Biotechnology and Food Composition

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Consumer interest in food composition has remained at a high level for the past ten to fifteen years in response to many health-related issues. Key nutritional concerns include level of fat intake, proportion of fat intake as saturated fat, and cholesterol content of foods. One of the more recent issues involves the role of naturally occurring antioxidants in foods and their role in prevention of certain cardiovascular diseases and cancers.

Our understanding of the linkages between human nutrition and health has expanded dramatically during this time, as has our application of biotechnology in research. This knowledge led to development of the "Dietary Guidelines", the Food Guide Pyramid" and expanded food labeling requirements. All were designed to help consumers make informed choices at the point of purchase and in food consumption patterns.

Similarly, application of biotechnology in food production and manufacture is expanding at a rapid rate. We now have chymosin that is produced by recombinant DNA technology being used in cottage cheese manufacture. We have the genetically altered Flavor-Saver® tomato, and many other agronomic examples of use of biotechnology. The tremendous diversity of food products available today and the detailed nutritional information provided with them, I believe, has led consumers to believe that food composition can be altered at will. Can application of biotechnology really provide us that capability, the capability to design foods and food products that have improved nutritional composition and are of acceptable "quality" and "safe"? The answer is yes, but there are many qualifications that need to shared along with that answer.

In reality, application of biotechnology to alter food composition is in its infancy, for foods of both plant and of animal origin. Much greater effort and progress has been made in using biotechnology to alter agronomic traits of plants and food producing animals, than for altering their composition. Among the reasons for this is the simple economic impact of the former as compared with the latter. Extending the shelf life of fresh fruit and vegetables, making plants more resistant to pests and drought or severe climatic conditions all have marked impact on the economics of production. Likewise, improving the efficiency with which animals convert feeds to milk and meat has greater impact on the cost and economy of production than would altering the composition of these foods. However, there are a few exciting examples that depict the potential for what may be achieved, and some to the results are quite dramatic.

A dramatic example in which biotechnology can be used to alter composition of food is found in several approaches that can be taken to reduce the fat content of meat. Although food products from animals have been a mainstay in the American diet, contributing between one-third to nearly all of many important nutrients, they are also a major source of fat, saturated fat and cholesterol. In the U.S. red meats and poultry contribute approximately 33% of total fat in our diets, while milk and dairy products contribute another 11% (National Research Council, 1988). Muscle foods also contribute approximately 40% of total saturated fatty acids and 40% of total cholesterol intake.

In response to consumer demand for leaner, low-fat foods, total fat content of fresh meat has been reduced 25 to 30% in the last 10 years (USDA, 1990, Buege, et al., 1991). Most of this reduction resulted from trimming more of the fat from fresh retail cuts of meat sold in the supermarkets, although a smaller but significant reduction was also achieved by genetic selection of the animals.

For several reasons, however, continued improvement has been slow. Market animals still contain approximately 25% carcass fat, much of which is trimmed away at various points along the distribution chain. This is true not only for beef, pork and lamb, but for poultry as well.

Removing unwanted fat post harvest represents inefficiencies in both production and in processing, both of which are costly. Cost of feeding these animals represents approximately 60 to 70% of the total cost of production. Producing leaner animals is more efficient because less feed is required per pound of gain as muscle as compared with the greater amount of feed required per pound of gain as fat. Increased economic return to the producer, increased efficiency of carcass cooling, reduced time trimming fat and decreased volume of fat rendered by the packer will result from production of leaner animals. How can this be achieved?

Modification of metabolism of growing animals to redirect use of absorbed nutrients toward greater rates of skeletal muscle growth and less fat synthesis and deposition can be achieved by altering the endocrine status of the animal. Increasing the concentration of somatotropin, or growth hormone, in the blood increases protein synthesis rate in muscle and reduces fat synthesis and deposition in adipose tissue during growth. This can be achieved by direct administration of the recombinantly-derived hormone, or by administration of the hormone which stimulates synthesis and secretion of somatotropin in the anterior pituitary gland at the base of the brain. Growth hormone releasing-factor (GRF) action can also be altered through immunological approaches.

Administration of porcine somatotropin (pST) to growing pigs being raised for pork provides a good illustration of the multiple effects and benefits of this technology. Several studies were conducted at Cornell University and elsewhere, to investigate the regulation of nutrient use by food-producing animals, with particular emphasis on somatotropin (Beermann et al., 1990a,b; Krick et al., 1992; Thiel et al., 1993). Somatotropin administration causes dose-dependent 40 to 80% decreases in lipid accretion rates and 35 to 75% lower fat content of the carcass, and 20 to 35% reductions in the amount of feed consumed per pound of live weight gain (see figure 1). Rates of protein deposition in the carcass are increased by 40 to 70%, resulting in 25 to 38% increases in skeletal muscle mass at the same live weight as control animals. A detailed description of the relative magnitudes of individual responses for average daily weight gain and amount of feed consumed, and of changes in bone and skin growth are presented in table 1. These improvements in carcass composition and growth performance are unprecedented.

Table 1: Dose Response Relationships for Porcine Somatotropin Effects on Growth Performance and Dissected Carcass Tissue Weights on Growing Swine[1]

	pST Dose, $\mu g \cdot kg^{-1} BW \cdot d^{-1}$				
Observation	0	50	100	150	200
Number of Animals	10	10	10	10	10
Growth Performance		Percentage Difference from Controls (%)			
Average Daily Gain, kg	.904	+8.0*	+13.1*	+13.3*	+13.3*
Daily Feed Intake, kg/d	2.90	-14.8*	-18.6*	-22.1**	-26.9**
Feed:Gain	3.22	-21.1*	-28.0**	-31.4**	-35.1**
Carcass Yield and Composition					
Muscle Mass, kg	30.92	+27.9**	+30.3**	+32.7**	+37.6**
Adipose Mass, kg	22.78	-35.7**	-54.6**	-65.7**	-74.1**
Bone Mass, kg	7.28	+10.2*	+14.3**	+16.2**	+17.3**
Skin Mass, kg	3.66	+14.8*	+36.1**	+35.0**	+38.3**

[1] Somatotropin was administered by daily injections and adjusted biweekly to increased live weight. Growth performance data were analyzed by analysis of variance using live weight as the covariate, (Krick and Boyd, unpublished data). Carcass data are summarized from Thiel et al. (1990).
*(P<.05) vs. control
**(P<.01) vs. control

Lipid content of skeletal muscle, also called marbling, is also reduced in step-wise fashion with incremental dose of pST administration. Results from a study in which effects of pST administration on different genotypes and genders of pigs were compared following treatment from 45 to 90 kg live weight are shown in table 2. Longissimus muscles in control animals from the unselected strain and lean strain barrows (castrate males) contained approximately 3.4% lipid, while the intact lean strain male pigs (boars) contained only 2.6% lipid on a wet-weight basis. Both genotypes and both genders exhibited large reductions in lipid concentration of the longissimus with pST administration, to levels far below those observed in most market weight pigs (0.5 to 1.3%). Protein and moisture concentrations averaged 22% and 73%, respectively, in control pig longissimus muscles and were each increased one percentage point with pST administration, regardless of dose. Ash concentration was unchanged. Analysis of other muscles and muscle groups in various carcass locations exhibited similar magnitude of change in proximate composition. Contrary to what consumers may expect, there was not change in cholesterol concentration in the longissimus muscles from pigs that received pST treatments (table 2). These data clearly demonstrate and confirm the relationship known for over thirty years, that changes in neutral lipid concentration in skeletal muscle tissue are independent of variation in cholesterol concentration.

This is explained by the primary location of the cholesterol being in membranes of cells, and not in the cytoplasm where the triglycerides are stored. It is interesting to note that no differences were observed in cholesterol concentration between genotypes or genders.

Table 2: Effects of Pst on Longissimus Lipid and Cholesterol Concentration - Genotype and Gender Effects

	Longissimus Lipid Concentration (%)				
	pST Dose, $\mu g \cdot kg^{-1} BW \cdot d^{-1}$				
Group	0	50	100	150	200
Fat Strain Barrows	3.43	2.50	1.77	2.60	1.32
Lean Strain Barrows	3.38	1.54	1.49	1.20	.77
Lean Strain Boars	2.57	1.54	1.03	1.01	.49

S = .96; n = 10; pST = P<.001; Genotype = P<.002; Sex = P<.08

	Cholesterol Concentration,(mg/100g)				
	pST Dose, $\mu g \cdot kg^{-1} BW \cdot d^{-1}$				
Group	0	50	100	150	200
Fat Strain Barrows	56.0	58.9	55.4	62.2	57.2
Lean Strain Barrows	56.4	58.9	59.0	57.4	61.2
Lean Strain Boars	55.4	55.7	54.0	55.9	57.1

Pooled S = 7.06

Marked change in proximate composition of adipose tissue was also observed with increasing dose of pST administration (see table 3). Linear reduction in adipose tissue mass was accompanied by linear decreases in lipid concentration and linear increases in protein and moisture concentrations of adipose tissue. Ash concentrations were not affected by pST administration.

With such large reductions in lipid concentration, treatment differences in fatty acid concentrations would also be expected. Analysis of lipid extracted from the longissimus muscle for fatty acid composition did show that the percentage of C18:2 (linoleic acid) was increased approximately three percentage points with pST administration (see table 4). These differences explained the significant increase observed in percentage of polyunsaturated fatty acids. Percentage of C16:1 (palmitoleic) and C18:1 (oleic acid) were decreased, resulting in a significant decrease in total monounsaturated fatty acid percentage. The only other significant change observed was a small decrease in percentage of C14:0 (myristic acid).

Table 3: Dose-Dependent Effects of Porcine Somatotropin on Adipose Tissue Distribution and Proximate Composition[1]

	Daily somatotropin dose, $\mu g \cdot kg^{-1} BW \cdot d^{-1}$				
	0	50	100	150	200
Adipose Tissue					
Weight, g	2285^{a}	1773^{a}	757^{b}	467^{b}	362^{b}
Protein, %	4.4^{a}	7.2^{b}	$8.7^{b,c}$	9.9^{c}	14.3^{d}
Water, %	19.1^{a}	26.9^{b}	31.3^{b}	38.2^{c}	49.1^{d}
Lipid, %	76.0^{a}	65.2^{b}	58.9^{b}	50.8^{c}	36.1^{d}
Ash, %	0.1	0.5	0.8	0.5	0.3

[1] Least square means represent 10 pigs per pST dose; data are expressed on a wet-weight basis.
[a,b,c,d] Means within a row with different superscripts differ ($P<.05$).

Table 4: Dose-Dependent Effects of Somatotropin on Fatty Acid Composition of Longissimus Intramuscular Lipid in 90 kg Barrows and Boars[1]

	Daily somatotropin dose, $\mu g \cdot kg^{-1} BW \cdot d^{-1}$		
	0	50	100
Number of pigs	20	20	20
C14:0 (myristic)	1.45^{a}	1.13^{b}	1.22^{b}
C16:0 (palmitic)	$24.86^{a,b}$	24.24^{a}	25.42^{b}
C16:1 (palmitoleic)	3.80^{a}	3.28^{b}	$3.43^{a,b}$
C18:0 (stearic)	11.66	12.38	11.69
C18:1 (oleic)	45.78^{a}	43.47^{b}	42.61^{b}
C18:2 (linoleic)	12.62^{a}	15.80^{b}	15.50^{b}
Total saturated	37.96	37.77	38.34
Total monounsaturated	49.57^{a}	46.75^{b}	46.04^{b}
Total polyunsaturated	12.62^{a}	15.80^{b}	15.50^{b}

[1] Data are expressed as percentages of the total lipid. The following fatty acid concentrations were below the level of detection: C12:0, C14:1, C18:3, C20:0, C20:1, C20:2, C20:4, C22:0, C22:1, C22:6, C24:0, C24:1. No sex effects were observed ($P>.05$).
[a,b] Means within a row with different superscripts differ ($P<.05$).

Administration of somatotropin in growing ruminants (cattle and sheep) produces similar effects on carcass and tissue composition, but of smaller magnitude than observed in pigs (Beermann and DeVol, 1991). Subsequent studies have shown that response to ST administration is constrained if adequate supply and proper amino acid balance are not provided in the diet. Administration of ST does not increase nutrient requirements per se, but the basic principles of nutrition must be adhered to for optimum efficiency of nutrient use for growth, as is required in both average and superior genotypes.

Other approaches to achieve the results demonstrated with exogenous administration of somatotropin include administration of growth hormone releasing factor (GRF), or a somatotropin secretagogue, and immunological manipulation of the somatotropin axis to enhance the normal metabolic effects of somatotropin (Beermann et al., 1990; Beermann and DeVol, 1991). The striking difference between direct administration of ST and GRF (or other ST secretagogues) is that a more frequent administration of GRF is required. This is because the transient increase in ST secretion lasts only 45 to 60 minutes after a single sc injection of GRF, whereas a single sc injection of ST will elevate ST concentrations for up to 8 to 12 hours. Slow-release forms of ST are now available which preclude the need for daily administration, and developing delivery technologies may eventually lead to more practical systems for use of peptide materials that cannot be orally administered.

Another class of metabolic modifiers has received intensive investigation in recent years, in anticipation that their use may also improve composition of gain and nutrient composition of carcasses and meat from beef cattle, pigs and sheep. This class of orally active catecholamine-like compounds, known as b-adrenergic agonists, have effects on protein accretion and lipid deposition as those observed with somatotropin administration in growing animals (see reviews by Beermann, 1993, 1994). Although time-course of responses and mechanisms of action are clearly different, the b-adrenergic agonists markedly increase the rate of skeletal muscle growth and concurrently reduce rates of lipid synthesis and deposition in cattle, sheep and pigs. Unlike bovine somatotropin, the b-agonists do not increase nutrient use for milk synthesis and secretion in lactating dairy cows.

These compounds do appear to be more efficacious in cattle and sheep than in pigs, but generalizations are difficult because marked differences exist in pharmacological characteristics of these compounds, including their rates of absorption, half-life in circulation, receptor specificity and metabolism. Because the effects are similar in magnitude to those observed with somatotropin, much interest in determining mode of action still exists, even though very few of these compounds may ever be reviewed by the FDA for approval for commercial use in food-producing animals.

In summary, opportunities for altering composition of foods through application of various biotechnologies do exist. Molecular approaches to alter the gene compliments of bacteria are in use for producing compounds which through their ability to alter metabolism in growing animals, do reduce lipid synthesis, deposition and lipid content of skeletal muscle and adipose tissue.

Transgenic animals have been produced which exhibit increased expression of inserted homologous or heterologous genes for somatotropin and somatotropin secretagogues. The practical application of the latter technology is still years away from implementation on a commercial scale. Likewise, although transgenic flaxseed and cotton seed may be released to producers within the next year or so, emphasis will remain on agronomic traits rather than on altering composition (Karen Marshall, personal communication). Economic incentives remain the dominant influence in directing use of current biotechnologies for enhancing food and fiber production systems. It appears that plants with altered composition, or which produce seed with altered composition may not be commercially available until around the turn of the century.

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pST Enhances Carcass Composition and Growth Efficiency of Pigs

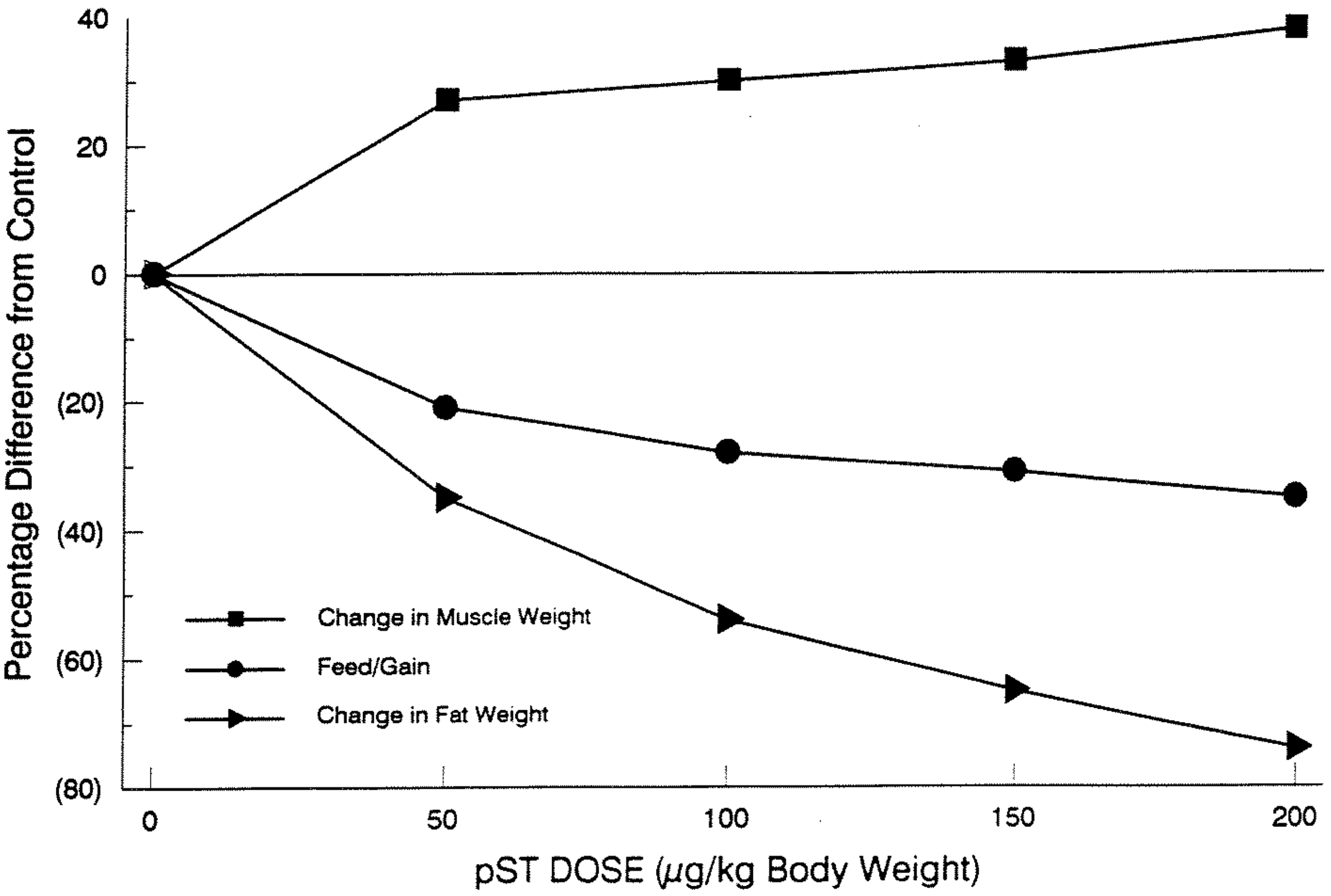

Figure 1: Daily administration of porcine somatotropin increases total muscle mass, decreases total carcass fat mass and reduces the amount of feed required per unit of body weight gain in a dose-dependent manner in market pigs.