Growth, Carcass Characteristics and Meat Quality

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SUMMARY: Rapid growth rate is very important economically because of a correlated response in improved feed conversion efficiency, and reduced non-feed costs. Advances in technology are greatly needed to practically and accurately predict carcass composition of breeding animals so that muscle growth rate can be determined rather than rate of live weight gain. Of the possible technologies for predicting carcass composition, ultrasound imaging is practical and accurate enough for pigs but not for cattle and sheep.

Males of all three species have faster growth rates, more desirable feed conversion efficiency, and superior carcass composition than castrates at a constage age. However, management (bulls and boars), flavor/odor (boars), tenderness (bulls and rams), and 'visual' meat quality (all three species) problems hinder their production in most countries.

Exogenous somatotropin dramatically increases growth rate, improves feed conversion efficiency and improves carcass composition of pigs, with only minimal negative effects on meat quality. β-agonists significantly increase growth rate in cattle and sheep, and improve carcass composition by increasing muscle mass. However, β-agonists can have significant negative effects on meat tenderness, and the safety of their use needs to be determined. Pigs transgenic for growth hormone signify 'breakthrough' progress in molecular genetics. The observation that their percentage of fat decreases as their weight increases is extremely interesting.

The swine industry is the most advanced in moving to objective, instrumental systems for predicting carcass composition. Electronic probes are very practical and accurate, whereas total body electrical conductivity shows considerable promise for near future application. Objective methods other than pH for measuring meat quality early postmortem are critically deficient.

Maximum yield of carcass percent muscle often must be sacrificed for 'optimum' yield of percent muscle because of the need for a certain level of fatness and(or) marbling for desirable meat palatability. Marbling is antagonistic to yield of percent muscle and meat nutrient density, especially in cattle.

Growth rate and feed conversion efficiency are moderately heritable, while longissimus muscle area, marbling, fat thickness, and meat tenderness are moderately-high to highly heritable. In the future, optimum integration of growth enhancement technologies with genetic selection may involve high selection intensity for tenderness and other quality traits, and utilizing growth enhancement technologies to improve growth rate, feed conversion efficiency and carcass composition. Opportunities are tremendous for making progress in more efficient production of quality meat.

INTRODUCTION: During the last several decades, numerous research papers have been published on animal growth, carcass characteristics, and meat quality. However, few of the published papers have examined the interrelationships among these three traits. Thornton (1990) cited a reference by Lawes and Gilbert dated 1859 that documented research on growth, carcass composition, and attributes of meat. During the century following the Lawes and Gilbert paper, progress in research on these traits was slow; however, during the last three decades, progress in research on these traits has been dramatic.

In order to discuss this topic, several terms need to be specifically defined. **Growth** of meat animals is defined as an increase in quantity of muscle and associated structural tissues, with some adipose tissue accretion included. Postnatal muscle growth occurs by hypertrophy of the muscle cells present at birth. **Fattening** is the term used when adipose tissue accretion is occurring at a faster rate than muscle accretion. Postnatal adipose tissue accretion occurs by hypertrophy of adipocytes and by recruitment (lipid filling) of adipoblasts (Smith, 1988). Some adipose tissue accretion is essential for the animal's well being, and indicates that animals are achieving their genetic potential for growth allowed by optimal nutrition. However, recent research with recombinant porcine somatotropin (rpST) clearly indicates that maximum genetic potential for muscle growth has not been reached with current genetic selection, nutrition, and management. In discussing growth, it is important to consider the **rate** (per unit of time), extent (mature size), **composition** (muscle versus adipose tissue), and **efficiency** (feed per unit of gain) of growth.

Optimum carcass **composition** is defined as the point at which a specified quality level is attained, carcass weight is acceptable, and maximum meat yield is attained. In a significant number of countries, the specified quality level requires a certain amount of carcass subcutaneous fat, primarily to assure adequate intramuscular fat (marbling). In other countries, the definition of carcass quality primarily is related to carcass yield (quantity) of muscle or boneless, closely trimmed meat. I support the philosophy of Hofmann (1990) that determining the percentage of meat yield in carcasses is not a measure of quality.

In this paper, quality of meat will be defined to include **visual**, **palatability**, and **nutritional** factors, with emphasis on palatability. **Visual** quality includes factors evaluated in grading or classifying carcasses and(or) factors that affect consumers' decisions when purchasing meat, such as meat color. **Palatability** factors include tenderness, juiciness and flavor intensity of cooked meat. **Nutritional** factors include proportions of protein, vitamins and minerals relative to fatness and caloric density. Meat of optimum quality then would be defined as being very appealing to consumers (fresh, attractive color, high proportion of lean, and nonexudative); being very tender, flavorful and juicy when cooked; and having a low-caloric, high-nutrient density.

The focal point of this paper will be traits which relate to fundamental properties of muscle, collagen, or fat that are significantly affected by genetics, livestock production and management. Discussion will include both complementary and antagonistic relationships among growth rate (GR), feed conversion efficiency (FCE), carcass composition (CC) and meat quality traits. Discussion also will include effects of growth enhancers, new technologies, and sex of animals on these traits.

<u>RESULTS AND DISCUSSION</u>: <u>Animal Growth</u>. Livestock producers commonly measure animal GR in terms of live weight gained per unit of time, or live weight gained per day of age. Two potentially significant errors in measuring live weight gains are variations in the composition of gain among animals and variations in gastrointestinal fill of sheep and cattle. Variations in composition of gain can be demonstrated by data in Table 1, which contains preliminary slaughter weight data for six of the 10 sire breeds from Cycle IV of the Germ Plasm Evaluation cooperative project between the U.S. Meat Animal Research Center, Clay Center, NE and Kansas State University. Yields of boneless meat trimmed of subcutaneous and accessible intermuscular fat also are presented. Piedmontese sired steers had the lowest live weight; however, they had a relatively high meat yield weight. Charolais sired steers had both heavy live and meat yield weights. Hereford × Angus reciprocal crosses were average in live weight and lowest in meat yield weight. These results reveal that live weights can be misleading. Data for feed efficiency have not yet been analyzed. In regard to gastronintestinal fill, variations easily can be as great as 5% in ruminant animals, which would equate to 25 kg on a 500 kg steer. Therefore, weighing conditions are extremely important in measuring weight gains of ruminant animals.

It would be much more valuable to measure muscle GR in animals than to measure live weight gain. However, measuring muscle growth accurately has been, and likely will continue to be, a major problem. Carcass physical dissection to determine percentage of muscle, is very time-consuming and expensive for use in progeny testing cattle and sheep. This, coupled with the long generation interval for cattle, makes progeny testing for CC in cattle impractical.

Currently, the only practical and reasonably accurate objective method for prediciting CC of live animals is ultrasound technology. Ultrasound technology has been shown to be acceptably accurate for measuring backfat depth and longissimus muscle area in swine for use in regression equations to predict carcass percentage of muscle. However, I support the statement made

TABLE 1. MEAN LIVE WEIGHTS AND MEAT YIELD WEIGHTS OF STEERS FROM PIEDMONTESE, SHORTHORN, NELLORE, CHAROLAIS, ANGUS AND HEREFORD SIRES MATED TO ANGUS AND HEREFORD DAMS AND SLAUGHTERED AT 417 DAYS OF AGE[a]

Sire breed	No.	Live weight, kg	Meat weight, kg
Piedmontese	53	495	229.2
Shorthorn	53	532	218.9
Nellore	61	509	226.5
Charolais	55	553	237.1
Hereford and Angus	58	519	214.8

[a]Preliminary data from Cundiff et al. (1990).

by Kempster (1989) that measuring these traits in cattle and sheep may not be sufficiently accurate. Waldner (1990) reported that ultrasound evaluation of longissimus muscle area and fat thickness in Brangus bulls from 4 mo to 24 mo of age was accurate only at 12 and 16 mo and not at other ages. McLaren et al. (1991) reported that correlations between carcass and ultrasound measures were low for cattle and sheep and high for swine. These authors stated that potentially large operator (technician) effects existed for all three species. Another limitation of ultrasound is that the percentage of perirenal fat, which is valuable in regression equations to predict beef and lamb carcass muscle yield, cannot be determined with ultrasound technology. Considerable research on ultrasound is being conducted around the world. Hopefully, advances will be made in the next few years to improve its accuracy for all three species.

Results from research on other technologies to determine CC of live animals suggests they may have long term potential. Techniques such as total body electrical conductivity (Forrest et al., 1989), and x-ray computerized tomography (Kallweit, E., personal communication) show promise of being accurate for research purposes. However, the potential of these technologies for industry application may be limited because of cost of the equipment.

Until muscle GR can be practically and accurately measured in live animals, rate and extent of live weight change will continue to be very important economically. Rapid GR improves FCE by reducing the amount of feed needed for maintenance and reducing labor, interest and other non-feed costs when animals are fed to a time-constant basis. Johansson et al. (1987) reported a genetic correlation between FCE and daily gain of pigs to be -0.96. Christian (1991) stated that GR in swine is twice as important economically as backfat thickness.

Heritability estimates of postweaning GR or weight at a constant age range from .30 to .40, which indicates that selection for GR will result in some genetic improvement. However, Ellis et al. (1988) stated that intensive selection for any quantitative trait using classical genetic methods will result in significant progress for several generations, then progress will be slow. Eisen (1990) stated that classical genetic methods must be combined with molecular genetics and endocrinology to gain a complete understanding of the kind of genetic variation that regulates growth.

Considerable GR differences exist among breeds of cattle and breeds of sheep. Largely, these breed differences are related to the **extent** (mature size) of growth. In general, the breeds with faster GR also have a larger mature size. Reliance on larger mature size to achieve faster GR is somewhat counterproductive because of increased feed maintenance costs of larger breeding animals. Considerably less difference exists in mature sizes of different breeds of swine than among breeds of cattle and sheep.

Sex of animals has a significant effect on GR. Table 2 illustrates that males of all three species grow faster than castrates and castrates grow faster than females. Therefore, not castrating males is a 'natural' way to significantly improve GR of animals that typically are castrated. Many countries castrate males for ease of management (especially bulls) and to improve meat quality. Dikeman et al. (1985) summarized research showing that life-long implantation of bulls with zeranol and slaughtering them at 12 to 15 mo of age dramatically reduced masculinity development and agonistic behavior, tended to improve meat quality, and did not adversely affect GR. 'Boar taint' of pork can be a major problem in boars reaching sexual maturity. Reasons for castrating rams are less justified than for castrating boars and bulls because management of rams and DFD meat are not significant problems. However, pelt removal can be more difficult for rams than for wethers. Production of bulls, boars, and rams for meat in the United States is almost non-existent. Most European countries leave bulls intact, and a few European countries leave boars intact. Thornton and Tume (1988) stated that an increasing proportion of New Zealand farmers are producing ram lambs for meat. With improved pastures, gains of 300 to 400 g/day and slaughter ages of 3 to 4 months have been attained for ram lambs.

Manipulation of Growth. Potential for manipulation of growth of meat animals has never been greater than at present. The key role of the somatotrophic axis in regulating growth has been known for several years. Most of the effects of rpST on muscle growth are probably mediated by insulin-like growth factor-I (IGF-I), often referred to as somatomedin C. Blair et al. (1990) stated that a simple measure of ST showing a consistent association with genetic merit for GR is not available, whereas IGF-I appears to be a useful physiological predictor of genetic merit for GR and an associated increase in mature size. However, the heritability estimate for IGF-I is only .15 (Blair et al., 1990).

Numerous research reports in Europe (Van der wal, 1990) and the United States (Etherton et al., 1989; Goodband et al., 1990; Steele et al., 1989) have shown dramatic increases in swine GR from administration of rpST. Meisinger (1989) summarized

TABLE 2. RANKINGS[a,b] OF SEXES AT A CONSTANT AGE WITHIN SPECIES FOR GROWTH RATE, FEED CONVERSION EFFICIENCY, CARCASS TRAITS AND MEAT QUALITY TRAITS

	Growth rate	Feed conversion efficiency	Feed intake	Fat thickness	Longissimus muscle area	Meat yield, %	Marbling	Tenderness	Meat nutrient density[c]
Cattle									
Bulls	1****	1***	1***	1****	1***	1****	3*	3*	1**
Steers	2**	2**	2**	2**	2**	2**	2***	1**	2*
Heifers	3*	3*	3*	3*	3*	3*	1***	2**	3*
Swine									
Boars	1***	1***	2*	1***	1***	1***	3*	3*	1**
Barrows	2**	3*	1**	3*	3*	3*	1***	1**	3*
Gilts	3*	2**	3*	2**	2**	2**	2*	2**	2*
Sheep									
Rams	1****	1**	1**	1***	1***	1***	3*	3*	1**
Wethers	2**	2*	2*	2**	2**	2**	2**	2**	2*
Ewes	3*	3*	3*	3*	3*	3*	1**	1**	3*

[a]1 = ranks highest for the trait, 3 = ranks lowest for the trait.
[b]Author's interpretation of the relative differences among sexes within a species. The magnitude of differences among rankings is indicated by the difference in number of asterisks. For example: * versus * = a minor or no difference
* versus ** = a distinct difference
* versus *** = a major difference
* versus **** = a dramatic difference.

[c]Proportion of protein, vitamins and minerals relative to caloric density of boneless meat trimmed free of subcutaneous fat and accessible intermuscular fat.

numerous studies on rpST, and concluded that the average improvement in GR was 16% and that $8 to $15 more return per head could be realized by swine producers using rpST, if it was approved. Administration of rpST produces similar growth response as seen in transgenic pigs that have the growth hormone gene inserted (Pursel et al., 1989). Kanis (1990a) stated that administration of rpST results in the same improvement in GR as long term selection and can, therefore, possibly serve as a model with regard to biological limits that could be expected with index selection. Boyd et al. (1989) concluded that the over-riding importance of rpST is that it has become an invaluable probe into the mechanisms of postnatal growth and metabolic regulation.

Effects of ST on GR of cattle and sheep are less dramatic than the effects on swine. Beerman et al. (1991) reviewed literature on ST in sheep and cattle and concluded that exogenous ST improves live weight gain and FCE in growing lambs and cattle. In some studies, bovine ST was effective in lambs.

ST technology for growth enhancement has not been approved for commercial use in any country to my knowledge. A major advantage to this technology is that the meat produced from ST treated animals does not appear to be any health or safety hazard. A disadvantage of ST is that animals must be injected daily or every other day. Potential profit for pharmaceutical companies producing ST likely will provide funds for continuing research, including development of a more practical delivery system.

Recent research has shown that it is possible to insert the somatropin gene into swine DNA and produce 'transgenic' pigs. However, present techniques cannot control the number of copies and the site of integration of the transferred gene in the genome of the receptor embryos (Kanis, 1990a). This can result in considerable variation in expression of the transferred gene. Wagner 1989) states that the phosphoenolpyruvate carboxykinase (PEPCK) promoter offers great possibilities for external regulation (via the carbohydrate content of the diet) of transgenic expression. Pigs transgenic for PEPCK/bST show improved growth without the negative health and structure problems observed in ST transgenic pigs. According to Kanis (1990a) and Van der wal (1990), gene transfer technology is still in its early stage of development.

Of great research interest is whether there are any additive or synergistic effects of administering rpST or feeding β-agonists to transgenic swine.

Feeding β-agonists to livestock is another method being researched to manipulate GR, FCE and CC. Convey et al. (1987) reported data showing that the β-agonist L-644,699 increased GR 17% in cattle and 15.5% in lambs. These authors further stated that the most consistent metabolic effect of feeding β-agonists is the dramatic increase in muscle size and reduction in fatness. Similarly, Beerman et al. (1986) also showed dramatic increases in muscle growth of lambs by feeding cimaterol. Van der wal (1990) presented compiled data from 12 swine experiments involving four β-agonists that showed an average of 10% increase in muscle mass. A significant advantage of β-agonists over ST is that they are mixed in the diet rather than injected, which greatly reduces labor input.

Implants containing sex steroids or compounds with steroid-like activity increase GR 5 to 10% in steers and heifers. Implants are less effective for sheep, and few are approved for their use. They are virtually ineffective in swine.

Few countries have approved the use of β-agonists in livestock production. Van der wal (1990) stated that these compounds involve a more complicated toxicological risk assessment than ST. Several countries have banned the previously approved use of sex steroid implants, although these decisions were not based on scientific evidence that they pose a human health or safety risk. Thornton and Tume (1988) stated that the future use of these implants is clouded by political-regulatory considerations. It is very possible that β-agonists and ST could be viewed in the same manner as implants.

Feed Conversion Efficiency. Christian (1991) stated that the relative economic value of FCE of live weight gain in swine is more than twice that of GR and that FCE of lean gain will become more important in the future for United States swine producers. Mulvaney et al. (1991) stated that FCE is four to five times more important economically than GR. The three main factors affecting FCE (kg feed/kg gain) are: 1) maintenance energy requirements, 2) feed intake, and 3) composition of gain. Maintenance energy requirements increase linearly as metabolic size (weight in $kg^{.75}$) increases. Therefore, as animals get older and heavier, maintenance requirements increase. Feed intake does not increase proportionately with increased maintenance requirements, which results in a higher proportion of energy utilized for maintenance and a poorer FCE. Therefore, livestock producers should feed animals for rapid GR while they are relatively young and have low maintenance requirements.

When FCE of muscle growth is the endpoint, and not live weight gain, it is not advantageous to feed for maximum live weight gain, because some of that gain will be excess adipose tissue. Complicating the relationship between metabolic size and feed intake is the fact that voluntary feed intake can differ among animals of similar metabolic size. Animals with higher than average voluntary feed intakes will have an advantage in GR and FCE because a higher proportion of their consumed energy will be available for gain. Conversely, animals with above average voluntary feed intake on ad libitum feeding tend to be fatter at the same age or live weight. Ellis et al. (1988) showed a negative genetic correlation between percentage of carcass muscle in swine and voluntary feed intake. Kanis (1990b) reported that not only do swine with high voluntary feed intake have more energy available for fat accretion; they also produce more fat on the same amount of feed. Thompson (1990) presented data demonstrating that selection for weaning weight in sheep resulted in increased voluntary feed intake, growth and body fat. For livestock producers, measuring individual animal feed intake often is not possible or economical. Therefore, the simplest way to improve FCE of live weight gain is to select for rapid GR or reduced body fat, which results in a correlated response in improved FCE.

The traditional method of selection for FCE in pigs has been to feed them ad libitum over a fixed weight range, which permits individuals to express their appetites (McPhee, 1989). This method results in reduced fat and daily feed intake, and no improvement in ADG. Because of this, McPhee (1989) proposed that measuring FCE on 'scale feeding' (each given the same amount of feed) would allow identification of the fast growing pigs as the ones that convert available feed into muscle rather than fat. This also resulted in a negative genetic correlation between growth rate and fatness compared with the usual positive genetic correlation between these traits in ad libitum feeding. When progeny from McPhee's select line were fed ad libitum, their feed intake was greater than that of the control line.

The third factor that affects FCE is composition of gain. Even though energy costs for tissue protein and adipose tissue accertion are both about 54 kj/g (Thorbek, 1977; Pullar et al., 1977), the above-maintenance feed-energy cost for muscle growth is little more than one-fourth that for fat because muscle consists of 70 to 75% water. Thus, selection of breeding animals with less body fat and marketing slaughter animals at lighter weights with reduced body fat will improve FCE significantly. This point can be emphasized by research reported by Ellis et al. (1988) in swine. These researchers showed more improvement in FCE in 10 generations through index selection for increased GR, reduced backfat, and FCE than researchers who have selected solely for FCE. Growth rate did not change very much over these 10 generations, whereas backfat decreased significantly, demonstrating the effect of reduced backfat on FCE. However, intense selection for increased muscling and reduced body fat often results in decreased feed intake capacity. At a certain point, reduced feed intake capacity may become a biological limitation for further progress in GR or CC.

A logical question to ask at this point is: how do sex and exogenous growth promoters affect FCE? It is well known that intact males of each species are superior in FCE than castrate male counterparts at the same age or weight (Table 2). This is due primarily to the distinct advantages in CC and GR of intact males. However, when bulls are fed to the same fatness as steers the advantage in FCE is lost. Steers and wethers are more efficient in feed utilization than heifers and ewes, respectively, whereas gilts are more efficient than barrows because of an advantage in leanness.

Administration of rpST to pigs decreases feed intake up to typical slaughter weights; however, FCE is improved because of the dramatic improvement in CC. On the other hand, Kanis et al. (1990a) showed that administration of rpST from 100 to 140 kg resulted in increased feed intake and a greater response in GR. In a summary of several research studies, Meisinger (1989) reported an average 24% improvement in FCE from rpST. Although the improvement in FCE of ruminants is not as dramatic as the improvement in swine, administration of ST to cattle (Enright, 1989) and sheep (Beerman et al., 1990) also improves FCE, primarily because of ST effects on CC.

β-agonists also improve FCE, but to a lesser and more variable extent than ST. Van der wal (1990) indicated the improvement in FCE of pigs ranged from 0 to 10%, depending on the β-agonist used. Convey et al. (1987) reported that L-644,969 improved FCE 9 to 20% in sheep and cattle. In comparison, sex-steroid implants improve FCE 5 to 10% in cattle.

It can be concluded that to optimize FCE, animals should be fed for rapid GR at a young age and slaughtered while growth predominates over fattening.

Carcass Composition. The ultimate measure of CC is careful physical dissection followed by chemical analyses of the component tissues. However, this procedure is extremely time consuming and very expensive. For decades, researchers have been looking for accurate and(or) objective methods for predicting CC. There also has been considerable discussion about whether carefully dissected muscle, or boneless, closely trimmed (most subcutaneous and accessible intermuscular fat removed) meat yield is the endpoint of preference. The first is most important for research purposes, whereas the latter may be just as important from an economic standpoint. Traits affecting CC, such as subcutaneous fat thickness and longissimus muscle area generally are moderately to highly heritable. Therefore, rapid genetic progress could be made in CC, if traits could be accurately measured in live animals.

Dramatic differences in CC exist among breeds of all three species. However, the differences in muscle-weight distribution are rather minor. Until fatness in all three species is controlled at the desired level, there probably is insufficient variation to make genetic change in muscle-weight distribution. In regard to fat distribution, dairy breeds of cattle deposit a higher proportion of fat internally and less subcutaneously than traditional British breeds (Berg, 1984). In addition, early fattening breeds usually have a higher subcutaneous/intermuscular fat ratio than larger, later fattening breeds.

Subjective evaluations of carcass fatness and muscling can be very accurate in determining CC, provided personnel are properly trained initially and are then 're-calibrated' on a routine basis. The goal in developing most objective methods for determining CC is that the accuracy will be equal to that of the most highly trained personnel. Unfortunately, not all personnel can be trained to the same level of competence. Individuals may differ in accuracy, even though they may be precise or repeatable and producers, processors, and retailers have less confidence in people than in instruments. Therefore, accurate and reliable instruments for determining CC will be vitally important for effective value-based marketing.

Kirton (1989) stated that the swine industry is the most advanced in moving to objective systems for measuring fat thickness and muscle depth. Electronic probes such as the MFA, SFK Fat-O-Meater, and Hennessy grading probe are accurate in measuring these traits in pork carcasses because the skin prevents stripping away of fat during dressing (which often occurs in beef and lamb) and also serves as a relatively rigid, firm base for probing. Because 75 to 80% of the total fat of pork carcasses is subcutaneous, an accurate measure of backfat thickness results in accurate regression equations to predict weight or percentage of muscle. Numerous researchers have found that measures of backfat are more closely related (inversely) to percentage of muscle than muscle cross-sectional area measurements.

The most sophisticated application of the optical, electronic, fat-lean probe principle is the Danish Classification Center for Pork Carcasses (Madsen, N., personal communication). Depths of fat and muscle, and total thickness at 15 positions are measured and incorporated by computer into a predicted yield of carcass muscle. Forrest et al. (1989) have shown that electronic probe measurements of longissimus depth and 10th rib fat depth plus carcass weight used in a regression equation to predict muscle yield resulted in an R^2 value of .79 (RSD = 2.19). That compares very favorably with actual ribbed carcass longissimus muscle area and fat depth measurements used in an equation with a resulting R^2 value of .83 (RSD = 2.07). Forrest et al. (1989) also used real time ultrasound measures of carcass traits in a regression equation and reported an R^2 value of .72 (RSD = 2.20) for muscle yield. Progress in developing accurate, instrumental methods for predicting beef and lamb CC has lagged behind that for predicting pork CC. Dissection or chemical analysis of the 9-10-11th rib section or wholesale round have been proven to be reasonably accurate in predicting beef CC.

Several other technologies show promise for determining CC. In the total body electrical conductivity (TOBEC) system described by Forrest et al. (1989), conductivity is measured at 64 equidistant intervals as carcasses move through a magnetic field. This system is accurate for predicting weight of muscle (R^2 = .89, RSD = 1.74) in pork carcasses. Two of these systems currently are being evaluated in commercial plants to determine the durability and dependability of the equipment. Magnetic resonance imaging and x-ray computerized tomography also appear to be accurate for determining CC for research purposes. High cost of these latter instruments, slow speed of operation, and other considerations will keep them from being commercialized for several years.

Administration of ST to animals has dramatic effects on CC, especially of pork. Meisinger (1989) summarized results from numerous research studies and reported that rpST decreased backfat an average of 25%. Van der wal (1990) presented data that showed a 25 to 32% increase in protein gain and an 8 to 25% reduction in fat gain, with the greatest decrease in fat gain occurring in American Durocs and the least decrease in Pietrains. In order to maximize performance and carcass characteristics, Goodband et al. (1990) found that the dietary lysine requirment must be doubled for rpST treated pigs compared to non-treated pigs. An unexpected negative effect of rpST is on dressing percent. McKeith et al. (1989) reported decreases in dressing percent up to 3.5%, which is quite significant. Beerman et al. (1990) reported that ovine ST decreased carcass lipid accretion rate by 30% in crossbred ewes and wethers. In another study (Beerman et al., 1991), rbST increased nitrogen balance in wether lambs by 22.5%. Mosely et al. (1990) found that the highest level of rbST increased percentage of protein by 39.4% and decreased percentage of lipid by 54.4% in soft tissue of beef 9-10-11th rib sections. Mosely et al. (1990) reported that GR was decreased by 37.7%, whereas FCE improved 35.4%. Other studies have reported either no effects or less dramatic effects on beef and lamb CC in response to rbST. Feeding β-agonists also are effective for increasing muscle growth and decreasing fat deposition in all three species. Convey et al. (1987) presented data on the β-agonist L-644,699 that caused 29, 42.9, and 26.6% reductions in fatness of beef, lamb and pork carcasses, respectively.

Sex-steroid implants are used in several countries to enhance CC of steers and heifers. Effects are less dramatic than for ST or β-agonists; however, they reduce fatness of beef carcasses by about 10%. They are safe, relatively low in cost, and require little labor investment. Few sex-steroid implants have been approved for sheep, and some are not effective. Sex-steroid implants essentially are not effective in swine.

I was not able to find any published research to determine possible additive or synergistic effects of ST, β-agonists, and implants on GR or CC. Because their modes of action are different, it is possible that the effects of β-agonists, ST and implants might be additive. Research of that nature needs to be done.

Initial research on the effect of introduction of a recombinant bovine growth hormone gene into pigs is very interesting. Pursel et al. (1989) and Solomon et al. (1990) studied 16 transgenic and 16 control pigs. These authors found that, as expected, as body weight of control pigs increased, percentage of carcass fat increased. However, for transgenic pigs, as body weight increased, percentage of carcass fat decreased! This is a much more dramatic effect on CC than that of ST.

Excluding the effects of exogenous manipulation of animal GR, the effects of GR on CC range from neutral to slightly negative. For cattle and sheep within a given biological type or frame size, animals with faster live weight gains during a constant time period generally are fatter. On the other hand, when faster growth results from selecting animals that are larger framed, more muscular and later fattening, the faster gaining animals have less fat and yield a higher percentage of muscle at a given age or weight. Animals of all three species should be fed to the level of fatness that is desirable or acceptable, but not to excess. Obviously, the desired level of fatness will differ from country to country. Increasing weight up to the desired level of fatness will improve dressing percent by decreasing the proportion of live weight that is internal organs, fill, hide, and other non carcass components.

Meat Quality. In this paper, quality of meat is divided into categories of **visual**, **palatability**, and **nutritional** factors. Hofmann (1990) categorized meat quality into the categories of sensory, nutritive, hygenic, and technological factors. Although extremely important, hygenic and technological factors will not be discussed in this paper. Published research on genetic effects on meat quality is somewhat limited, whereas published research on environmental effects on meat quality is extensive. Marbling, muscle myoglobin concentration, texture and tenderness of beef are under a significant amount of genetic control (Dikeman, 1990). Less is known about the heritability of tenderness and muscle myoglobin concentration in swine and sheep, although marbling is known to be highly heritable in swine (Barton-Gade, 1990).

Maturity has definite effects on the **visual** quality of beef and lamb by its effect on meat color, which is very important to consumers in their purchase decisions. Myoglobin concentration in muscle increases significantly as animals mature (especially beef), resulting in darker colored meat. As animals mature, collagen crosslinking and resistance to heat increases, with a concommitant decrease in tenderness of meat. In addition, color of beef fat often is more yellow in older cattle, and consumers discriminate against yellow fat. Producers should manage cattle and sheep for rapid GR in order to minimize collagen maturation, and meat and fat color problems. Because swine are fed high concentrate diets in nearly all countries, collagen maturation, and meat and fat color typically are not problems.

Subcutaneous fat thickness typically is considered to be a quantity trait because it is very highly correlated (negatively) with percentage of carcass muscle; however, subcutaneous fat thickness sometimes is included as a quality trait (Dikeman, 1987; Wood, 1990). The amount and kind of fat (color and firmness) indicate the extent cattle and sheep have been fed high energy diets, and the amount has a direct effect on postmortem chilling rate of muscle because of its insulation property. Therefore, beef or lamb carcasses with thin subcutaneous fat are more likely to cold toughen, unless ideal electrical stimulation and chill conditions exist. In addition, carcasses with thin fat generally will have less marbling, which is important economically in some countries. In the United States, cattle are fed to have 8 to 10 mm of fat thickness over the longissimus muscle in order to meet minimum marbling requirements for the Choice grade, and also to minimize chances for cold toughening.

Subcutaneous fat thickness of pork carcasses seldom is considered as a quality trait. In the United States, the message from consumers is very clear that the fat content of pork must be significantly reduced. A recent 'market basket' study (Buege et al., 1990) evaluated the amount of fat on 14 different retail cuts of pork from representative supermarkets in the United States. They reported that eight pork retail cuts had 43% less fat (raw-basis) than reported in USDA Handbook 8-10 published in 1983. However, they did not provide any data indicating that fatness of market pigs had been reduced. Rather, pork processing plants and retailers primarily have removed fat by close-trimming of retail cuts. Because 75 to 80% of total pork carcass fat is subcutaneous, most fat can be easily removed from all cuts except the belly (bacon). However, bacon was not one of the cuts included in the study.

Quality of subcutaneous fat is more of a consideration for pork carcasses than a minimum (essential) amount of fat. Firmness of pork fat is highly affected by the degree of unsaturation of fat in the diet. Feeding swine a diet containing unsaturated fat, such as that found in peanuts or soy oil, results in a soft, oily fat.

There appear to be limits to the extent that fatness can be reduced without having negative effects on pork quality. Wood (1990) summarized several studies relating backfat thickness to pork quality. Extremely trim carcasses (8 mm P_2 backfat) were found to have a higher incidence of fat separation from muscle, increased softness of fat, increased meat drip loss, decreased tenderness (consumer panel), and reduced juiciness (trained panel) when compared to carcasses having up to 16 mm P_2 backfat. Furthermore, Dransfield and Lockyer (1985) found that pork longissimus muscles excised pre-rigor cold-shortened when chilled at 3°C or below. These authors speculated that about 10% of carcasses with 12 mm or less backfat and rapidly chilled, would have cold-toughened longissimus muscles. They stated that ultra-rapid chilling of carcasses in conjunction with very lean pig production and hot deboning of pork, could result in 60% of carcasses cold-toughening. These results suggest that reducing fat below about 12 mm may result in pork quality and meat palatability problems.

The importance of marbling in meat tenderness evaluation is controversial. There is a high negative genetic correlation between marbling and percentage of muscle in beef carcasses. Therefore, intense selection for marbling will result in a decrease in percentage of muscle. In addition, genetic or phenotypic correlations of marbling with meat tenderness are rather low. Marbling in beef carcasses is related to tenderness when age and nutrition are quite variable. Marbling provides some insurance against cookery abuse by consumers (cooking too rapidly or to a high endpoint temperature), helps solubilize collagen when heated, helps retain juiciness, contributes to flavor, and provides some lubrication effect during chewing. Numerous U.S. studies show that cooked longissimus palatability (primarily tenderness) decreases significantly when ether-extractable lipid drops below 3%. The minimum amount of ether-extractable lipid necessary for carcasses to exhibit adequate marbling to quality for U.S. Choice is about 4.5%. When cattle are fed high-energy diets, slaughtered at a young age, and handled properly postmortem, depositing enough marbling for the Choice quality grade is not important for meat palatability. However, it is important for economic reasons because of price discounts for carcasses not meeting Choice quality.

Even though heritability for marbling in cattle is moderately high, selection for it is difficult because it cannot be evaluated accurately in live cattle. On the other hand, numerous researchers have reported breed differences in marbling. Koch et al. (1976, 1979, 1982) and Cundiff et al. (1990) obtained data on large numbers of cattle and reported significant breed differences when compared at the same percentage of carcass fat trim. Therefore, production systems using breeds with a history of the desired level of marbling, may be more effective than selecting for it within breeds. Because of the genetic antagonism between marbling and yield of boneless, closely trimmed meat, crossbreeding programs can be valuable in managing this antagonism. In crossbreeding programs, exploitation of breed differences is optimized when sire breeds selected for growth rate, muscling and reduced body fat are mated to dam breeds or crosses with medium mature size and high genetic potential for marbling and maternal traits. However, it should be noted that the effect of heterosis on carcass traits is almost negligible.

Marbling usually is not evaluated in pork carcasses to assess meat quality. The percentage of intramuscular lipid in pork longissimus muscles is low relative to the amount of subcutaneous fat on carcasses. Wood (1990) stated that longissimus muscle ether-extractable lipid in pigs of the white breeds is 1 to 2%, and in very lean pigs declines to about .5%. Numerous studies have shown that Durocs have higher marbling than other breeds. Barton-Gade (1990) stated that the heritability of marbling in swine is very high (range of .50 to .81). Wood (1990) stated that selection for both high marbling and lean carcasses would be successful. The short generation interval and large number of offspring make it much easier to make genetic progress for marbling in swine than in sheep and cattle.

Barton-Gade (1990) described changes in carcass composition and meat quality between 1983 and 1988 in the four breeds of swine used in Denmark. During the study, daily gain and meat content generally increased, whereas the incidence of pale, soft and exudative meat decreased to the point that it is not a problem in three of the four breeds. Shear values increased, mainly because of more susceptibility to cold toughening but also because of decreased intramuscular fat content. This Danish research suggests that about 2% total intramuscular lipid may be necessary for desirable meat palatability, which may need to become a breeder goal. Wood (1990) stated that significant differences in juiciness and tenderness existed between 'lean' (average 8 mm P_2, .55% intramuscular lipid), and 'fat' (average 16 mm P_2 , .96% intramuscular lipid) carcasses. He concluded that .5% intramuscular lipid is too low and at least 1% is necessary for desirable meat palatability.

Most studies with sheep have shown that the effects of breed on meat palatability are small. There is a positive effect of fatness on meat palatability, possibly connected with the slower chilling and reduced chance of cold shortening of carcasses with at least 4 mm of fat cover (Dikeman, 1987).

Rate of muscle pH decline and ultimate pH can have dramatic effects on meat color, firmness, and water-holding capacity. pH also has significant effects on meat tenderness. Hofmann (1990) stated that pH is one of the most important indicators of quality in meat. Marsh (1983) reported that early-postmortem pH and temperature were related to beef tenderness and that high pH meat was very tender when cold-shortening had not occurred. Pre-slaughter stress can cause muscle glycogen depletion and high ultimate pH, which results in DFD meat. Pale, soft and exudative (PSE) pork is caused by both genetic and environmental factors. A rapid pH decline postmorten while muscle temperature is still high results in PSE meat. Judge (1991) stated that PSE pork results in many cases from stress susceptibility in pigs, a condition expressed by a homozygous recessive trait commonly known as the halothane gene. 'Screening' against the halothane gene will result in a decreased incidence of PSE pork and at a much faster rate than conventional breeding methods (Webb et al., 1986).

In general, tenderness is identified as the most important meat palatability trait. In cattle, there are distinct breed differences in tenderness and evidence that tenderness is moderately high in heritability (Dikeman, 1990). Numerous studies have shown that meat from Bos indicus cattle is less tender than meat from Bos taurus cattle and that these tenderness differences exist even when marbling is constant (Koch et al., 1979, 1982; Cundiff et al., 1990). Cundiff et al. (1990) compared 11 sire breeds mated to Hereford and Angus dams and found that Piedmontese (noted for muscular hypertrophy) sired steers had less fat in all depot sites than all other crosses; however, they had lower longissimus shear values than nearly all of the other breed crosses. Some other researchers have suggested that 'double muscled' cattle have a lower concentration of collagen, which also is more soluble.

Except for boar taint, flavor intensity of meat is highly effected by environmental factors. Nutritional regimen can have significant effects on flavor of meat from cattle and sheep. Consumers accustomed to eating beef or lamb from animals feeding on grass prefer it over that of meat from animals fed grain, whereas the opposite is true in countries where cattle and sheep are grain fed. For the trait of juiciness, the major contributor is water remaining in cooked meat. Therefore, degree of doneness following cooking affects juiciness the most. Meat that is PSE will lose more moisture during cooking than normal pH or DFD meat. Marbling's role in juiciness is that the melted fat may act as a barrier to moisture loss during cooking.

The most obvious effect of sex on meat palatability is that of 'boar taint', which can be extremely objectionable if boars are not slaughtered before reaching puberty. Meat from barrows tends to be the most tender, juicy and flavorful because of higher marbling content compared to that from boars and gilts (Barton-Gade, 1987). Meat from young boars, bulls, and rams has a higher nutrient density than meat from castrates and females because of lower fat content (Table 2). Meat from bulls, boars, and rams tends to be less tender and less juicy than meat from castrates or females, with minor differences existing between meat from castrates and females. In addition, fat from rams tends to be softer and more yellowish red in color than fat from wethers and ewes.

Effects of rpST on pork quality range from neutral to slightly negative. McKeith et al. (1989), Merkel (1988) and Prusa (1989) suggest that pork from rpST treated pigs may have softer lean and fat, reduced intramuscular fat content, and slightly reduced tenderness. There is no evidence, however, that rpST treatment causes a greater incidence of PSE pork. Nutrient density will be higher for most cuts of meat from rpST-treated pigs because of reduced intra- and intermuscular fat content. Solomon et al. (1990) reported that rpST treatment resulted in lean tissue containing 40% less saturated fat, 37% less monounsaturated fat, and 0% less polyunsaturated fat than lean from controls. Little research has been done on effects of ST treatment of cattle and sheep on meat quality.

Effects of β-agonists on beef and lamb meat quality generally are negative. The most notable effects are decreased tenderness in both species and increased muscle pH in lamb meat (Merkel, 1988). Marbling and flank fat streaking also tend to be reduced in beef and lamb, respectively. On the other hand, nutrient density is higher for meat from cattle and sheep fed β-agonists. The effects of β-agonists on quality of meat from pigs appear to be negligible. In regard to meat safety, Van der wal (1990) stated that the safety of β-agonists needs to be established. Sex-steroid implants have little effect on meat quality in sheep and cattle with the exception that trenbolone acetate (a synthetic testosterone) may reduce marbling.

Highly **nutritious** meat has a low-caloric, high-nutrient density. Therefore, 'fattening' of animals is antagonistic to high nutritional density. Additionally, cholesterol concentration is significantly higher in subcutaneous fat than in intramuscular fat; therefore, closely trimmed meat will have less cholesterol than meat containing subcutaneous fat. However, differences in intramuscular fat contents result in minor differences in cholesterol density.

Objective, instrumental methods for accurately predicting or measuring meat quality are lacking in the livestock and meat industry around the world. Ideally, these objective quality measurements should be applied soon after slaughter. Of the few instrumental methods available to predict the ultimate quality of meat early post-mortem, pH measurement appears to be the most promising. Early post-mortem pH may be accurate for predicting tenderness of beef and may be useful in predicting whether pork will be DFD, normal, or PSE.

Interrelationships among Growth Rate, Carcass Composition, and Meat Quality. Rapid GR generally has a positive effect on meat quality, particularly tenderness of beef and lamb. Meat from rapidly growing cattle and sheep has a higher proportion of its muscle collagen as newly synthesized collagen, which has a lower thermal shrinkage temperature. This lowers the residual strength retained by collagen after heating and reduces the compression effects of collagen thermal shrinkage on myofibrillar proteins. In addition, rapidly growing cattle and sheep may have increased proteolytic enzyme activity post-mortem. Rapidly growing animals also tend to deposit more subcutaneous fat, which may help prevent cold-toughening and result in more intramuscular fat that may increase tenderness and juiciness. Rapid GR will generally have a negative effect on meat nutrient density because of increased lipid content of meat from rapidly growing animals. Because pigs are nearly always fed for rapid GR and are slaughtered at a young age, the swine industry already is taking full advantage of the positive relationship between rapid GR and meat quality.

If some fat is considered essential for desirable meat palatability, maximum yield of percentage of muscle and meat quality generally are antagonistic to each other. Because of this antagonism, it is more appropriate to define **optimum** carcass composition as the point at which maximum meat yield is obtained at a minimum specified fat level.

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