Opportunities for Science and Technology to Improve Production Systems to Assure Animal Well-Being and Economic Viability

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Introduction

It is instructive to examine the past when attempting to understand the present and anticipate the future. In this spirit I believe we can agree that developments in science and technology have had a great influence not only on the production and processing of food animals, but also on our dietary habits. Before these developments, domestication of plants and animals facilitated many changes in the food we eat and in its production. Domestication, a process recent in terms of human history, has greatly affected civilization. It allowed for development of industrial societies. These societies provide their citizens with many benefits as well as a myriad of problems associated with unprecedented population growth, increased urbanization, and an explosion in communications, which increase social contact among people.

Great changes continue to occur in food animal agriculture. Husbandry, transportation, and slaughtering practices are under constant scrutiny. Scientists are becoming more aware that they must take a holistic approach and be concerned with how their findings are used and the impact of their efforts on various segments of society. Rightfully, there is increasing debate concerning all aspects of food animal agriculture. Answers to questions are often unavailable because of a lack of scientific evidence. Alternatives are advocated, and current practices defended without scientific evidence. Research is often difficult, not just because of a lack of basic knowledge, inadequate methods, and need for an interfacing of disciplines, but because both economic and humanitarian considerations are involved. These impediments should not be reasons for dismay; they should be viewed as opportunities and challenges for science and technology.

Domestication

A central item in evaluation and improvement of production systems is assessment of well-being of animals in environments to which they are exposed. Because there are interactions between genotypes and environments, the process should be viewed in an evolutionary context including domestication. As pointed out by Darwin (1875), domestic animals were modified through unconscious selection. Population means were changed across generations by selecting individuals exhibiting desirable traits and culling the others. Therefore, domestication should be viewed as a continuing process by which humans, trying to achieve certain goals, attempt to modify the expression of traits by genetic and/or nongenetic means.

Five stages of early domestication described by Zeuner (1963) were reviewed by Hart (1985), who alludes to the emergence of a sixth stage. Hart points out that domestic animals retain species behaviors such as social interactions, reproduction, feed intake, and elimination that are typical of their wild ancestors. He wonders if a new stage in domestication may be occurring by which human intervention will be necessary for domestic animals to survive in the wild. Stated another way, how far has selection gone in modifying traits in food animals so that their ability to adapt has been reduced? Behavioral, physiological, and morphological changes that have occurred in animals during domestication have been quantitative rather than qualitative, with modifications reflecting altered thresholds rather than elimination or introduction of traits (Price, 1984). Food animals reproduce readily with their wild ancestors, suggesting that the process is minor in an evolutionary context. Production practices have changed greatly, and breeding programs have intensified since the middle of the 20th century. Thus it may be instructive to return to the past and review behavioral characteristics of the higher vertebrates that became the major sources of today's food animal production.

For most of the world, food animals (excluding those from the sea) come from three orders. These orders are *Artiodactyla* (e.g., cattle, goats, swine), *Anseriformes* (e.g., ducks, geese,), *Galliformes*, (e.g., chickens, turkeys). Hale (1969) pointed out that these orders of animals were amenable to domestication because they exhibited certain behavioral traits favorable to the process. Hale's list of these behaviors included a hierarchical group structure that facilitated combining of sexes and varying population size, precocial young with rapid parent-offspring attachments, promiscuous sexual behavior, positive reactions to humans, general dietary habits, and ability to adapt to a range of environments.

Advances in science and changes in technology have accelerated the process of domestication of food animals. Dramatic changes in production and marketing practices have occurred, especially in industrial societies. Contributing to these changes are increased costs of land, labor, and energy. Environmental concerns are of great magnitude and importance. It may be argued that improvements in feed utilization may be of greater value in reducing the volume of animal waste than in reducing feed intake. Artificial insemination, artificial incubation, rearing of young separate from their parents, and feeding of specialized diets are examples of technologies that have reduced the importance of many behaviors that initially facilitated domestication of food animals.

One item, however, continues to be paramount, i.e., adaptability to a range of environments. The buffering used by individuals and populations in coping with changes in their physical and social environments involves complex behavioral, genetic, and physiological responses that influence well-being. In viewing the buffering, the environment should neither cause over stimulation nor be so void of stimuli that animals express the consequences of deprivation (Mench, 1992). Another element that may be factored into the equation is use of compounds and introduction of genetic materials that alter specific parts of an animal. There is need to know types of interactions that exist and how they may create skeletal, metabolic, and muscle disorders or modify resistance to toxins and infectious agents. Such information is essential for design of production systems that not only provide optimum stimuli for well-being of food animals but also enhance economic returns.

Today

Food animal production can be divided into two groups: animals that have to be killed because they are grown to provide meat per se (e.g., beef cattle, broilers, ducks, sheep, swine, turkeys) and those grown mainly because they produce a product (e.g., eggs, milk) without having to be sacrificed. In both cases, there should be concern with the ultimate death of the animal. Science and technology must examine and develop improved methods for transporting and slaughtering food animals (e.g., Bayliss and Hinton, 1990; Nicol and Scott, 1990; Grandin, l993).

It is my opinion that many changes made in food animal agriculture during the past several decades were based on economics rather than well-being of the individual animal. Labor and capital costs have received primary emphasis. Regardless of the species, production units became larger and more intensive. The ability of an individual to adapt to its environment depends on selection during the history of the population and adjustments made during its life. Rapid and sometimes dramatic changes in production practices may not provide time for biological adjustments to occur. Little information is available on genetic techniques available for making such estimates, but with few exceptions (e.g., Siegel et al., l992), molecular geneticists working with food animals appear to be more intent on mapping the genome of their species and on investigating marker-assisted selection (both important topics) than on addressing questions such as those involving genetic diversity.

Food animal agriculture had difficulty almost three decades ago when attempting to respond to criticisms raised by Harrison (1964) in her book *Animal Machines*. A response based mainly on productivity levels was not acceptable then and is not acceptable now because well-being and productivity should be viewed both long- and short-term. Criteria to evaluate well-being should include production, physiological, behavioral, and immunological traits both at the individual and population level. When developing these criteria, we should remember that, barring mutation, the genome of an individual remains the same from the time of fertilization, while physiological, behavioral, and immunological status can be quite dynamic during the life of an individual. Science is providing models, and techniques are becoming available for integrating physiological, behavioral, and immunological criteria (e.g., Marsh, l992; Sapolsky, l992; Koene, 1993). Awareness of economic realism implies that production traits must be factored into the paradigm. In this context, Appleby et al. (1992) have attempted to examine poultry production systems. Additional attempts are essential, not only for poultry, but for all food animals.

Opportunities

Backgrounds, attitudes, and traditions are among many things that influence how well-being of food animals is viewed. There is the saying that everyone is ignorant, but ignorant about different things. The issues being discussed at this conference provide opportunities for individuals with diverse educational backgrounds and training in specific disciplines to integrate their knowledge and capabilities. Topics such as pain, drives, reproduction, growth, motivation, stress, homeostasis, and profit have different meanings to different people. Philosophical, theological, and economic issues can expand our thinking and bias our beliefs.

In discussing welfare (well-being), Mench (1992) states that definition is central to techniques used in measurement. As stated previously, there is no single criterion for measuring well-being. Yet we must remember that traits that are measured must be recurrently identified and classified. Also, production systems must be realistic in an economic world when human populations are expanding exponentially. Without population control this conference will, in the long-term, be merely an intellectual exercise.

Economically, there is concern with the animal and the production unit. These are separate items and should not be viewed as the same. Natural selection works at the level of the individual, and biologically the individual is the main focus. There is plasticity within individuals that can work in many ways to enhance short- and long-term survival. There are costs to the animal for such plasticity, because finite resources have to be allocated. Phenotypic variation of traits within populations depends on genetic and nongenetic variation. Computer simulations may be useful in evaluation of well-being and economic viability. They must, however, be based on assumptions that are biologically realistic. Moreover, models must also be tested in the real world.

Behavior, both in humans and food animals, is a hurdle in improving production systems through science and technology. For humans a behavioral impediment to studying animal well-being with economic viability is that of protecting turf. Economists have views that differ from those of behaviorists, whose views differ from those of physiologists or veterinarians. Then, too, there are the engineers and, perhaps most important, farmers. It has been argued, with I believe some merit, that because primary considerations were economic, food animals were molded to fit specifications of equipment manufacturers rather than systems being designed to meet the biological needs of the animal. My sense is that this attitude is changing rapidly.

Well-being of food animals consists of more than general health, vigor, and vitality. Measures of production performance have played a prominent role in evaluation. Today other criteria are becoming more relevant. There is a voluminous literature on behavioral responses, immunocompetence, physiological responses, and production traits in food animals. Lacking, however, is literature where these criteria are considered in the same experiment. Multiple criteria are essential for measuring well-being of food animals, and generalizations should be tempered because responses may be modified by genotype, age, sex, environmental experiences, motivational states, and many other factors. Technology is providing increasingly sophisticated tools for use by both scientists and those involved in food animal production. It is essential that linkages be strengthened among all groups. Many of us associated with food animals take pride in being able to evaluate subjectively the status of flocks and herds as well as individual animals. Sounds can be helpful, and, with the use of sonographs, subjective impressions can be quantitatively evaluated (e.g., Stone et al., 1984; Koene, 1993). It is essential that quantification be used to evaluate the reliability of many subjective measures that will always be a part of food animal agriculture. The human element is not something to ignore. This comment is made, however, with the understanding that we must avoid the motto “opinion is worth more than knowledge.”

It is not uncommon for physiological and behavioral changes to occur concomitantly. Even when technology is available to obtain reliable measures of both behaviors and of physiological characteristics, interpretation of their meaning may be difficult. This issue has been discussed by several scientists (e.g., Dantzer and Mormede, 1985; Odberg, 1987). Relationships of humans and animals can take many forms, and the importance of positive relationships between them is well documented. Responsibilities of humans increase with intensification of food animal agriculture because mechanization may reduce the contact between them. Development of alternative production systems is coming into vogue. Such systems must consider the human factor as well as the food animal, and it must be remembered that economic viability includes many stages in the production and marketing chain.

Some Examples

At Virginia Tech, I have been fortunate to work with colleagues from several disciplines in a study of what may be called well-being. Our approach involves use of an adaptation model for the individual as well as selection theory (Siegel, 1984). Conceptualization of our thinking was recently published (Siegel, 1993), with the following paragraphs coming mostly from that paper and another published a few years earlier (Siegel, 1989).

Physiological adaptation has been viewed traditionally in the context of Selye’s General Adaptation Syndrome (GAS), with diseases of adaptation studied extensively. Adaptation is usually delineated into short-term flight or fight responses and longer duration accommodation responses involving the hypothalamic-pituitary-adrenal axis and its association with immunocompetence and health (Siegel, 1980). There is also an important distinction between what may be considered perception and physical aspects (McBride, 1980), as well as considerable genetic variation throughout the stimulus-response process.

Multigeneration behavioral and physiological relationships regarding environmental settings have been a fertile area of study for decades (e.g., Calhoun, 1962a, b). These relationships have become increasingly popular in studying food animals. Models have been proposed to describe individual and evolutionary adaptations to stimuli via behavioral and physiological means. Processes that use existing behaviors and those associated with perception and habituation may avoid involvement of physiological aspects of certain phases of GAS. An example of such a model (McBride, 1980; Siegel, 1984) proposed several vehicles for adaptation, including how innate behaviors and behavioral modifications precluded expression of various physiological responses and associated costs. Behavioral and physiological responses are not mutually exclusive. Habituation can reduce the magnitude of physiological change to subsequent exposures to a stimulus. Chickens adapting to feed restriction regimens are an example of habituation (e.g., Gross and Siegel, 1986; Zulkifli et al., 1993). Examples of innate responses are newly hatched chicks pecking at and swallowing small bright objects and newborn mammals sucking on protruding objects and swallowing fluids (Craig, 1981). The functions of these behaviors are locating and ingesting food. When the behavioral repertoire is inadequate, then GAS may become activated with an additional cost of accommodating the stimulus.

Preclusion of sensory information can be debilitating to the organism, and prolonged physiological adaptation can cause deviant behaviors. Adaptation should be viewed not only as successful or unsuccessful but with awareness that there is genetic variability among those individuals considered successful in adapting. This genetic variation, which provides a vehicle for the selection process, can be presented at several levels, ranging from sensory perception to suppression of immunological responses to foreign antigens (Siegel and Dunnington, 1990).

My colleague, Dr. Gross, and I were interested in evaluating heritable differences in responses to social strife and in whether genetic variation was sufficient to obtain a measurable response to selection. Development of diverse lines from a common gene pool had potential for conducting numerous experiments involving behavior, genetics, and well-being. The selection procedure was simple. Typically, chicks were reared as sex-intermingled flocks in battery brooders until about 35 days of age, when they were transferred to other cages and maintained as 8-bird groups. At about 63 days of age, they were subjected to social strife by moving them into new unisexual flocks regularly according to a plan that precluded contact with previously encountered individuals. After a fixed period (usually 14 days) plasma corticosterone concentrations were measured. Opposite extremes from the base generation provided parents to produce high and low corticosterone response lines to the social strife. Thus, truncation selection was practiced within each line for either high or low plasma corticosterone concentrations.

Separation of lines was rapid, and by the sixth generation there was essentially no overlap in plasma corticosterone distributions between individuals of the selected lines. Pre-movement plasma corticosterone concentrations were similar for both lines, showing that differences were in response to the social strife. In generations 7 and 8, the selection criterion was changed from plasma corticosterone concentrations to ratios of heterophils lymphocytes (H:L) in peripheral blood after two days of rotation (Gross and Siegel, 1985). The pattern between lines followed that for plasma corticosterone concentrations, with H:L ratios being greater for the high than low line and essentially no overlap between lines.

To evaluate responses to non-social stressors, chickens from these lines were fasted for two days or given an intravenous inoculation of *E. coli*. Both lines responded similarly to these stressors, with H:L ratios being considerably higher for *E. coli* inoculation than for fasting (1.90 versus 0.73). These results implied that selection was for differences in perception of environmental situations or in behavioral adaptations that filtered out physiological processes associated with the GAS. These results supported the models of McBride (1980) and Siegel (1984) and showed that genetic variation in perception can influence general well-being of individuals. Cognizance of this effect may influence health status and be advantageous at both ends of the spectrum (i.e., some individuals adapt inadequately, while others may over-adapt and divert resources from other functions).

Genotype by environment interactions occur when, relative to each other, individuals from a series of genotypes do not respond similarly in a series of environments. Numerous reports appeared during the 1970’s showing behavioral involvement with genotype by environment interactions. Implications of these interactions can be considerable when viewed in the context of well-being. Although genotype by environment interactions limit inferences of how different genotypes respond in different environments, generalizations may be made. For example, although different feeding regimens are needed for meat- and egg-type chickens, a unique regime is not needed for each meat-type stock.

Experiments involving production and disease resistance of our high and low cortisterone-response lines generally showed extreme responses for the high line in a higher strife environment and the low line in a lower strife environment. Whether or not an extreme response was advantageous depended on the measurement criteria. The low line-low strife combination was more susceptible to infections from endemic bacteria and external parasites and high-high to viral infections. These data are consistent with the view that general well-being may be at an intermediate level where the animal is neither under- nor over-stressed.

The Future

Development of separate breeding programs for food animals resulted in populations that differ in growth and reproductive potential and behavioral responses. Differences in behavioral responses can contribute to a cascade of effects with negative influences on well-being. Environmental factors may modify some of these influences. Such demands are consistent with the history of domestication, particularly when economics is the driving force in deciding selection criteria. Genetic changes in traits result in reallocation of resources and may preclude compromises. Artificial selection for economic traits may modify expression of behaviors that reduce non-adaptive energy expenditures in particular environments. Individuals with high genetic potential for growth "and/or" reproduction may divert resources to achieve that potential from immunoresponsiveness and therefore become more vulnerable to pathogens. Conversely, those with high genetic potential for immunoresponsiveness may over-respond, resulting in a lack of resources for growth or reproduction.

The coming years will see a continuation of intense selection in animals grown for egg and milk production as well as in those grown for meat. Although there will be a leveling of intensification of husbandry practices, production units will become larger and increasingly mechanized. Human-food animal relationships will become less personal, and associated behavioral responses should be addressed, or there will be deterioration of well-being. Scientific and technological procedures will require a multidisciplinary approach with a problem orientation. This orientation will necessitate that scientists and technologists are trained more broadly so that they understand the language used in other disciplines. Intellectually, they must understand that the challenge will be to develop settings in which there are optimum stimuli to elicit behavioral and physiological responses with greatest biological advantage to animals of a particular stock in a realistic economic setting.

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