Biotechnologically Modified Animal Products

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The 1990s have become the decade of food safety and environmental awareness. The entire social contract between consumers, food producers and provisioners is in transition. From a consumer's perspective, safety, healthfulness, and the environmental aspects of food are interrelated and inseparable. The dramatic success of agricultural biotechnology has led to expectations and demands for products with desirable composition and food value that are safe and wholesome, and a food supply that is bountiful, appealing, nutritious, healthful, economic, convenient and safe.

In addition, as the American consumer has become more weight-and health-conscious, food is expected to impart health benefits which extend beyond mere nutritive value. Consumers recognize weight gain and its' associated effects on health as a national health problem. The Institute of Food Technologists (IFT) recently estimated that over 34 million people in the United States are overweight—13 percent are described as severely obese. The population has evolved into a "lean conscious society" where a high priority is placed on ways to get and stay trimmer. People are more concerned about exercise, consumers' diet, and food quality assisting in this change in lifestyle. This consciousness is evident in the desire for leaner animal products with less fat and cholesterol than found in traditional animal products.

Along with consumers, the animal industry also wishes to reduce the wasteful production of excessive carcass fat. The current yearly production of six billion pounds of waste and trim fat from beef cattle is equiva-

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lent to two Iowa corn crops in feed energy, and must be reduced as rapidly as possible. While extensive trimming of animal products' fat occurs from slaughter through to the consumer and results in a reasonably lean animal product, preventing excessive fat deposition where it occurs will minimize carcass waste, increase production efficiency, and effectively reduce the caloric content of the animal product delivered to consumers.

To accomplish this requires use of biotechnology in the production segments; for animals this is during stages of growth and production. A rapidly increasing fraction of consumers also expects foods to be further processed and table or consumption ready, requiring new technologies in post-harvest segments of food production. Further, the desire for food safety assurance will require development and integration of sensitive biotechnology-based monitoring throughout all stages of producing a food from conception to consumption in HACCP quality assurance systems.

Role of Biotechnology in Quality and Safety of Animal Foods

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Consumers, for several reasons, have become increasingly concerned about the quality and safety of the food supply, including animal derived foods. This reflects concerns surfaced through media and special interest attention to unknown risks in the environment and food supply. Consumers are now questioning whether, in fact, biotechnology should even be used in food production. The basis for biotechnology's use in producing consumer-desired animal products must be explored in order to further understand these concerns.

Why Use Biotechnology in Animal Production?

The animal industry must regulate animal production in order to deliver consumer-desired foods and / or other required specialty (i.e., health) products. Appropriate technologies allow the modification of animal products

to better fit consumers' nutritional needs and desires. Currently it is difficult sometimes to separate food from medicine since many foods contain components (i.e., specific types of fibers) associated with improvement in some body function. As opportunities arise to genetically engineer animal systems to produce specific needed protein compounds, such as insulin and other life-support proteins in milk, the distinction between medicine and food will become even more clouded. Biotechnology will become an even more important component in the modification or regulation of key aspects of animal production from conception of the animal through delivery to the consumer, to allow the efficient provisioning of needed animal-based food and health products.

Current technologies used in animal production modify growth, resulting in leaner products with less fat. For example, beef production incorporates anabolic implants which produce a leaner product. Emerging technologies promise similar options for pork and poultry, with applications for fish as well. It would be unfortunate if safe, efficacious technologies for producing safer and healthier consumer-desired animal products were rejected by consumers on the basis of misinformation through special interest (i.e., vegetarian, animal rights) agendas. In assessing options for the use of biotechnologies, those which enhance real and / or perceived product quality or safety and the quality of life of the consumer are most readily accepted. Unfortunately, the value of these technologies has not been communicated to consumers with the same message penetration as the emotional appeal for "natural" food production systems.

What Needs To Be Modified In Animal Food Products?

Food products suitable for biotechnological modification include meat, milk, and eggs. Many animal products currently produced may need to be modified to provide foods more closely aligned with contemporary nutrient needs and food choices of specific consumers. For many reasons, amounts of fat, specifically those fatty acids known to elevate cholesterol production (saturated with more than 16 carbons) or those known to enhance tumor growth (i.e., 18:2, Iinoleic), may need to be reduced in common diets in many people. Hence, appropriate changes in both fat content of foods and composition of fat present (fatty acids) may be desirable. Cholesterol levels in foods *per se* are not as important, because only a small fraction of this cholesterol is absorbed—therefore diet contributes only a very small fraction of the overall daily cholesterol production in humans. Nevertheless, consumer perceptions indicate that a reduction in cholesterol levels in animal foods would also be desirable.

Other modifications could also be useful. For example, the amount and type of protein present in foods is also important, and changes in animal function to produce consumer-desired types of protein (e.g., white vs. red meat, fiber size, etc.) would be useful. Biotechnology which reduces levels of natural carcinogens, or enhances levels of anti-carcinogens also would be important in producing animal foods which are perceived as safe. Options to accomplish this currently exist for some components (e.g., aflatoxins) and have been studied or are in development for others (e.g., pesticides).

Mechanisms To Modify Animal Products

Animal food products represent an integration of events ranging from initiation to harvest, and from post-harvest processing to produce, preserve and deliver foods to consumers. In turn, biotechnological options to modify animal products exist in all segments of production. Some key options include: modification of substrates used, modification of growth and systemic production processes, and post-harvest product processing. These are accomplished in several ways and can be categorized as follows:

feedstuff selection and processing
digestive tract processing physiology
physiological repartitioning
tissue specific modification

Feedstuff Selection and Processing Although this is an area that has received substantial attention, especially in recent years, feedstuff selection and processing is not a new phemomena. For quite some time, mechanisms which modify the fatty acid composition of animal products have been established, particularly in animals, with minimal microbial modification of feeds prior to absorption. For example, the fatty acid composition of pork and poultry products largely reflects dietary fatty acid composition. As a consequence, composition of fat within some limits can be modified easily in meat products from these species through the selection of feed ingredients.

Once a desirable combination of fatty acids for human needs is clearly established, feeding-management systems can be developed to produce products which better reflect these needs. Challenges in the preservation and development of consumer-acceptable products with modified fatty acid composition are substantial and will provide numerous opportunities for biotechnology.

Further opportunities to modify the fatty acid composition of products such as meat and milk from cattle and sheep are limited currently and will require development of novel biotechnology to make substantial progress. Selection and processing of feedstuffs to limit microbial access to, and modification of, fatty acids represents an area of current interest and considerable challenge. Some progress with calcium and other salts of fatty acids (i.e., fatty acid soaps) has been demonstrated and products are currently being marketed for dairy cattle, primarily to increase energy intake and milk fat production with lesser emphasis on modification of milk fat composition. Further development of related biotechnology will be required to produce significant modification of fatty acid composition of beef or lamb products.

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Another area of biotechnologically important feedstuff processing is the development of procedures to sequester, degrade and / or limit absorption of natural and synthetic toxins such that safer animal products without these toxins can be produced consistently. For example, products developed for other feed uses have found application in binding aflatoxins to limit absorption in animals, thus reducing levels of toxins in products such as milk. Further development of this technology is encouraged, emphasizing options which limit further transfer of natural, environmental, crop production and microbial feedstuff toxins to animal products. Such measures will be required to establish consumer confidence in the production of safe meat and milk products.

Digestive Tract Processing Physiology Much research has been conducted on digestive physiology in order to understand the absorption mechanisms for various nutrients and substrates for metabolism. Biotechnological applications in two major areas may be important. One, options which alter the distribution or function of specific microbes in the fermentative compartments of the digestive tract of ruminants may in turn alter the substrates delivered for use to the animal tissues. Possible modifications include: volatile fatty acids and long chain fatty acid modification and synthesis resulting in altered composition of fat in animal food products produced. Two, modification of the digestive tract conditions and processing through pH, enzyme activity, flow rates, passage, retention time, and absorptive mechanisms, among others, will allow altered substrate

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delivery to the animal tissues. This will modify the rate and composition of animal tissue growth, producing modified food products.

Physiological Repartitioning to Produce Leaner Animal Products Repartitioning of growth and the consequent modification of animal products has received major attention in recent years. Repartitioning clearly provides the most direct and efficacious mechanism for changing the protein and fat content of animal tissues. The objective is to repartition the growth patterns in animals to produce leaner animal products and less fat from all animals. While repartitioning is the eventual goal of many genetic engineering initiatives, systems employing these concepts such as transgenic animals are not likely to surface any time soon. A number of options are feasible in developing systems employing growth regulating biotechnology in several forms to produce leaner animal products, and these include the following:

a. Genetics
b. Endogenous regulation
    intact animals
    castrated-spayed
    autoimmunization
c. Exogenous regulation
    repartitioning agents
    estrogens
    zeranol
    androgens (e.g., TBA)
    growth hormone
    beta-agonists
    growth hormone releasing factor

Mechanisms of regulation include: priorities for protein vs. fat, redirection of nutrients, tissue mobilization, and limits for daily deposition

All options listed above have been investigated to varying degrees across animal species in developing targeted growth management systems to most efficiently produce desired leaner animal products. While genetic directives provide general targets for body and carcass composition, other factors really determine the extent to which these theoretical limits will actually be reached, or how patterns and priorities for growth will be followed or translated into and realized as growth. In all animal types, the energy available translates genetic directives through tissue regulation into patterns of growth.

Nutrition is directly linked to rate and composition of growth in several ways. Available energy is used to meet maintenance needs, protein growth, and fat deposition, primarily in that order. Thus, composition of meat products reflects levels of available substrates provided relative to maintenance and limits for protein growth with additional energy usually deposited as fat. The magnitude of nutritionally regulated changes in body composition at a given weight reflect animal priorities, rates of growth and length of time that animals are growing at respective rates. Slower (deferred) growth for extended periods of time invariably results in leaner carcasses at any selected weight. External regulation through growth-regulating biotechnology redirecting growth allows the integration of growth potential with nutrient supply resulting in the desired animal products.

Repartitioning mechanisms involved in redirection of growth include: modification of priorities for nutrient use for protein vs. fat deposition; alteration of tissue turnover; modification of daily tissue deposition limits; and modification of nutrient supply. Eventually, growth hormone, releasing factors for growth hormone, beta-agonists and / or immunization strategies to remove negative feedback on growth (e.g., somatostatin) may provide additional mechanisms with which to regulate growth. These may work in concert with, or replace, current growth regulation technology. These alternatives are currently in development.

Current estrogenic growth regulators such as growth hormone, and beta-agonists used in development for several animal species, are effective repartitioning agents which modify growth by shifting nutrients from fat to protein accretion (Fig. 1). Also they usually enhance rate of growth as well, serving to further increase lean tissue production. Rate and efficiency of lean tissue growth are critical components in enhancing lean animal production through conventional animal feeding and management systems. In addition to more efficient production, they provide the opportunity to regulate growth in order to tailor animal production to meet consumer desires for leaner animal products. While current growth regulators have been used for several decades, the basis for their function has only recently begun to be understood. This understanding is important for the development of growth regulation systems which allow programmed growth of animals.

Recent research provides new insights into the mechanisms by which growth regulating biotechnologies operate in animals. Protein growth is a daily function, and theoretically, cellular mechanisms establish the maxi-

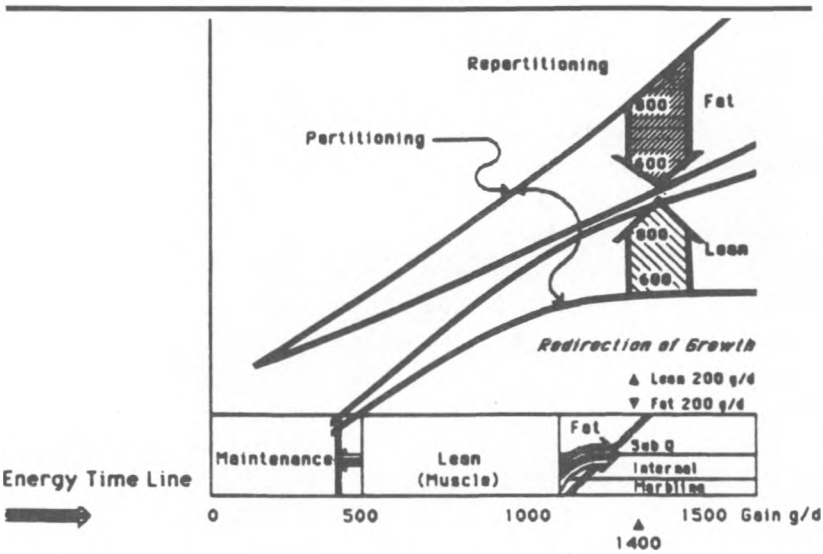

Figure 1 Rate vs. composition of gain and repartitioning of nutrients from fat growth to protein growth vs. rate of growth.

mal rates for daily protein synthesis. In actuality, cellular limits for protein growth are not often reached due to physiological factors, including hormonal and nutritional mechanisms which set priorities limiting protein deposition.

Carcass animal products reflect accumulative growth from birth to slaughter. As a consequence, use of growth regulation biotechnologies from birth to slaughter provides lifetime growth regulation and provides the maximal redirection of nutrients from fat to protein and lean tissue production. The longer growth regulators are provided, the greater the increase in total lean animal product with a simultaneous reduction in fat.

While several options exist for producing leaner animal products, the product must be acceptable, even desirable in the marketplace. Thus, the degree to which these production strategies impact the production of lean animal products must also be assessed in terms of product acceptability. For example, forage-fed beef, because of its darker and softer lean will not have the retail case shelf-life equal to that of grain fed beef. This presents a serious problem from the consumer acceptance standpoint. Meat from these carcasses is also borderline in taste acceptability.

Tissue Specific Modification Growth regulators and repartitioning agents function through reducing fat deposition. Since a relationship of fatness to marbling exists, a reduction in marbling and resulting quality

grade can be expected when fatness is reduced. However, for example, with current estrogenic growth regulators, consumer acceptability, shear force, palatability and tenderness are altered to a lesser extent than expected from the reduction in fat. This reflects the greater reduction in subcutaneous and kidney-pelvic fat than in intramuscular or marbling fat with estrogenic growth regulators when nutrients are redirected from fat to lean. This allows carcass quality to be maintained with a lower total degree of fatness.

Safety Background

Growth regulators currently approved for use with beef cattle are either endogenous compounds already present in human and animals (e.g., estrogen, testosterone, or progesterone), or are compounds developed through biotechnology to mimic these endogenous substances (e.g., zeranol or trenbolone acetate). None of these compounds are ever fed to animals in the United States. Instead, they are placed in the ear, which does not normally enter the food chain. When used in cattle, production residues in meat are extremely low and lower than naturally occurring levels in meat from cows and bulls. Levels of hormones produced in people every day are many thousands to millions times greater than present in meat either naturally or as a result of use of a growth regulator in cattle. Also, other foods, especially vegetables, salad oil, etc. provide thousands of times more estrogen than meat from cattle, whether receiving growth regulators or not, and less than 10 percent of what is consumed is absorbed by humans—so the contribution from beef is truly negligible.

Growth regulators in development, including growth hormone, beta-agonists, growth hormone releasing factor, and immunization will be equally safe but also subject to public perception.

European Economic Community Safety Issues

The European Economic Community(EEC) imposed a ban on beef imports from the United States and other countries using anabolic growth regulators commonly referred to as “hormones”. The ban was originally launched under the guise of “safety” issues. The directive for the ban has been adopted by the EEC although all safety issues were dismissed long ago by both the EEC's own commission, “The Lamming Commission” and by the United States own regulatory agencies, the Food Safety and Inspection Service (FSIS) branch of USDA, and FDA).

While the need to produce leaner, health-promoting animal products has become painfully clear, the segmentation of the industry, and its' divergent goals, objectives and profit centers, has resulted in mixed signals at best.

In contrast to the United States, where biotechnology is tightly and efficiently regulated such that no violative residues were found in the past four years of the USDA-FSIS National Residue Program, as much as one fourth of the beef produced in the EEC contains unacceptable residues of compounds never cleared for use in cattle. Some of these compounds are known carcinogens such as DES. A safety issue exists with EEC beef because of the use of unapproved "cocktails" of many potent drugs directly injected into the muscle of growing cattle on EEC farms which came about as a result of bans on the use of approved products instated during the past two years.

Current Market Signals

While the need to produce leaner, health-promoting animal products has become painfully clear, the segmentation of the industry, and its' divergent goals, objectives and profit centers, has resulted in mixed signals at best. In typical scenarios, incentives to produce fatter animal products often prevail. Incentives for producing leaner animal products must be established in all segments of the industry to assure coordination of growth toward optimal market endpoints.

One of the major problems is the short "shelf-life" of animals nearing slaughter endpoints. The concept of shelf life was developed to define the time and/or weight interval over which an animal maintains its current quality or yield grade. For some animal types, shelf-life in the feedlot may not be appreciably longer than post-harvest shelf-life in the retail trade. Extending this interval would provide more flexibility in marketing, and animals could increase in fatness at a slower rate, so that overfeeding would be less deleterious to lean animal production. Repartitioning agents provide options for increasing the shelf life of animals.

Diet-Health Aspects of Modified Animal Products

In concert with consumer desires to be, think, and eat "leaner", there is also an interest in reducing fat consumption, particularly saturated fat, and cholesterol levels—both dietary and circulating. The most common concerns are that animal products are high in calories, saturated fat, and cholesterol.

An average three-ounce cooked lean beef, for example, provides only 73 mg of cholesterol, which is less than 25 percent of the American Heart Association's recommendation of 300 mg per day. This average three ounce

portion of cooked lean beef provides only 192 kcalories of energy, less than 10 percent of a 2000 kcalorie diet. Less than half of this energy (85 kilocalories) comes from fat and the saturated fat component contributes only half of that. These levels of calories from fat are far below the American Heart Association's recommendations of no more than 30 and 10 percent of total calories from fat and saturated fat, respectively. As is evident, lean animal products fit well within dietary guidelines; the challenge from the production perspective is to produce inherently lean animal products which do not require extensive trimming along the retail chain. Opportunities for reduction in fat and fatty acid modification will further advance the potential to deliver consumer-tailored, safe and healthful animal products.

Implications of Social/Political Policy

Recently, the EEC proposed a ban on imports of animal products from countries using growth regulators. Recent data were summarized to assess the impact on the industry in the United States. In a summary of growth regulation studies at Texas A&M University, the change in net return on a lean retail product basis including feed, interest, implant cost, yardage and with an average retail product value of $2.50/lb, averaged $96.68 per animal. This represents a net value to the United States beef industry of approximately 2.5 billion dollars with these data as above. These data are consistent with results of a 1987 USDA study indicating a $2.4 to $4.1 billion reduction in net return on a retail products basis if currently approved growth regulators were not used in the United States depending on feeding and marketing management alternatives. Worldwide implications would obviously be much greater, and this is borne out in the USDA study.

Clearly, when safe, approved, efficacious biotechnology is banned to serve popular, protectionist, or political purposes, only unapproved technology will be available for use. Use of approved safe growth regulators allows application of biotechnology to produce leaner beef products consistent with dietary and health needs of consumers. The ban on this technology in the EEC has resulted in the delivery of fatter beef products to European consumers, a situation inconsistent with the needs of United States and other consumers.

Similar restrictions are forthcoming or are currently in place regarding the use of growth hormone-based technology currently in development to modify meat animal products (i.e., EEC) or quantity of milk produced per animal (as seen in Minnesota and Wisconsin).

In producing environmentally sensitive animal products, the adoption of technology (such as grain feeding, ionophores) to reduce methane, or growth regulators to enhance lean tissue growth, reduces the methane per unit of beef produced. Elimination of these technologies (i.e., growth regulation ban by EEC) would result in decreases in rates of lean tissue growth and more methane per unit of beef produced. Hence, disallowing technology for more efficient production of meat (growth regulators by EEC) or as suggested for milk production (i.e., BST) would directly increase the animal contribution to global warming by requiring the production of more methane per unit of product, be it meat, milk, fiber or draft power. While the contribution of the United States beef cattle industry to annual global methane production (0.5 percent of total estimated production, 0.1 percent of all global warming) is not outstanding, it will be important to facilitate transfer of all available technology to enhance rate and efficiency of growth to reduce methane emissions from beef cattle production systems in the United States and worldwide, to further limit the contribution of cattle to global warming and changing of the earth's climates.

Conclusions

Meeting the demands imposed by consumers and industry for health consciousness and animal efficiency in the production of high quality, safe, lean, and healthful animal products requires immediate attention to the issue of increasing lean tissue and reducing fat deposition in animals. The ability to produce highly palatable and acceptable lean animal products is of critical importance for the animal industry. The calorie consciousness of consumers requires a sincere effort on the part of the animal products industry to produce leaner animal products to meet diet and health concerns of an increas.. Jly perceptive consumer. Lean animal products fit well within dietary guidelines; the challenge is to produce animal products that are lean in the carcass and do not need extensive trimming along the retail chain to make them lean.

Unique challenges face the animal industry in the design and development of new technologies that will allow production of lean animal products rather than require extensive trimming to make them lean. This will require development of greater lean tissue deposition throughout the life cycle and extensive redirection of feed energy from fat to protein growth through all phases of growth.

However, society is increasingly concerned about the use of chemicals and residues in our food supply. The animal industry must develop, communicate and extend the use of current and new biotechnologies and sys-

tem to efficiently produce leaner animal products. Technologies providing economic return without known benefit in enhancing quality of life and/or with perceived negative human health implications (e.g., residues) may be short-lived.

Our primary challenge is to develop systems employing current and new biotechnologies which will allow us to produce specific uniform products from diverse animal production systems in a range of designer foods.

The successful development and implementation of animal products will depend on consumer desires and demands.

Most importantly, we must clearly 1) *define* needed consumer attributes of specific products and then 2) *derive* targeted-integrated biotechnology based production systems to efficiently produce these products in order to 3) *develop* more desirable products than currently exist in the animal products industry. Our total system from conception to consumption must be consumer driven and must focus on the final target product as biotechnology-production-management-marketing options are selected. Concurrently, all technology implemented in the production system must eventually be marketed to the final consumer as well; currently this is seldom accomplished. There will be increasingly limited opportunities to use technologies inconsistent with quality of life of consumers, and in the future, both the product as well as the system used to produce it will need to be consistent with consumer needs and attitudes.

The successful development and implementation of animal products will depend on consumer desires and demands. While animal-product biotechnologies have the potential to provide seemingly desirable products more efficiently than current systems, their introduction and development relies ultimately on consumer acceptance. In addition to consumer concerns, consumers and developers alike need to consider carefully the social and economic implications of biotechnological developments.

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