursel et al., 1998), pigs (females and intact males) were harvested at 120 kg body weight (Table 6). In comparison to sibling controls, T-females (gilts) and T-intact males (boars) had less carcass fat (9.9 and 8.1%, respectively), and more lean (8.6 and 3.6%, respectively). Loin eye areas were larger (38 vs 32 cm^2, gilts; 38 vs 35 cm^2, boars) and average backfat thickness less (31.1 vs 33.7 mm, gilts; 25.8 vs 29.2 mm, boars) in T-pigs than control pigs. Shear force values for control pigs was 7.7 kg and 7.3 kg for IGF-I T-pigs with no significant differences between boars or gilts. One consideration for the relatively small response in lean tissue accretion in male T-pigs was that intact males were used rather than castrated males. Therefore, a second study (Pursel et al., 1999a,b; Eastridge et al., 1999) was performed using transgenic females and barrows comparing them to sibling controls (Table 7). T-gilts and barrows had less carcass fat (15 and 19%), less average backfat thickness (14 and 18%), more carcass lean tissue (9 and 12%), and larger loin-eye areas (36 and 29%), respectively. Five selected muscles that were removed from one side of the carcass were significantly heavier for T-pigs than controls. For example the rectus femoris was 20% heavier, the psoas major 19%, the biceps femoris 13%, the triceps brachii 11%, and the semitendinosus 8% heavier in T-pigs compared to controls. Enhancing IGF-I specifically in skeletal muscle had a positive effect on carcass composition of swine and using barrows instead of boars illustrated

TABLE 5. Characteristics of cSKI transgenic pigs compared to control pigs.

	Control		cSKI	
Trait	**Barrow**	**Gilt**	**Barrow**	**Gilt**
Number of pigs	17	12	26	15
Lipids, %				
Carcass	26.81	29.79	23.39	27.82
Lean	2.23	2.12	3.25	4.65
Shear force, kg/1.3 cm	5.72	6.48	6.64	7.07

TABLE 6. Comparison of control and IGF-I transgene in boars and gilts.

	Control		IGF-I transgenic		P-Value[a]		
Trait	**Boar**	**Gilt**	**Boar**	**Gilt**	**T[b]**	**S**	**T×S**
Number	19	14	18	19			
Average backfat, mm	29.2	33.7	25.8	31.1	**	**	NS
Loin eye area, cm^2	35	32	38	38	**	*	**
Carcass composition (estimated)							
Fat, %	27.5	33.0	25.6	29.7	**	**	**
Lean, %	60.3	54.2	62.2	58.2	**	**	**
Bone, %	12.2	12.8	12.2	12.1	NS	NS	NS
Longissimus muscle							
Cooking yield, %	65.6	65.8	66.2	67.2	NS	NS	NS
Shear-force, kg/1.3 cm	7.6	7.8	7.2	7.3	NS	NS	NS
Semitendinosus muscle weight, g	433.9	423.4	460.7	431.4	NS	NS	NS
Longissimus muscle fiber types[c], %							
SO	11.0	10.6	10.5	10.5	NS	NS	NS
FOG	18.9	16.3	16.6	15.7	NS	*	NS
FG	70.2	73.0	72.8	73.8	NS	NS	NS
Longissimus muscle fiber area, µm							
SO	2763	2443	3161	3170	NS	NS	NS
FOG	2500	2097	2722	2447	*	NS	NS
FG	4147	3920	4238	4212	NS	NS	NS

[a]*P < .05; ** P<.01; NS = not significant.
[b]T = transgenic; S = sex; T × S = interaction.
[c]Muscle fiber types were: SO = slow-twitch oxidative; FOG = fast-twitch oxidative/glycolytic; FG = fast-twitch glycolytic.
Bee et al. (1997a,b) and Pursel et al. (1998).

TABLE 7. Comparison of control and IGF-I transgene in barrows and gilts.

	Control		IGF-I transgenic		P-value[a]		
Trait	**Barrow**	**Gilt**	**Barrow**	**Gilt**	**T[b]**	**S**	**T×S**
Number	19	7	7	7			
Live weight, kg	122.5	123.1	120.4	119.9	*	NS	NS
Carcass side weight, kg	47.5	47.0	46.5	45.8	*	NS	NS
Loin eye area, cm^2	31.1	32.0	37.9	41.4	**	NS	NS
Average backfat, mm	35.8	31.8	29.4	27.7	**	NS	NS
Carcass lipids, %	33.4	31.7	27.8	25.7	**	NS	NS
Longissimus muscle							
Cooking yield, %	73.7	74.3	73.5	73.0	NS	NS	NS
Shear force, kg/1.3 cm	6.1	6.5	6.5	6.2	NS	NS	NS
Muscle weights, g[c]							
BF	1569	1681	1793	1745	**	NS	*
ST	485	510	533	498	.059	NS	.057
RF	469	489	549	574	**	NS	NS
PM	572	555	653	659	**	NS	NS
TB	776	787	837	854	*	NS	NS

[a]*P < .05; **P < .01; NS = not significant.
[b]T = transgenic; S = sex; T × S = interaction.
[c]Muscles were dissected from the carcass at slaughter and trimmed of all external fat before weighing. BF= biceps femoris; ST = semitendinosus; RF = rectus femoris; PM = psoas major and minor; TB = triceps brachii.
Eastridge et al. (1999) and Pursel et al. (1999a).

the effects. Shear force values for control pigs was 6.52 kg and 6.42 kg for IGF-I T-pigs with no significant differences between barrows or gilts (Eastridge et al., 1999).

Pursel et al. (1999c) evaluated the IGF-I transgene in pigs from two breeding lines that were used in their 1999a,b studies. Eight muscles were excised from one side of each carcass and seven out of the eight muscles were heavier in T-pigs than in controls. For example, the biceps femoris was 13% heavier, the semitendinosus 7% heavier, the rectus femoris 18% heavier, the psoas major 14% heavier, the triceps brachii 13% heavier, the quadriceps group 15% heavier, and the obliquus externus abdominis 19% heavier in T-pigs compared to controls. The supra spinatus muscle was the only muscle evaluated that was not affected by the inclusion of the IGF-I transgene. IGF-I barrows had 10% less carcass fat and IGF-I gilts had 23% less carcass fat. Meat tenderness evaluated using shear force determination was 1 kg lower in IGF-I barrows compared to controls (5.3 vs 6.3 kg) but no difference was found for gilts (6.7 vs 6.3 kg, IGF-I vs control).

Muscle morphology. The IGF-I transgene pigs (boars and gilts) from the Pursel et al. (1998) study and reported by Bee et al. (1997a,b) exhibited an increase in FG fibers and a decrease in FOG fibers (Table 6). All fibers increased in size with the hypertrophic response being greatest for the SO fibers followed by the FOG and FG fibers. Bee et al. (1997b) also reported that IGF-I transgene expression altered the distribution of slow and fast isomyosin forms. The IGF-I transgene pigs (barrow and gilts) reported by Eastridge et al. (1999) showed that there was no difference in fiber type percentages between the T-pigs and controls (Table 8) but that the increase in muscle mass was due to an increase in muscle fiber area (hypertrophy) for all three fiber types.

Bovine and Ovine with Growth-Related Transgenes

To date, transgenic cattle produced by microinjection of DNA into pronuclei is inefficient and extremely costly, in large part due to the cost of maintaining numerous pregnancies to term. Numerous pregnancies result in non-transgenic progeny. The success rate in both bovine and ovine is significantly less than that for swine. No carcass data are available for transgenic bovine or ovine. The cloning technology described by Wilmut in 1997 has introduced the successful cloning of cattle and sheep, however, these research programs have not looked at carcass data as well. To date the effects of cloning farm animals on carcass and meat composition and quality have not been investigated.

Conclusions

Potential for manipulation of growth and composition of farm animals has never been greater than at present due to the wide array of strategies for altering the balance between lean and fat. Recent discoveries of repartitioning effects of somatotropin, select ß-adrenergic agonists, as well as the va-

TABLE 8. Muscle fiber characteristics in control and IGF-I transgene barrows and gilts.

	Control		IGF-I transgenic		P-Value[a]		
Trait	**Barrow**	**Gilt**	**Barrow**	**Gilt**	**T[b]**	**S**	**T×S**
Number	6	6	7	7			
Longissimus fiber distribution[c]							
SO, %	15.3	12.7	13.9	13.6	NS	NS	NS
FOG, %	15.1	16.7	15.8	16.1	NS	NS	NS
FG,%	69.6	70.6	70.3	70.3	NS	NS	NS
Longissimus fiber area, µm^2							
SO	3086	3354	3424	4166	**	**	NS
FOG	3318	3241	3811	3964	**	NS	NS
FG	6500	6036	6756	7387	**	NS	*
RF[d] fiber distribution							
SO, %	9.3	7.6	6.6	8.9	NS	NS	**
FOG, %	44.9	40.3	38.5	43.2	NS	NS	**
FG,%	45.7	52.0	55.0	47.9	NS	NS	**
RF fiber area, µm^2							
SO	2728	3306	4292	4444	**	NS	NS
FOG	2571	3315	3587	3640	**	*	*
FG	4817	5409	5876	7230	**	**	NS

[a]*P < .05; **P < .01; NS = not significant.
[b]T = transgenic; S = sex; T × S = interaction.
[c]Fiber types are SO = slow-twitch oxidative; FOG = fast-twitch oxidative/glycolytic; FG = fast-twitch glycolytic.
[d]RF = rectus femoris muscle.
Eastridge et al. (1999).

TABLE 9. Comparison of control and IGF-I transgene in barrows and gilts.

	Control		IGF-I Transgenic		P- Value[a]		
Trait	**Barrow**	**Gilt**	**Barrow**	**Gilt**	**T[b]**	**S**	**T*S**
Number	8	11	10	10			
Live weight, kg	118.8	120.2	118.1	120.1	NS	NS	NS
Carcass side weight, kg	47.3	47.0	46.9	46.5	NS	NS	NS
Carcass lipid, %	29.5	28.9	26.6	22.2	**	*	NS
Longissimus muscle							
Cooking yield, %	75.3	73.8	76.2	76.4	**	NS	NS
Shear force, kg/1.3 cm	6.3	6.4	5.3	6.7	NS	**	*
Muscle weights, g[c]							
BF	1598	1623	1740	1885	**	NS	NS
ST	489	479	484	543	NS	NS	NS
RF	451	474	494	595	**	**	*
PM	572	581	628	685	**	NS	NS
TB	757	819	810	964	**	**	NS
SS	111	99	93	110	NS	NS	NS
Quadriceps	1176	1195	1235	1487	**	**	**
OEA	488	519	601	596	*	NS	NS

[a]*P < .05; **P < .01.

[b]T = transgenic; S = sex; T × S = interaction.

[c]Muscles were: BF = biceps femoris; ST = semitendinosus; RF = rectus femoris; PM = psoas major and minor; TB = triceps brachii; SS = superspinatus; Quad = quadriceps group; OEA = obliquis externus abdominous.

Pursel et al. (1999c).

riety of growth-promoting agents, and gene manipulation techniques offer a wide range of strategies. Although progress is being made, much more needs to be accomplished. Eating quality and safety must not be sacrificed as leaner animals are developed. We are still a long way from fully understanding the integrated mechanisms resulting from manipulation of growth and carcass composition and possible effects on meat quality (either positive or negative) as a result of the biotechnological techniques described in this paper.

References

Bee, G., M.B. Solomon, and V.G. Pursel. 1997a. Expression of an IGF-I transgene on skeletal muscle morphology in swine. Exp. Biol. (FASEB) 11:A415, #2405.

Bee, G., M.B. Solomon, and V. G. Pursel. 1997b. Growth response of muscle fibers to the expression of an IGF-I transgene targeting skeletal muscle in pigs. Proceedings 50th Annual Reciprocal Meat Conference, p. 165.

Bowen, R.A., M.L. Reed, A. Schnieke, G.E. Seidel, Jr., A. Stacey, and W.K. Thomas. 1994. Transgenic cattle resulting from biopsied embryos: Expression of c-sKI in a transgenic calf. Biology Reproduction 50:664–668.

Coleman, M.E., F. DeMayo, K.C. Yin, H.M. Lee, R. Geske, and C. Montgomery. 1995. Myogenic vector expression of insulin-like growth factor I stimulates muscle cell differentiation and myofiber hypertrophy in transgenic mice. J. Biol. Chem. 270:12109–12116.

Eastridge, J.S., M.B. Solomon, V.G. Pursel, and A.D. Mitchell. 1999. Response of porcine skeletal muscle enhanced by an IGF-I transgene. Proceedings of 52nd Annual Reciprocal Meat Conference. p 125.

National Research Council. Designing Foods. 1988. Animal Product Options in the Market Place. National Academy Press, Washington, DC.

Ono, Y., M.B. Solomon, C.M. Evock-Clover, N.C. Steele, and K. Maruyama. 1995. Effects of porcine somatotropin administration on porcine muscles located within different regions of the body. J. Anim. Sci. 73:2282–2288.

Palmiter, R.D., R.L. Brinster, R.E. Hammer, M.E. Trumbauer, M.G. Rosenfeld, N.C. Birnberg, and R.M. Evans. 1982. Dramatic growth of mice that develop from eggs microinjected with metallothionein-growth hormone fusion genes. Nature 300:611.

Pursel, V.G., G. Bee, K.D. Wells, A.D. Mitchell, T. Elsasser, R.J. Wall, M.B. Solomon, M.E. Coleman, and R.J. Schwartz. 1998. Expression of IGF-I in skeletal muscle of transgenic swine. J. Anim. Sci. 76(Suppl. 1):130.

Pursel, V.G., A.D. Mitchell, J.S. Eastridge, K.D. Wells, R.J. Wall, M.B. Solomon, M.E. Coleman, and R.J. Schwartz. 1999c. Carcass composition resulting from cross of an IGF-I transgenic boar with two lines of hybrid swine. Presented at: Transgenic Animals Conference, August 15–19, Tahoe City, CA.

Pursel, V.G., A.D. Mitchell, K.D. Wells, R.J. Wall, M.E. Coleman, and R.J. Schwartz. 1999a. Enhanced carcass composition in IGF-I transgenic barrows and gilts. J. Anim. Sci. 77(Suppl. 1):157.

Pursel, V.G., C.A. Pinkert, K.F. Miller, D.J. Bolt, R.G. Campbell, R.D. Palmiter, R.L. Brinster, and R.E. Hammer. 1989. Genetic engineering of livestock. Science (Washington, DC) 244:1281–1288.

Pursel, V.G. and C.E. Rexroad, Jr. 1993. Status of research with transgenic farm animals. J. Anim. Sci. 71(Suppl. 3):10–19.

Pursel, V.G., P. Sutrave, R.J. Wall, A.M. Kelly, and S.H. Hughes. 1992. Transfer of c-SKI gene into swine to enhance muscle development. Theriogenology 37:278.

Pursel, V.G., R.J. Wall, A.D. Mitchell, T.H. Elsasser, M.B. Solomon, M.E. Coleman, F. DeMayo, and R.J. Schwartz. 1999b. Expression of insulin-like growth factor-I in skeletal muscle of transgenic swine. CAB International. In: Transgenic Animals in Agriculture. Murray, J.D., Anderson, G.B., Oberbauer, A.M., McGloughlin, M.M. (Eds.) pp 131–144.

Solomon, M.B., R.G. Campbell, and N.C. Steele, 1990. Effect of sex and exogenous porcine somatotropin on longissimus muscle fiber characteristics of growing pigs. J. Anim. Sci. 68:1176–1182.

Solomon, M.B., R.G. Campbell, N.C. Steele, and T.J. Caperna. 1989. Occurrence of giant fibers and pale, soft, exudative (PSE) muscle in pigs treated with porcine somatotropin (pST). Proceedings of 35th International Congress of Meat Science and Technology, vol. 3, pp 1077–1085.

Solomon, M.B., R.G. Campbell, N.C. Steele, and T.J. Caperna. 1991a. Effects of exogenous porcine somatotropin administration between 30 and

60 kilograms on longissimus muscle fiber morphology and meat tenderness of pigs grown to 90 kilograms. J. Anim. Sci. 69:641–645.
Solomon, M.B., R.G. Campbell, N.C. Steele, T.J. Caperna, and J.P. McMurtry. 1988. Effect of feed intake and exogenous porcine somatotropin on carcass traits and longissimus muscle fiber characteristics of pigs weighing 55 kg live weight. J. Anim. Sci. 66:3279–3284.
Solomon, M.B., T.J. Caperna, R.J. Mroz, N.C. Steele. 1994. Influence of dietary protein and recombinant porcine somatotropin administration in young pigs: III. Muscle fiber morphology and meat tenderness. J. Anim. Sci. 72:615–621.
Solomon, M.B. and V.G. Pursel. 1994. Partitioning of carcass components of transgenic pigs. Proceedings of 40th International Congress of Meat Science and Technology, S-VII.01, pp 11–17.
Solomon, M.B., V.G. Pursel, E.W. Paroczay, and D.J. Bolt. 1994. Lipid composition of carcass tissue from transgenic pigs expressing a bovine growth hormone gene. J. Anim. Sci. 72:1242–1246.
Solomon, M.B., N.C. Steele, T.J. Caperna, and V.G. Pursel. 1991b. A further look at the effects of growth hormone on morphological muscle characteristics in pigs. Proceedings of 37th International Congress of Meat Science and Technology (1), pp 497–501.
Sutrave, P., A.M. Kelly, and S.H. Hughes. 1990. sKI can cause selective growth of skeletal muscle in transgenic mice. Genes and Development 4:1462–1472.
Zapf, J., C. Schmid, and E.R. Froesch, 1984. Biological and immunological properties of insulin-like growth factors (IGF) I & II. Clin. Endocrinol. Metab. 13:3–12.