Effect of Heat Stress on Placental Function

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Chronic heat stress during cattle and sheep pregnancy has been known for some time to impact the outcome, as measured by birth weight. We have used the exposure of pregnant ewes to chronic heat stress (40°C for 12 hours/day and 35°C for 12 hours/day), beginning at 35 to 40 days gestational age (dGA), to induce functional placental insufficiency and intrauterine growth restriction (IUGR) in sheep. Near-term (135 dGA) the singleton fetuses are hypoxic, hypoglycemic, and have significantly reduced concentrations of insulin and insulin-like growth factor-1 (IGF-1). This is associated with an approximately 50% reduction in placental and fetal mass. Doppler ultrasound measurements of the umbilical artery revealed increased resistance and pulsatility indices, reflective of elevated placental vascular resistance, which was later demonstrated *in vivo*. Consequently, we demonstrated that the placental vascular architecture was altered by 90 dGA, and examined the ontogeny of a variety of vascular growth factors and their receptors, demonstrating altered expression following 15 days in treatment, as well as near-term. The early responses resembled the response to hypoxia, leading us to examine uterine blood flow, uterine O_2 extraction and umbilical vein oxygenation from 40 to 55 dGA.

Absolute uterine artery blood flow (ml/min), between 40 and 55 dGA, tended to be reduced in response to maternal heat stress, but blood flow relative to placental or fetal mass was not reduced. The reduction in absolute uterine artery blood flow may result from reductions in maternal cardiac output, in response to maternal hypocapnia, reduced maternal heart rate and reduced maternal arterial blood pressure. However, uterine oxygen uptake and extraction was not impacted during this initial window of maternal heat stress, nor was umbilical vein PO_2, O_2 content or O_2 capacity, leading us to conclude that chronic heat stress was not inducing uterine hypoperfusion during the window of placental development. However, at 135 dGA, absolute uterine artery blood flow (ml/min) is significantly reduced, whereas relative uterine artery blood flow (ml/min/100 g placenta) is significantly increased and relative umbilical vein blood flow (ml/min/kg fetus) is significantly reduced as is umbilical O_2 uptake. These data suggest that O_2 delivery to the uterus is not rate limiting, but rather placental extraction of O_2 is diminished, leading to fetal hypoxemia. Additionally, umbilical uptake of glucose and amino acids are also diminished during late gestation in these pregnancies.

Chronic heat stress, occurring during the window of placental development, results in functional placental insufficiency and IUGR. Significant growth restriction increases the mortality and morbidity rate of the offspring. What is now apparent from human epidemiological studies as well as animal models, reductions in birth weight reflective of placental insufficiency are associated with altered metabolic and cardiovascular function postnatally and in adulthood. This may reflect the fetus resetting metabolic “set-points” in response to inadequate *in utero* nutrition, which has the potential of impacting numerous livestock production traits.

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Effects of heat stress on nutrient utilization

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Although advances in environmental cooling systems ameliorate production losses during summer months, heat stress continues to markedly cost the American dairy and beef industry. Factors contributing to this economic issue include decreased milk production, increased metabolic disorders and health problems (rumen acidosis, death, etc.), slow growth, compromised milk quality, and reduced reproductive performance. Heat stress will become more of a concern in the future as metabolic heat production (i.e. body heat) increases in parallel with advancing milk yield and if climate change continues toward a warmer environment as some predict.

Reduced feed intake caused by heat stress was traditionally assumed to be primarily responsible for the decrease in milk yield. However, we have recently demonstrated (using a pair-feeding model) that reduced nutrient intake (indirect effects of heat) accounts for only about 35-50% of the heat stress-induced decrease in milk synthesis (Rhoads et al., 2009; Wheelock et al., 2010). A large portion of the direct effects (not mediated by decreased feed intake) of heat may be a consequence of energy intake independent changes in nutrient partitioning. For instance, the metabolic profile of a heat-stressed cow differs from what would be expected from a lactating cow on a lowered plane of nutrition and this is primarily characterized by low NEFA levels (Rhoads et al., 2009). In addition, despite reduced feed intake and body weight loss heat-stressed cows and growing calves have increased basal and stimulated insulin levels and increased glucose clearance in response to a glucose tolerance test. Increased plasma NEFA concentrations are a classic glucose “sparing” mechanism by which animals on a low plane of nutrition implement to maximize milk synthesis. The fact that heat-stressed cows fail to enlist this “shift” in post-absorptive energetic metabolism (despite inadequate nutrient intake) is likely the outcome of insulin’s potent antilipolytic action. Regardless of the mechanism(s) our research indicates heat stress directly (not mediated by feed intake) impacts energetics and nutrient partitioning.

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Dairy productivity in a warm climate: The evolution of an approach.

Amiel Berman

The productivity of a dairy farming in warm climates is a reflection of interactions between the production potential of the animal, nutritional knowledge, veterinary care, availability of technologies, availability of investment, active extension service, close interchange between farmers, extension and research as well as readiness to accept innovations. Advance in productivity depends upon definition of limiting factors at each stage and the taking of appropriate correction steps. Time required for implementation of correcting steps may vary from a few years to decades.

The concept of local breeds as adapted to local climates is a carry-over of Drawinian views. It took decades of research to show it is futile, and that productivity is predominantly dependent on the metabolic rate an animal is capable to sustain in a given environment. Crossbreeding between local breeds and Holstein did not convey heat tolerance at similar production levels. Progress in productivity has been made, wherever veterinary care and nutrition were adequate, when improvement of heat balance has been attempted.

Improvement of radiant heat exchange by large shaded area per cow, high roofs (with greater exposure to cool sky and cooler roof surface) and night exposure to cool sky took decades to implement over the country. On farm studies of thermal balance altered concepts of comfort temperature range obtained in climatic chambers: they were significantly higher, production dependent, with a 2-3 hours lag relative to air temperature cycle. Forced air flow by fans was introduced which significantly improved thermal state as well as conception rate (CR) at 25 to 32^{o}C ambient, and rapidly adopted. The next significant step was to develop heat extraction for the surface of the animal by forced evaporation from a wetted hair coat. Such heat extraction is independent of ambient temperature and largely unaffected by air humidity. It enables maintenance of high metabolic heat production at high temperatures and humidity. The holding pen of the milking parlor was enlarged for cooling the cows before milking and additional times. Heat extraction was furthered and feeding stimulated by setting forced evaporation also along the feeding line. These increased summer milk production to 93-98% of winter levels and reduced to half the seasonal decrease in CR. Summer CR still remained about 20% units below winter level.

Additional heat stress relief might be attained by ambient temperature reduction. This was shown to be feasible only when ambient relative humidity is below 55%, which limits its usage to drier areas only. Additional relief may be attained by reducing the vasoconstrictor response to cooling that limits heat extraction from body core and by increasing body area exposed to higher air velocity. Further research is needed to define the minimal hyperthermia compatible with maintenance of normal reproductive function as well as to reduce water input into the system. Also, dairy farm management routine needs to be integrated with heat stress relief measures.

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OVERVIEW OF THE PROGRESS IN REDUCING ENVIRONMENTAL EFFECTS ON CATTLE

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Hot weather can have negative impacts on feedlot cattle by reducing animal performance and compromising animal well-being. In most circumstances, animals adapt with amazing ease – balancing their heat production (maintenance energy, production levels, feed intake and activity) with their ability to lose heat through sensible and latent means (changing the behavior, shifting blood flow, and increasing respiration rate to maximize heat losses). However, impacts of this excess heat load can range from little or no effect to death of vulnerable animals during an extreme heat event. Several severe heat waves have occurred in the Midwestern USA in the previous 10 years that have caused the death of thousands of feedlot cattle and loss of millions of dollars in revenue to the cattle industry, both in direct animal losses and indirect performance losses.

Heat stress can be defined using three components: the environmental conditions, how susceptible the animal is to heat stress, and the management strategies employed. Environmental conditions are difficult to summarize because many factors need to be included. Factors include current environmental conditions (temperature, humidity, wind speed, and solar radiation), along with other factors including overnight lows, length of extreme hot weather. In addition, there are several factors which affect the micro-climate of the feedlot including saturated soils, irrigation of surrounding fields, and wind breaks. An individual animal's susceptibility to heat stress is influenced by several factors including species, color, condition score or finish, temperament, sex, coat thickness, and previous exposure. Some of the management options have included diet changes, feeding times, shade, sprinkling the animals, and wetting the soil surface.

While the past and current production systems have functioned on a cost/return basis, times are changing in animal care with increased pressure from animal welfare groups. The question arises: "Is there a better method of managing feedlot cattle to improve animal well-being and reduce stress (and in the worst case situations reduce the likelihood of death losses), while maintaining an economically viable system?" Future management schemes will need to use our knowledge of all three components of animal heat stress (environmental conditions, animal susceptibility, and management schemes) in an integrated management approach.

IDENTIFICATION OF TRAITS ASSOCIATED WITH THERMAL TOLERANCE
Chad C. Chase, Jr., USDA-ARS

Producers of beef cattle can appreciate the positive attributes of heat tolerance particularly in their cowherd. In most instances this has been accomplished through breeding systems that incorporate heat tolerance from Brahman. The Senepol, a tropically adapted *Bos taurus* breed from the US Virgin Islands, was evaluated at STARS during the '80s and '90s. During those evaluations evidence became clear that Senepol were as heat tolerant as Brahman and were more heat tolerant than temperate *Bos taurus* (e.g., Hereford, Angus, Holstein). One characteristic that was evident was that the Senepol had a short, sleek hair coat. Additional observations from studies at STARS led us to conclude that the short, sleek hair coat trait appeared to be controlled by a single gene with a dominant mode of inheritance. We refer to this short, sleek hair coat trait as slick. In numerous studies it was shown that slick-haired animals had rectal temperatures 0.9 to 1.1˚F lower than contemporaries with normal hair coats in Florida during summer. In dairy production in the U.S., a generally more intensive industry, most efforts have been placed on modifying the environment rather than on introducing tropical adaptation *per se*. Although there may be many reasons for this, undoubtedly one is the predominance of the Holstein breed stemming from its superior milk production. However, it should be noted that in Florida during summer it is not uncommon for pregnancy rates at well-managed dairies to fall below 15%. This has been attributed to a failure in estrus detection, but also to embryonic mortality. An alternative means of improving thermotolerance in these cattle is to introgress favorable genetics from other breeds, such as the *Slick* hair gene from Senepol into Holstein.

We are interested in utilizing molecular techniques to identify the *Slick* hair gene and to use marker-assisted selection to identify homozygous *slick* sires that will sire only Slick-haired progeny. We collected hair coat data and stored white blood cells from purebred Senepol parents and crossbred Senepol progeny for up to three generations. Initially we concentrated on a Senepol sire that was heterozygous for the *Slick* hair gene and an equal number of his daughters that were either slick or normal haired. We performed a scan of the bovine genome using the DNA pooling strategy and typed over 300 microsatellite markers. Results indicated that bovine chromosome 20 was the most likely candidate chromosome harboring the *Slick* hair gene. The *Slick* gene was more accurately positioned on chromosome 20 using additional individuals (from new families) and targeted microsatellite markers. Mapping the *Slick* hair gene locus is the first step towards the identification of the causative mutation responsible for slick hair coat. We found a strong association between at least two closely positioned markers on chromosome 20 and the slick haired phenotype. In conclusion, we have identified molecular markers tightly linked to the *Slick* gene. This should greatly facilitate the introgression of the *Slick* gene into other economically important breeds such as Angus.

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Molecular Basis of Breed Differences in Heat Tolerance
Effect of Thermal Stress on Gene Networks

Robert Collier, University of Arizona

Evidence to date suggests there is significant genotype by environment interaction for production traits in dairy cattle indicating substantial variation in phenotypic responses to the environment. This variation is associated with 3 levels of physiologic regulation. These are; differences in heat accumulation and heat loss associated with variation in hair coat thickness, depth and color, skin vascularization, sweat gland population and anatomic structures associated with thermal regulation; differences in endocrine regulation of acclimation and coordination of cellular and systemic acclimation and the regulation of the cellular heat shock response. This presentation will discuss these levels of regulation and evidence for breed differences in them.

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Photoperiod and Thermal Effects During the Transition Period

Geoffrey E. Dahl, Department of Animal Sciences, IFAS, University of Florida

Photoperiod and ambient temperature (esp. thermal stress) are the two primary environmental cues that animals use to drive long term physiological adjustments to their environment. Investigation of short day photoperiod (SDPP) exposure and heat stress abatement during the dry period has revealed that both management interventions 1) improve yield in the subsequent lactation, and 2) improve immune status during the transition into lactation. Successful navigation of challenges cows face during the transition period can dramatically improve the outcome of the subsequent lactation. Thus, management approaches that positively impact the transition can benefit cow performance and health and overall productive efficiency.

The common physiological mechanism that underlies the response to decreasing light and cooling is altered prolactin (PRL) secretion and signaling, which then affects gene expression at the mammary, hepatic and immune tissue levels. Relative to long day photoperiod exposure, dry cows on SDPP have reduced circulating PRL, increased expression of PRL-receptor (PRL-r) mRNA in mammary and immune tissue, and lower expression of the suppressor of cytokine signaling genes. Mammary growth is greater in SDPP cows versus those on long days, and SDPP cows produce 3 to 4 kg/d more milk in the subsequent lactation.

Recent studies with heat stressed dry cows, characterized by greater circulating PRL, supports the concept that elevated PRL during the dry period is detrimental to yield in the next lactation, as was observed with photoperiodic responses. In addition, cooling during the dry period enhances immune status relative to heat stress, and shifts hepatic gene expression away from pathways that favor lipid accumulation. Active cooling with fans and soakers is preferred to simply providing shade, as the response is greatest in studies that achieved the largest decrease in overall body temperature. Furthermore the response was greater when cooling was imposed for the entire dry period, suggesting some degree of a duration effect. Cooling of dry cows offers an easily implemented, non-invasive approach to improve yield and health of cows during the transition.

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Heat Stress Indices for Management Decisions

John Gaughan – University of Queensland
Terry Mader – University of Nebraska

This presentation will focus on climatic indices, such as the THI, which have been, and are being used to determine the impact of heat stress on cattle and other livestock. We will discuss heat stress indices and models from the perspective of both beef and dairy management, in both an intensive and an extensive environment. The limitations of the climate indices, and why there is a need for new indices will be discussed. We will investigate attempts to make adjustments to the THI, as well as other indices and models which are been developed to assess (and predict) the impact of climatic conditions on cattle performance. The impact of climatic conditions (in the context of the indices) on reproductive and growth performance in both dairy and beef cattle will be discussed.

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FACTORS AFFECTING EMBRYONIC SURVIVAL DURING HEAT STRESS

Peter J. Hansen, University of Florida

Heat stress reduces the likelihood that an embryo can survive and develop in the reproductive tract. Understanding the factors that determine whether an embryo exposed to heat stress will live or die can result in new strategies for improving fertility of lactating cows during heat stress. One important attribute of the embryo is that it becomes more resistant to heat stress as pregnancy advances. Embryo transfer can be an effective fertility-enhancing strategy for the heat-stressed cow because most of the effects of heat stress to reduce fertility occur before the blastocyst stage of development when embryos are typically transferred. Moreover, effects of heat stress on estrus detection can be bypassed by use of ovulation synchronization schemes and timed embryo transfer. It is now possible to transfer cryopreserved embryos produced in vitro with sexed semen for reasonable cost and with improved pregnancy rates compared to AI. Embryo resistance to heat stress can also be improved by exposure to insulin-like growth factor-1 [a molecule increased by bovine somatotropin (BST)]. To date, experiments with BST have resulted in small but non-significant increases in fertility during summer. Addition of insulin-like growth factor-1 to embryo culture medium can increase survival of transferred embryos in the summer. It may also be possible to increase fertility in the summer by feeding antioxidants because part of the effect of elevated temperature on embryonic survival involves increased production of free radicals. There are also genes that control resistance to heat stress – identification of specific genetic variants that protect embryos could lead to genetic improvement for thermotolerance.

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Epigenetic regulation of gene expression and cellular functions induced by butyrate, an example of interactions between gene and nutrients

Congjun Li, Robert W. Li, Ted H Elsasser and Erin E Connor

Epigenetics has been defined as 'the study of heritable changes in genome function that occur without a change in DNA sequence'. Research on nutrigenomics, the genome-nutrient interface and epigenomics is in its infancy with respect to livestock species.

Feed costs are the single greatest expense to dairy and beef production and are estimated to account for approximately 50% of production costs. Inefficiency of nutrient uptake and use by the animal can also contribute to economic losses resulting from lowered production, decreased fertility and longevity, and compromised immune function. Volatile short-chain fatty acids (VFAs, acetate, propionate, and butyrate) are nutrients especially critical to ruminants, and are formed during microbial fermentation of dietary fiber in the gastrointestinal tract and are directly absorbed at the site of production Volatile fatty acids (VFA), especially butyrate, participate in metabolism both as nutrients and as regulators of histone deacetylation. The major biochemical change that occurs in cells treated with butyrate is the global hyperacetylation of histones, which is also one of the major epigenetic regulators. One paradigmatic example of nutrient-epigenetic-phenotype relationship is that of volatile fatty acids (VFA) and their gene expression regulation activities. Utilizing gene expression profiling, our studies indicated that butyrate induces many significant changes in the expression of genes associated with regulatory pathways that are critical to cell growth, immune response and signal transduction. We identified 450 genes significantly regulated by sodium butyrate at a very stringent false discovery rate (FDR) = 0%. The functional category and pathway analyses of the microarray data revealed that four canonical pathways (Cell cycles checkpoint; pyrimidine metabolism; G1/S checkpoint regulation and purine metabolism) were significantly perturbed. The biologically relevant networks and pathways of these genes were also identified. *IGF2*, *TGFB1*, *TP53*, *E2F4*, and *CDC2* were established as being centered in these genomic networks. The profound changes in gene expression induced by butyrate in bovine cells elucidate the pleiotropic effects of histone acetylation. However, histone acetylation is not the only epigenetic mechanisms that induced by VFA. Our recent studies indicate that VFA also induces reactivation of the somatically heritable imprint genes such as IGF2 (loss of imprinting, LOI). Butyrate-induced histone acetylation also interferes with miRNA, a group of non-coding short RNAs. These highly conserved, ~21-mer RNAs can regulate the expression of genes by binding to the 3'-untranslated regions (3'-UTR) of specific mRNAs. Butyrate induced biological effects in bovine cells provide an example of epigenetic regulation of genome and a basis for understanding the full range of the biological roles and the molecular mechanisms that butyrate may play in animal cell growth, proliferation, and energy metabolisms.

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EFFECT OF HEAT STRESS ON OVARIAN FUNCTION

Matthew Lucy, University of Missouri

Heat stress affects reproduction in all major farm species. Dairy cattle are particularly sensitive to heat stress because of the metabolic heat produced in lactating cows. The effects of heat stress can be directly related to the increase in body temperature in heat-stressed cows. The increase in body temperature affects the reproductive tract. The changes in the reproductive tract influence the ability of a cow to become pregnant during heat stress.

The ovary houses ovarian follicles and corpora lutea, each of which influences the ability of the cow to become pregnant. Ovarian follicles contain gametes (oocytes) as well as somatic cells that synthesize estradiol. Estradiol has a variety of actions that include causing estrus and the luteinizing hormone (LH) surge that is necessary for ovulation. Oocytes that reside in the ovary are damaged by heat stress. The negative effects of heat stress on oocytes are manifested in the summer as well as in the fall, after ambient temperatures have decreased. Follicles that are developing on the ovary in heat-stressed cows can be damaged in the summer but nevertheless continue growing throughout the fall. Apparently, these damaged follicles ovulate low fertility oocytes during the fall. This phenomenon explains the seasonal carry-over effects of heat stress on reproduction in cattle.

The somatic cells that produce estradiol within the follicles can also be damaged by heat stress. We found that follicles did not grow normally and had low estradiol production in cows and heifers subjected to heat stress. Others have studied heat stress and found similar effects on ovarian follicles. Heat stress, therefore, damages ovarian follicles and causes a decrease in estradiol synthesis. This decrease in estradiol synthesis can influence expression of estrus and ovulation. Whether or not heat stress affects the corpus luteum during the mid-luteal phase is less clear. Heat stress has been shown to increase, decrease or have no effect on blood concentrations of progesterone arising from the corpus luteum.

Cows must be observed in estrus so they can be inseminated artificially. There is clear evidence that heat stress decreases the length and intensity of estrus. Heat stress decreased follicular estradiol in the studies mentioned above. The decrease in estrous intensity, therefore, may be caused by a decrease in follicular estradiol secretion and systemic estradiol concentrations. An equally likely cause of reduced estrous expression is the physical inactivity caused by heat stress. Cows are less active during heat stress and therefore less likely to ride other cows during heat stress.

Heat stress decreases fertility in cattle. The decrease in fertility is caused by elevated body temperature that influences ovarian function, estrous expression, oocyte health, and embryonic development. In response to these limitations, dairymen should increase environmental and reproductive management of cows during heat stress. For example cooling dairy cows and increasing the frequency of estrous detection will improve pregnancy rates. Timed AI may also be used as an alternative to estrous detection. Future strategies for managing heat stress may involve embryo transfer if sources of affordable high-quality embryos become available. It may also be possible to removed damaged follicles from the ovary by transvaginal aspiration to hasten the recovery period after heat stress.

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HEAT AND COLD STRESS EFFECTS ON CATTLE

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While new knowledge about animal responses to the environment continues to be developed, managing cattle to reduce the impact of climate remains a challenge. In particular, additional environmental management strategies are needed to guide managers when making decisions prior to and during periods of adverse weather. In the Midwest and Plain states losses of confined cattle exceeded 2,000 head during each of seven separate heat waves, which occurred over the past 15 years. The heat waves of 1995, 1999, 2006 and 2009 were particularly severe with documented cattle losses in Midwestern states approaching 5,000 or more head each year. The winters of 1992-93, 1996-97, 1997-98, 2006-07, and 2008-09 also caused hardship for cattle producers with some feedlots reporting losses in excess of 1,000 head. Up to 50% of the newborn calves were lost in many areas with over 75,000 head of cattle lost in the Northern Plains states during the 1996-97 and 2008-2009 winters. Late fall and early winter snowstorms in 1992, 1997, and 2006 resulted in the loss of over 30,000 head of feedlot cattle each year in the Southern Plains of the United States. Economic losses from reduced cattle performance likely exceed those associated with cattle death losses by 5- to 10-fold. Generally, cattle efficiencies and daily gain are decreased between 5 to 10% for the entire feeding period as a result of early winter moisture combined with poor drying conditions and/or prolonged cold stress. Mud appears to be the single largest contributor to poor cattle performance in winter and spring.

In summer feeding studies, restricting feed intake to 85% of ad libitum lowers body temperature (BT) approximately .5 °C (.9 °F), even after the period of feed restriction ended. Sprinkling feedlot cattle was more effective in cooling cattle if sprinkling was done in the morning versus in the afternoon. Certainly it is recommended to start cooling strategies prior to cattle showing signs of heat stress (panting). Sprinkling of pen surfaces may be as much or more beneficial than sprinkling the cattle. Cooling the surface would appear to provide a heat sink for cattle to dissipate body heat, thus allowing cattle to better adapt to environmental conditions vs adapting to being wetted. Also, during hot days, BT of black-hided cattle can be over .5 °C (.9 °F) greater than BT of white-hided cattle. In handling studies, moving cattle through working facilities requires an expenditure of energy causing an elevation of average BT between .5 and 1.0 °C (.9 and 1.8 °F), depending on the ambient conditions. Strategies designed to reduce the detrimental effects of heat stress while maintaining animal productivity need to be implemented. During hot days minimal handling of cattle is recommended for promoting animal comfort.

The use of bedded barns did not lessen heat stress in the summer, as measured by the temperature humidity index (THI) but acted as a shade to decrease the solar heat load on the animal. During the summer season, temperatures, as well as THI levels, were generally greatest at the front of the building. Also, 2 to 4ºC greater temperatures were maintained in the building when compared to outside conditions, possibly by the decreased air flow through the building. Bedded barn facilities appear to be useful for buffering cattle against the adverse effects of the environment under hot and cold conditions even though less airflow and greater RH were found within the barn when compared to outside conditions. These are a few examples that suggest rational, cost effective management systems are needed to reduce climate-related losses in cattle. Such systems should incorporate tools and information about cattle responses to weather challenges for managers to use in helping animals cope with adverse climatic conditions.

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Genetics of Heat Tolerance in Holsteins

Ignacy Misztal, University of Georgia

In many parts of the world, Holsteins are exposed to heat stress at least seasonally. During heat stress, production and fertility decline while health problems increase. Heat stress can be managed by physical modification of the environment (shade, sprinklers and fans). Cooling is extremely effective in dry environments but less so in humid conditions. When humidity reaches 100% at night, evaporative cooling loses efficiency. Higher heat tolerance can be achieved by selecting or crossbreeding more heat-tolerant animals. Crossbreds in dairy cattle have been successful under extensive, but not intensive, management because of much lower production levels than purebreds. Therefore, the remaining option is to select more heat resistant purebreds, predominantly Holsteins.

A method to analyze heat stress with information from public weather stations on test days was developed at UGA. Decreases in performance are considered to be a function of a temperature-humidity index (THI), which is the temperature equivalent to 100% humidity. Animals with smaller decline in performance at high THI are considered to be more heat tolerant. Analyses revealed that heat stress starts at about 19–23 °C at 100% humidity, heat tolerance has a substantial genetic component, and correlation between milk yield under mild temperatures and rate of yield decline under high THI is about −0.4. Consequently, animals that were continually selected in cold climates would gradually show worsening performance under heat stress.
Later studies at UGA developed a national genetic evaluation of U.S. Holstein for heat stress using test days in 3 parities. Trends for heat tolerance were flat in the first parity and strongly negative in the later two parities. Daughters of heat-tolerant sires had lower milk yields with higher fat and protein percentages and lower scores for dairy form but longer productive life and greater fertility than did daughters of bulls with low heat tolerance. Thus selection on fluid milk alone would reduce heat tolerance while selection on a comprehensive index may not.

A comprehensive genetic evaluation for heat tolerance is possible for many traits. Because only a fraction of records are made under heat stress, the reliability of PTA for heat stress is low for all but the most popular bulls. However, an improved accuracy for young bulls can now be obtained with the genomic information. Maintaining a single strain of Holstein globally will lead to a steady loss of heat tolerance that may be no longer managed by cooling systems. If genetic evaluations for heat stress are available, inclusion of the genomic information allows for low cost identification of medium-reliability young sires superior for heat tolerance. This creates an opportunity to create a heat tolerant line of Holsteins.

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Thermal Stress Alters Gene Expression and Metabolic Priorities

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At the onset of heat stress, dairy cattle initiate a series of whole body adaptations in an effort to cope with and dissipate additional heat load. These include well-known physiological changes such as increased respiration rate and sweating rate and decreased feed intake. Environmentally induced hyperthermia in ruminants depresses production as a consequence of reduced feed intake but it is unclear how shifts in metabolism may further affect milk yield, lean tissue accretion and physiological acclimation. Our evidence indicates that cattle experiencing heat stress do not appear to engage metabolic and glucose-sparing adaptations consistent with their plane of nutrition. In this context, the liver is uniquely positioned to direct exogenously and endogenously derived nutrients for use by other metabolically active tissues such as the mammary gland and skeletal muscle. Despite the prominent role of the liver in whole-body metabolism, alterations in the molecular mechanisms leading to hepatic adaptation during heat challenge are unclear in the dairy cow. We are using management tools and metabolic modifiers, such as bovine somatotropin, in an attempt to better understand and improve hepatic function during heat stress.

Because a large proportion of an animal's mass is comprised of skeletal muscle, alterations in skeletal muscle metabolism and function can have a profound impact on whole-animal energy metabolism and nutrient homeostasis especially during periods of stress. We have initiated a series of studies to understand how hyperthermia influences the set points of several metabolic pathways within skeletal muscle. One of our first studies examined the effect of heat strain on the skeletal muscle gene expression profile during beef cattle adaptation to chronic heat stress conditions using microarray analysis. Interrogation of this dataset by pathway analysis has revealed dramatic changes in the skeletal muscle transcriptional profile relating to mitochondrial function. It appears that during heat stress bovine skeletal muscle experiences mitochondrial dysfunction leading to impaired cellular energy status. This may have broad implications for the reduced growth and heat intolerance seen during heat stress especially if skeletal muscle is not able to make necessary contributions to whole-body energy homeostasis.

Accurately understanding the biological mechanism(s) by which thermal stress reduces animal performance is critical for developing novel approaches (i.e. genetic, managerial and nutritional) to preserve growth and lactation especially given the critical importance of nutrients, such as glucose, to animal production and well being in these situations.

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EFFECT OF HEAT STRESS ON OOCYTE COMPETENCE AND EMBRYONIC SURVIVAL

Zvi Roth, HUJI, IL

The current presentation discusses the immediate and delayed effects of heat stress on oocyte developmental competence and on the developing embryo. It also describes some potential methods for their alleviation. The concept presented here suggests that perturbations in the follicular microenvironment, to which the oocytes are exposed through development, reduce their competence to undergo maturation, successful fertilization and developing of a vital embryo. Among the potential alterations are reduction in gonadotropin secretion, modification in follicular growth, attenuation of dominance and disruption of steroidogenesis. With respect to the oocyte, exposing oocytes to heat shock during maturation impaired the resumption of meiosis and increased the proportion of apoptotic oocytes through the sphingomyelin pathway. GV-stage oocytes are also sensitive to thermal stress and are expressed by delayed cleavage timing and reduced embryonic development. Recent studies provide new evidences that expression of genes, which are involved in early embryonic development, is impaired upon summer heat stress or induced heat shock. Elevated temperature can act directly on the embryo to compromise development. Preimplantation bovine embryos become more resistant to elevated temperature as they advance in development. The cellular consequences of heat shock have been best described for the bovine two-cell embryo. At that stage, exposure to 41°C causes disruption of the microfilament and microtubule network which in turn results in a redistribution of organelles. There is also an increase in the proportion of swollen mitochondria and a tendency of reduced oxygen consumption.

Evaporative cooling methods are the most common strategy used to alleviate the effect of heat stress. However, there is a compelling need for additional ways to improve fertility during the summer and the following autumn. Hormonal treatments are suggested to enhance the removal of the impaired follicles, for example, synchronization of follicular waves by GnRH and PG administration. An alternative is the stimulation of follicular growth by short treatment with bST or FSH. Other strategies such as timed AI and embryo transfer have been used recently. Therefore, optimizing the procedures for cryopreservation is highly relevant. Protection of the ovarian pool of oocytes from thermal stress via nutritional manipulations or administration of ROS and/or other survival factors should be taken into account. A better understanding of the mechanisms by which heat stress impairs fertility may lead to the development of additional approaches to alleviate these effects.

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Housing systems to reduce environmental impacts on lactating dairy cows

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The dairy industry has a wide variety of housing options for dairy cattle including dry-lots, dessert barns, naturally ventilated freestalls, tie stalls, pack barns and mechanically ventilated freestalls. Decisions concerning housing have been driven by climate, cost and business philosophy.

In the past the dairy industry has traditionally used naturally ventilated facilities and used evaporative cooling or low pressure soakers in combination with fans to minimize the impact of heat stress. During winter months curtains have been used to reduce wind chill. However, with the exception of tie stall barns little emphasis has been put on providing a warmer environment for the cow during cold stress. In recent years an alternative system has been developed to house dairy cattle. Low profile cross ventilated dairy facilities provides producers with another option to house dairy cattle. These facilities incorporate the use of cross ventilation and evaporative cooling to manage heat stress. Low profile cross ventilated facilities also provides the opportunity to reduce the impact cold stress in northern climates. These facilities are unique in their ability to mitigate the impact of cold stress. These facilities have the potential to improve production efficiency during periods of heat and cold stress.

One of the advantages of cross ventilated facilities is the orientation of the air flow to cow resting in a freestall. In tunnel ventilated facilities airflow is perpendicular to the resting cow. While in cross ventilated facilities airflow is parallel to the cow increasing the surface area of the cow that is impacted.

A number of design factors are critical to construct a cross ventilated facility correctly. Some of these factors include building width, baffle design, ventilation rate, type of evaporative cooling, and design of the cooling system.

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OVERVIEW OF HEAT STRESS EFFECTS ON THERMAL STATUS: ISSUES AND QUESTIONS

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Cattle are continuously exposed to general stress. Often, the stress level is in the range of "good stress" that enhances productivity. Once the critical breaking point is reached, however, the "good stress" becomes distress which is displayed in the animal as system strain. Bovine heat strain results in over a billion dollar annual loss to producers due to impacts on health, nutrition, and reproduction. Thermal strain represents the combined effects of ambient stressors, and is the integrated sum of their actions. The result may be an imbalance of animal heat production (i.e., the primary source of heat gain) and heat loss which translates into reduced performance and increased cost to increase heat dissipation. One step toward a solution may be to use indicators of either ambient or animal thermal conditions to predict animal thermal status or performance during heat exposure. The Temperature Humidity Index (THI) that combines both air temperature and percent relative humidity has been traditionally used as an indicator of ambient condition to make this prediction. Unfortunately, it does not account for complicating factors such as breed, age, health, gender, geographic origin, and adaptation. New technologies will increase access to both ambient and animal indicators of animal thermal status, such as air and body temperatures, and become strategic decision tools that rapidly account for these factors. Several characteristics of the strain:stress relationships may be useful in quantifying heat impact. One is the critical breaking point in core temperature, respiration rate, and sweat rate that precedes heat-induced strain. Another is the slope of the strain:stress relationship that accounts for breed differences. More importantly, it may be possible to utilize these endpoints to identify and predict adaptation to summer heat stress. The adaptive ability of an animal is likely the most important factor which determines an it's ability to tolerate and perform well in an ever-changing environment. Ultimately, an animal:ambient index may be most useful because it combines critical animal indicators, such as daily minimum core temperature, with dynamic ambient variables, like the rate of rise in air temperature. Additional studies are needed at this point that use new technologies to evaluate in laboratory and field environments the potential predictors of thermal status that can be related to performance, with the goal being to reduce the loss in productivity that accompanies summer heat stress.

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HEAT STRESS EFFECTS ON REPRODUCTION/NUTRITION

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Major advancements have been made in our understanding of reproductive physiology and endocrinology of the estrous cycle, early pregnancy and the postpartum period. Advancements in these areas have led to new successful and efficient reproductive management programs that need to be integrated into the environmental, nutritional and herd health management programs of high producing lactating dairy cows. Indeed these programs provide a platform to quantify strategies to enhance reproductive performance during seasonal periods of heat stress. It is the impact of the peripartum (i.e., transition period) and postpartum periods during seasonal transition phases of heat stress and strategic targeting of nutraceuticals, on immune status and subsequent reproductive performance, which is the focus of this presentation.

The incidence of puerperal metritis was affected by abnormal calving, parity and calving season. During seasonal periods of heat stress in a subtropical environment (i.e., THI $\geq$ 72), the occurrence of puerperal metritis (15%) did not differ between primiparous and multiparous cows; whereas, during the cool season the occurrence of metritis was 39% in primiparous cows verus 11% in multiparous cows. The decrease in calf birth weight during seasonal periods of heat stress likely contributed to a reduction in both abnormal calvings and subsequent metrtitis in primiparous cows.

Inclusion of specific nutraceuticals in the diet to improve reproductive function offers an exciting new dimension to dairy cattle management. Pre- and postpartum feeding of organic Se-yeast (0.33 mg/Kg), during summer in the Se deficient state of Florida, improved selenium status of lactating dairy cows, enhanced neutrophil function (i.e., phagocytosis and oxidative burst) and humoral immune/antibody responses, reduced incidence of fever, and improved both uterine health and subsequent fertility to second service.

Feeding calcium salts of safflower oil, a linoleic acid rich supplement, during peripartum of dairy cows altered immune status: increased caruncle n:6/n-3 fatty acid ratio at parturition; improved neutrophil bactericidal function; increased abundance of the L-selectin adhesion molecule; enhanced production of cytokines (i.e., TNF-α and IL-1β), and increased plasma concentrations of haptoglobin and fibrinogen. Conversely, feeding calcium salts of fish oil during the breeding period attenuated TNF-α secretion from neutrophils in response to LPS. These responses were compared to control cows fed calcium salts of palm oil. Following the transition period, feeding calcium salts of fish oil reduced pregnancy loss after first service and increased pregnancy per insemination after the second service. This beneficial effect of feeding calcium salts of fish oil was augmented when calcium salts of safflower oil were fed previously in the transition period. An interaction of transition and breeding diets by season was detected for second service pregnancies per AI. Feeding fish oil in the breeding period following safflower oil in the transition period stimulated pregnancy per AI for second service in the warm season; whereas feeding palm oil in the breeding period following safflower oil in the transition period had no beneficial effect on second service pregnancy per AI. Collectively, strategic supplementation of fatty acids accordingly to physiological stage can selectively benefit immune function, maximize production and improve reproductive responses of lactating dairy cows.

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WHY GENOMICS WORKS AND WHAT IS COMING

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Increasing the efficiency of milk production continues to be needed both to meet the demand from an increasing population and to minimize competition for scarce resources. The recent availability of genomic tools provides an opportunity for substantially increasing the rate of genetic improvement. The challenge has been to translate the promise of this technology into workable programs for the industry. Since April 2008, genomic evaluations have been calculated and distributed based on single-nucleotide polymorphism (SNP) marker genotypes from DNA samples that were collected on farms. The Illumina BovineSNP50 BeadChip provides genotypes for over 50,000 SNP. Those SNP are used to track inheritance of chromosomal segments, and the impact of each segment is estimated for each trait. The primary benefit of genomic evaluations is that they can be generated as soon as a DNA sample can be taken, which means that a bull can be used heavily as soon as he can produce semen rather than having to wait several years until he has a progeny test. The accuracy of a genomic evaluation depends on how many genotyped animals with evaluations are available to estimate the SNP effects. Evaluation accuracy continues to increase as bulls are progeny tested and information on their daughters becomes available. Currently, accuracy of genomic evaluations for milk yield averages 75% for young bulls, which is equivalent to a progeny test with 33 daughters. Confidence in genomic evaluations has been increasing because the top genomically tested bulls generally have retained their ranking after their daughter information becomes available. Semen from bulls with only genomic evaluations is being marketed and is attractive because those bulls dominate the top rankings. Internationally, Canada has partnered with the United States to share genotype data. Similar sharing is being developed in Europe with the potential of a larger population of predictor animals than in North America. New Zealand has been an early adopter of genomic evaluation and emphasizes marketing a team of genomically evaluated bulls. Next year, genotyping chips with 600,000 SNP are expected, which presents a challenge on how to merge genotypes from the new chip with those from the current 50,000 SNP chip. Methods to enable estimating the missing SNP (imputation) are being developed. Low-cost chips with many fewer SNP also are being developed for parentage confirmation or discovery as well as for first-stage screening of genetic merit, and their results could be enhanced with imputation. Once a genotype is available, it can be applied to any trait that has data available for estimating SNP effects. For new traits that are expensive to measure, data may only be available from research populations. The value of genomic evaluations for new traits will depend on how accurately their SNP effects can be estimated for the population of interest. For heat tolerance, adequate data may be available to support a genetic evaluation system. Once traditional evaluations are available, genomic evaluations could enable rapid progress.

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