ENVIRONMENTAL STRESS AND MEAT QUALITY 1, 2

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In the broadest sense, the term "environmental stress" encompasses any stressful situation. On the other hand, there is a plethora of terms with subtle and pronounced differences in meaning which are used by environmental physiologists to describe the responses of animals to their surroundings (Folk, 1966). Additionally, the working boundaries one establishes in the field depends on his point of view with respect to the animal populations of interest, the degree of environmental control utilized and the level of response observed in the organism.

In this paper, major emphasis is given to the cumulative effects of chronic or continued environmental stressors on meat quality. This is not intended to minimize the importance of preslaughter handling practices as they affect postmortem muscle physiology. Rather, this decision is made in light of the recent comprehensive reviews published by Hedrick (1965) and Lawrie (1966) which deal with many aspects of the stress response and its manifestations in the musculature. In addition, the adaptive mechanisms by which animals resist stress influence muscle characteristics in ways that contrast to the immediate stress effects. Included, therefore, are the environmental influences exerted on muscle development and differentiation. Of particular interest is the role of the environment in establishing the metabolic capabilities of muscle tissue and the consequences in terms of postmortem physiological and chemical changes.

Stress Resistance and Stress Susceptibility. The ultimate response elicited by a stressor in any tissue depends on the ability of the animal to cope with the stress and the mechanism by which homeostasis is maintained. There are profound differences in these attributes among animals of different species and among those of the same species. This difference is easily recognizable in the paradox of the etiologies of dark-cutting beef and pale, soft, exudative pork muscle. These conditions can result from similar pre-slaughter treatments (psychological stress), yet, in the former case, there is glycogen mobilization from the muscle for systemic use in the emergency; whereas, in the latter instance, the circulatory system is apparently incapable of readily transporting lactate accumulations out of the muscle, and thereby is incapable of maintaining physiological conditions.

Stress susceptibility or stress resistance may be identified in certain genetic strains of pigs. The research of Judge, Cassens and Briskey (1967) demonstrated that pre-slaughter restraint elicited changes in muscle gross morphology that became progressively more severe as the duration of restraint was prolonged in a strain of Poland China pigs. In a strain of Chester White pigs, the initial results of restraint were similar, but as the treatment was prolonged these animals were able to respond and their muscle morphology returned to a condition similar to that of the unrestrained animals. This study shows that some animals have defense mechanisms which are capable of restoring physiological balance in the tissue during severe stress, whereas others do not possess these mechanisms and the stress condition becomes progressively more severe.

The stress susceptible porcine animal has been further characterized on the basis of its ability to maintain homeostasis in a warm environment. The findings of Forrest et al. (1968) revealed that 10-min. exposure to a 42°C environment causes increases followed by sharp reductions of respiratory rate, heart rate and cardiac output. They also reported increased partial pressure of carbon dioxide, decreased partial pressure of oxygen and decreased pH in the venous blood of these animals. The stress resistant pigs were able to withstand longer durations of heat stress with only minor changes in the gases and pH of the blood.

Some measures of endocrine function have also been reported for the stress susceptible pig (Judge, Briskey and Meyer, 1966; Judge et al. 1968a). When a susceptible group was subjected to ambient temperatures of 21 to

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24° C. after having been previously acclimated to a cool environment, certain unusual responses were recorded. Whereas the resistant animals experienced reductions in serum protein-bound iodine with time in the environment, the susceptible animals had deceased followed by increased serum PBI values. These animals also had relatively low thyroid I-131 uptake at the time their PBI values were high. Since the latter animals had high concentrations of lactic acid in their muscles, it is apparent that the high level of circulating thyroid hormone failed to stimulate oxidative metabolism in muscle tissue.

The animals described above (Judge et al., 1966, 1968a) were utilized in studies of adrenal gland function. Urinary 17-ketosteroids, 17-hydroxycorticosteroids and catecholamine levels were determined on samples collected during close confinement of the animals in the warm environment. The stress-susceptible pigs were reported to have some degree of adrenal insufficiency.

Other evidence is available to support the view that certain pigs have adrenal insufficiency. Degenerative changes in the zona reticularis were noted by Cassens, Judge and Briskey (1965). The abnormalities appeared as sudanophilic bodies, an abundance of which was associated with rapid muscle glycolysis and highly contracted sarcomeres. Ludvigsen (1957) observed that certain pigs had low levels of blood lactate after exercise which was viewed as evidence of poor circulatory function and inadequate adrenal cortical steroids.

Direct determinations of 17-hydroxycorticosteroids have been performed on the plasma of pigs ranging in age from 1 day to 9 to 12 mo. (Dvorak, 1967). These animals of unspecified breed experienced rapid declines in blood steroid levels. By the time the pigs were 16 to 30 days old, the hormone quantities had diminished to levels that were eight times lower than in the 1-day-old pigs. These age associated changes are unique for the pig, since several other species have increased steroid production with advancing age.

The studies cited above emphasize that there are marked differences in the endocrine status of porcine animals, and presumably these differences play important roles in the responses of these animals to continual environmental stress. The stress susceptible pig, therefore, may represent the result of intense selection for economically important traits with concomitant loss of defense mechanisms originally necessary for survival. This view may be related to the tendency for muscularity and the pale, soft, exudative muscle condition to be associated (Topel, Merkel and Wismer-Pedersen, 1967; Judge et al., 1968b). Current research depicts the stress susceptible pig as an individual whose physiological adjustments during stress are poorly coordinated and augmented by the endocrines, whose muscle undergoes extremely rapid rates of postmortem change with the accompanying development of the pale, soft, exudative condition and whose carcass is frequently well-muscled.

It is possible that conditions similar to those described above exist in other species, but only limited numbers of observations of comparable muscle conditions have been reported. In any case, it is important to consider the genetic background of the animals whose stress responses are to be evaluated.

**Chronic Stress and Meat Quality.** The earliest studies on the effects of long-term stress on meat quality were those of Mitchell and Hamilton (1933) using cattle. They reported that regular exercise on a treadmill throughout the feeding period resulted in muscle that was lower in fat, water and collagen but higher in glycogen than that of the control animals. Bull and Rusk (1942) found no qualitative differences in the muscles of exercised and control beef animals. In more recent studies of the effects of exercise during the growth period of lambs, Spaeth et al. (1967) reported that the legs of the exercised animals were more tender than the unexercised controls.

The growing lamb served as the experimental animal in studies designed to chronically activate the stress response and relate these responses to muscle properties (Judge and Stob, 1963; Bramblett, Judge and Vail, 1963). The treatments consisted of (1) daily electrical shock, (2) daily injection of epinephrine, (3) daily injection of saline and (4) unhandled control. Of particular interest was the ability of the animals to maintain growth of the lean tissues in spite of the relatively severe stress. The epinephrine injections elicited the most pronounced alterations in muscle properties of the treatments utilized. There were increases in muscle pH and depletion of muscle glycogen but, surprisingly, the hormone treatment produced an increased liver glycogen level. This phenomenon was explained as a difference in the
sensitivity of muscle and liver glycogen to the mobilizing effects of epinephrine. The muscle lactate was obviously transported to the liver for resynthesis into glycogen as in the “transfer” phenomenon reported by Sokal and Sarcione (1959). This observation probably relates to the mechanism by which these animals adapted to the stress treatment. It is conceivable that the chronic treatments resulted in exaggeration in the difference in stress sensitivity that normally exists between the peripheral tissues and those of the more vital visceral organs. Thus, the chronic stress may have rendered the muscle relatively more sensitive to external stimuli as compared to other body tissues.

Palatability studies on the chops from the animals just discussed revealed that muscle tenderness was reduced by the epinephrine and electric shock treatments (Bramblett et al., 1963). Since these muscles were relatively high in pH and were similar to those of the other treatments in water-holding capacity, it is probable that some constituent other than the contractile proteins, such as a connective tissue, was responsible for the difference in tenderness. Little is known of the effects of long-term stress on the connective tissues of meat animals. This area of work promises to shed light on many unanswered questions on meat quality.

A series of experiments have been conducted utilizing climate-control chambers in which the rearing environment of swine may be precisely controlled (Judge, 1968). Data have been reported on the effects of temperature acclimation and humidity level on the quality attributes of the muscles. These studies were conducted on genetic strains of three breeds of pigs (Landrace, Hampshire and Poland China) which produced high incidences of pale, soft, exudative muscle (Bramblett et al., 1963). Since these muscles were relatively high in pH and were similar to those of the other treatments in water-holding capacity, it is probable that some constituent other than the contractile proteins, such as a connective tissue, was responsible for the difference in tenderness. Little is known of the effects of long-term stress on the connective tissues of meat animals. This area of work promises to shed light on many unanswered questions on meat quality.

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of pH decline in the muscles (Howe et al., 1969), and, consequently, may have had an induced or aggravated adrenal insufficiency (Judge et al., 1968a; Cassens et al., 1965). Other workers have also reported cases of induced adrenal insufficiency. Nagel et al. (1965) observed that certain monkeys held in captivity did not respond normally to stress. They postulated that the stress of captivity depleted adrenocortical reserves and altered normal physiological responses.

Adrenal insufficiency may be manifested in the musculature in a number of ways. These include abnormal electrolyte balance and carbohydrate metabolism. With respect to the glucocorticoids, there is an intimate association with the maintenance of the microcirculation. Schayer (1964) has postulated that all the actions of this group of hormones can be related to their control of the small blood vessels. In this theory, the vasodilator action of histamine is opposed by the glucocorticoids, so that adrenal insufficiency is reflected as a defect in the microcirculation.

If certain rearing environments place demands on the pituitary adrenal axis that are difficult to meet or cannot be met, the animal may lose the capacity to resist a secondary stress. In this event, the development of the circulatory system may occur in an internal environment that is dominated by histamine or other intrinsic dilators. Such a suggestion is supported by reports of functional deficiencies of blood vessels in porcine animals (Merkel, 1968). Thus, an inadequate circulatory system would not maintain physiological conditions locally in muscle after a massive discharge of nervous impulses such as that occurring upon death. These circumstances would explain the immediate build-up of lactic acid that occurs in some pigs after stunning. It is likely that these animals experience almost complete circulatory collapse before or during exsanguination.

Some insight was gained into the relation of severe stress responses in acclimated and unacclimated pigs in the study reported by Addis et al. (1967b). They demonstrated the feasibility of predicting muscle quality factors in porcine animals by observing their body temperature and respiratory rate during severe heat stress. It was observed that the meat quality factors of animals reared in constant temperatures were more predictable than those reared in fluctuating temperatures. This research indicates that temperature acclimation may exert some of its favorable effects on meat quality by stabilizing stress reactions and enabling the animals to respond in a predictable and physiologically coordinated way.

The importance of temperature acclimation in maintaining normal conditions in postmortem muscle is emphasized by the results of surveys of the incidence of various degrees of pork quality. In Ohio (Judge et al., 1959) and Wisconsin (Forrest, Gundlack and Briskey 1968) the highest incidence of pale, soft, exudative muscle occurred in seasons of the year when temperatures were either warm or variable.

When animals acclimate to given climatic conditions, they adjust their thermogenic and thermolytic processes to maintain normal body temperature. In certain unacclimated animals (those subjected to fluctuating temperatures) Thomas and Judge (1968) observed that progressive hyperthermia occurred during growth and these animals had the most rapid postmortem muscle pH decline of any group studied. However, animals subjected to constant temperature during growth could maintain constant body temperature even though the ambient temperature was as high as 32°C. In this case, respiratory rate was rapid due to the need for heat dissipation. It was observed, in some cases, that increased humidity raised respiratory rate when a given temperature was considered. It was in these constant warm (27 or 32°C) temperatures and high (80%) or moderate (40%) humidity levels that the stress susceptible pigs described earlier exhibited the slowest rate of postmortem muscle pH decline of the experimental groups.

The foregoing discussion suggests that tissue hyperthermia may be induced by the environment but, if sufficient time is available, the animal will accomplish metabolic acclimation and will retain normal muscle properties. This may require a "revision of the enzyme patterns" that Potter (1958) emphasized was characteristic of the "slow response" to stress. Metabolic acclimation, therefore, probably occurs in muscle as a result of the stimuli resulting from hyperthermia. Frankel, Ellis and Cain (1963) identified a tissue hypoxia in the hyperthermic dog which was precipitated by a build-up of lactic acid. They postulated that the hypoxia resulted from circulatory failure under the hyperthermic conditions.

Porcine animals rely on increased respira-
tory rates as the principal method for heat dissipation (Robinson and Lee, 1941). When this occurs over prolonged periods of time, as in high temperature-high humidity conditions, it is logical that the great quantities of oxygen are inspired. Thus, the opportunity is afforded for increased ventilation of the tissues. Such circumstances might be beneficial to the development of normal, myoglobin—rich muscle in stress-susceptible pigs whose circulatory systems are inherently inefficient.

Summary

The elements of the environment exert important effects on the growth and development of meat animals that are manifested in muscle. These influences are probably responsible for much of the variability that exists in the acceptability of muscle as a food. Environmental control offers the opportunity to minimize this variability in meat quality. As our understanding of these relationships becomes greater, it is possible that growing environments may be designed to encourage the most desirable internal environment in the animal.

Literature Cited


