ENERGY METABOLISM, BLOOD CHEMISTRIES, AND THERMOBALANCE OF LARGE WHITE MALE TURKEYS EXPOSED TO TEMPERATURE DISTRESS

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CHAPTER 1

INTRODUCTION

The performance of turkeys is affected by nutrition and ambient temperature. Ambient temperature affects performance primarily by reducing feed consumption which subsequently reduces body weight gain (NRC, 1981). A deeper understanding of the interactions between environmental temperature and feed intake is needed so that turkey rations can be formulated to provide optimal nutrient combinations during different seasons and at various geographical locations.

The reduction in feed intake, occurring as a result of ambient temperatures above the thermoneutral zone, is thought to be the factor primarily responsible for reduced growth rate and egg production. With laying hens, Polin (1983) observed a 30% decrease in feed intake at ambient temperature of 32 C. Rose and Michie (1987) reported that for each 1 C increase in temperature, feed intake of BUT (British United Turkeys) female turkeys decreased by 1.2% and feed conversion ratio fell by 0.6%. Mitchell and Kosin (1954) and Thomason et al. (1972) reported that moderate increases in ambient temperature depress turkey egg production and egg size. Turkeys reared at high temperatures have reduced body weight gains (De Albuquerque et al., 1978) and reduced breast yield (Bray, 1985).

Nutrient requirements are not directly influenced by environmental temperature according to one review (NRC, 1981). Instead, the decreased feed and nutrient intake could account fully for the adverse responses of poultry undergoing mild heat distress. The reduction in feed intake during heat distress presumably is due to a shift in energy metabolism and consequent physiological chances (Sturkie, 1976). Acutely heat stressed

poultry must dissipate the body heat they generate to maintain a normal body temperature. As the ambient temperature increases, heat dissipation becomes more difficult because nonevaporative cooling, the heat loss due to convection, conduction and radiation, declines as ambient temperature increases. Nonevaporative cooling is the most efficient method for poultry to dissipate heat.

Because nonevaporative cooling declines as ambient temperature increases, poultry are forced to depend more on evaporative heat dissipation to remove body heat arising from its maintenance and/or production energy. This is accomplished by panting or by increasing the respiration rate. As ambient temperature increases and exceeds 39 C, dissipating heat to the environment becomes more difficult which may force body temperature to increase. The rate of heat dissipation depends on the difference in temperature between the body surface and the bird's surroundings.

As body temperature increases due to heat distress, blood gases become altered. Carbon dioxide is lost as the bird attempts to remove more heat via moisture in its breath. At a critical point, panting (increased respiratory frequency and minute volume but decreased respiratory amplitude and tidal volume) begins. Hyperthermic panting precipitates respiratory alkalosis (Richards, 1970). Chronic heat distressed broilers suffer from intermittent respiratory alkalosis during panting; with acute heat distress, broilers pant continuously and suffer from alkalosis (Teeter et al, 1985). The blood becomes more alkaline (Kohne and Jones, 1975). If the bird is a layer, shell quality declines because the deposition of calcium onto the shell requires a blood pH of 7.4 for proper cation and anion balance. The reduction in partial pressure of carbon dioxide associated with respiratory alkalosis alters electrolyte movement across cell membranes (Fenn and Asano, 1956; Brown and Goot, 1963; Lade and Brown, 1963). During alkalosis, concentrations of cations and anions are shifted in the blood (Harrison and Biellier, 1969; Kohne and Jones, 1975) with excessive loss of potassium through the kidneys (Huston,

1978). Finally, extreme heat distress causes death from failure of kidneys and(or) the respiratory system.

Although the specific routes of heat loss (nonevaporative and evaporative cooling) are well defined qualitatively, little research has been conducted with male and female turkeys to quantitatively estimate the irrelative importance. The capacity of turkeys of various ages to lose heat at elevated ambient temperature needs to be quantified (Emmans, 1989). More thorough understanding of heat dissipation routes and energy metabolism may enhance profitability of turkey production.

According to Brody (1945), basal heat production is convenient as a baseline for measuring the heat increments of muscular work, feeding, feed metabolism, lactation, gestation and keeping warm in cold weather. Basal heat production is defined as the heat produced during complete rest in the post-absorptive condition. Basal heat production per unit weight in homeotherms decreases as body weight increases. Consequently, body weight alone is not suitable as a reference base for metabolism. According to the laws of Newton and Stefan - Boltzmann, the rate of cooling of a body is proportional to its surface area. For a cube, Sarrus and Rameaux (1837) calculated that surface area, which for a sphere equals 2/3 power of weight, could be used as a reference base for heat production. In 1932, Kleiber reported that the 3/4 power of weight was useful as a reference base across species for adult animals. At about the same time, Brody published results reporting that the 0.73 power of weight was an ideal cross-species reference base. The Conference on Energy Metabolism in 1935 tentatively adopted the 0.73 power of body weight as a reference base for energy metabolism. Smaller, growing turkeys usually have higher heat production than larger turkeys, both per unit weight and per unit of metabolic body size ($Wt.^{75}$) (Buffington et al., 1974; Afifi, 1975; Nichelmann et al., 1976; Macleod et al., 1980). Macleod et al., (1985) stated that $Wt.^{75}$ is unlikely to be the most suitable scaling factor for turkeys at different stages of growth even though it seems adequate over the narrow weight range in domestic fowl.

The objectives of our studies were to measure metabolic responses by Large White turkey males exposed to thermoneutral and acute and heat distress environments. Measurements included: blood chemistries (glucose, triglycerides, albumin, lactate dehydrogenase, aspartate amino transferase, uric acid, creatine, total protein, sodium, potassium, chloride, magnesium, calcium and phosphorus); and bird thermobalance (heat production, body temperature, evaporative cooling, nonevaporative cooling, respiration rate, respiration efficiency and heat content). The resulting thermobalance and blood chemistry data should be usefull to propose rate-limiting aspects of metabolism for maintaining proper bird body temperature and feed consumption under the environmental and age conditions specified. Our aim was to collect baseline data to aid in developing therapeutic regimens to reduce the deleterious consequences of heat distress.

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CHAPTER II

REVIEW OF LITERATURE

Introduction

Commercial interest in the turkey is increasing, but the amount of information available concerning the energy metabolism of the species is limited. Information is lacking that describes the turkey's metabolic responses to various ambient temperatures. Such information is crucial for specifying the thermal environment at which production is optimal.

With the increasing importance of confinement rearing of market turkeys and turkey breeder hens, optimum environmental conditions for maximum growth and/or productive performance must be established. These conditions include temperature, humidity, lighting, population density and diet. Effects of various environmental factors must be understood by both turkey producers and engineers in order to optimize the environment needed for turkey production.

Divergence from the optimal environment can result in animal distress which decreases growth rate, feed consumption and feed efficiency and increases mortality. Basic nutritional, physiological and thermal environment interactions must be well understood before management practices can be established to decrease animal distress and to increase production.

production increased linearly as temperature decreased below 35 C, indicating a lower critical temperature not below 35 C (Farrell and Swain, 1977a,b).

Feed Efficiency

High environmental temperatures limit growth and reduce feed conversion ratios. Brody (1945) noted that the zone of neutrality for turkeys was between 20 and 28 C and that turkeys are not tolerant of high temperatures. Rose and Michie (1987) reported values for BUT female turkeys (10-15 weeks old); for each 1 C increase in temperature (14 to 23 C) feed intake decreased by 1.2% and food conversion ratio decreased by 0.6%. De Albuquerque et al. (1978) observed that feed efficiency improved approximately 1.2% for each 1 C increase in temperature (10 to 26.7 C) in male and female Large White turkeys 8 to 24 weeks of age and that addition of 8% fat to the diet while holding the energy to protein ratio constant improved feed efficiency by 4.9%. Performance of male BUT (20 weeks old) turkeys has been reported by Hurwitz et al. (1983); feed efficiency hardly changed between 10 and 20 C but it was depressed at 35 C. According to previous work, feed efficiency is improved at high temperatures due to decline in both gain and feed intake.

Body Weight

High temperatures reduce not only body weight gains (De Albuquerque et al., 1978) but also breast meat yield as a proportion of total meat yield (Bray, 1985). Hellickson et al. (1966) showed that weight gain depended on temperature with optimum performance between 15.6 and 21.1 C in Broad Breasted turkeys 12-24 weeks of age. Potter et al. (1970) reported that for turkeys (8 to 16 weeks of age), body weight gain increased 0.14% for each 1 C increase in temperature (from 4.4 to 18.3 C). Body weights for Large White turkeys (8-24 weeks of age) maintained at constant temperatures of 10, 18.3, 26.7 and 35 C were reported by De Albuquerque, et al., (1978). These authors indicated that maximum body weight gains were obtained when birds were maintained at 10 and 18.3 C; at 26.7 and 35 C, weight gains declined 6 and 13%, respectively, from that

production increased linearly as temperature decreased below 35 C, indicating a lower critical temperature not below 35 C (Farrell and Swain, 1977a,b).

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observed in the 10 C environment. Weight gains were greatest at 18.3 for males and at 10 C for females.

Water Intake

When poultry are exposed to high ambient temperatures, they drink more water. Water consumption by chickens was increased when ambient temperatures above 32 C (Fox, 1951; Boone and Huston, 1967). Water consumption of Broad Breasted White (Nicholas Strain) at 47 weeks of age and of Broad Breasted Bronze (American Strain) at 42 weeks of age were recorded at 10, 21.1, 32.2 and 37.8 C by Parker et al. (1972). Birds at 37.8 C had water consumption equal to four-fold those at 32.2 C and was increased two-fold during early stages of the stress. However, by 14 days of treatment, birds had acclimated to their environments as indicated by stable water intake. Water consumption remained stable throughout the treatment period for the 21.1 C group but intake decreased over time for the 10 C group.

Egg Production and Quality

Parker (1947) and Shoffner et al., (1962) found that egg production declined as seasonal temperatures increased during the breeding season. Mitchell and Kosin (1954) and Kosin and Mitchell (1955) reported that pre-heating hens before they commenced egg production resulted in greater initial egg production levels. However, total egg production was not affected by pre-heating treatments. Also, maintaining hens at 10C during the breeding season was detrimental to egg production due to increased broodiness. The deleterious effects of broodiness on egg production has been documented by Parker and Barton (1945), Jones and Kohlmeyer (1947), Smyth and Leighton (1953) and McCartney (1956). Mitchell and Kosin (1954) and Kosin and Mitchell (1955) found that broodiness increased in constant temperature pens as compared to uncontrolled ones, resulting in lower egg production. An increase of broodiness during the summer months also has been reported by Marsden et al. (1966). Parker (1947) found

that egg weights inclined from January to June. Mitchell and Kosin (1954) reported that egg weights were lower in constant 18.3 C pens than in uncontrolled temperature pens.

Thomason et al. (1972) determined the effects of constant environmental temperatures of 12.8, 21.1 and 29.4 C on the reproductive performance of Large White female turkeys. A constant temperature of 29.4 C resulted in reduced egg production, feed consumption, body weights, egg weights, the effectiveness of broody control and increased the incidence of mortality and bird molting when compared to hens maintained at 12.8 and 21.1 C. However, fertility, hatchability, percentage settable eggs and shell thickness were not affected by the temperature environments. Pen temperature treatments of 12.8 and 21.1 C yielded similar results for all reproductive parameters studied.

The effects of environment on egg production have been reported by Rosebrough and Steele (1985). Large White breeder females were maintained at a constant (21 C) or a cyclic temperature regimen (12 to 27 C). Hens produced more eggs when maintained under cyclic temperature conditions, although this observation was tempered by the fact that fewer hens were broody. Furthermore, more of the fertile eggs from the hens held at the cyclic temperature resulted in live poults.

Heat Distress Effects on Carcass Composition

Three trials conducted by Hellickson et al. (1967) studied the effect of constant ambient temperature (80, 70, 60 and 50 F) on fat deposition in Broad-Breasted and Broad-Breasted White male and female turkeys (12 to 24 weeks of age). Fat deposition was reported to be greatest in the range from 60 to 70 F and decreases at a temperature of 80 F. De Albuquerque et al. (1978) reported that carcass composition of Large White male and female turkeys (8 to 24 weeks of age) in constant environmental temperatures of 10, 18.3, 26.7 and 35 C. The authors found that environmental temperature, sex and diet had no significant effect on feathering, live market quality or New York dressed weight.

However, the highest eviscerated yields were obtained at 18.3 and the lowest at 35 C. The incidence of pendulous crops increased with the higher temperatures. Adrenal weights were greater in males than those of females; however, adrenal weight was unaffected by other factors under study.

Rose and Michie (1987) examined the effects of 4 constant temperatures (14, 17, 20 or 23 C) in BUT female turkeys (10 to 15 weeks of age) and reported that eviscerated carcass weights, abdominal fat and total meat yields were not altered by environmental temperature. However, the higher temperatures resulted in a lower breast meat yield and an increase in the dark meat yield which greatly reduced the breast meat:dark meat ratio. Body composition and meat yield of 20 week old Large White Nicholas male turkeys under constant and cycling temperature regimens have been examined by Halvorson et al. (1991). Under intermittent lighting conditions, constant 21 C or cycling temperatures decreased breast meat yield and increased the percentage of total leg in comparison with 7 C temperature treatment. The proportions of abdominal fat and body fat decreased as temperature increased. Birds at the 7 C constant temperature environment had lower carcass moisture (%) and higher protein (%) than birds at 21 C constant ambient temperature.

Heat Distress Effects on Blood Chemistries

Parker and Boone (1971) measured blood pH, clotting time, red blood cell count, hematocrit, hemoglobin and erythrocyte sedimentation rate of 56 Broad Breasted Bronze and Broad Breasted White male turkeys (36 and 43 weeks of age, respectively) at 10, 21.1, 32.2 and 37.8 C. In trial 1, blood was analyzed on day 0 (prestress), 1, 7, 14 and 21 days of stress and 7, 14, 21 days of postress. In trial 2, blood was analyzed on day 0 (prestress), 7, 14, 21 and 28 days of stress and 7, 14, 21 and 28 days of postress. No significant differences were detected among these varieties of turkeys for any of the

criteria measured; therefore, the data were pooled. The 37.8 C group had lower blood pH (7.16 to 7.30) due to temperature in trial 1 at 7 days of the stress period. The blood pH values of all 4 groups returned to prestress values by 21 days of stress. No significant differences among treatments or with time during postress were detected except at 14 days. Blood pH was so variable that no definite trends were established, although at 14 days of stress the blood pH reached its low point in both trials which could indicate acclimation. No significant differences in blood clotting time were noted for temperature or for time in either trial. Due to the great variability of clotting time (40 to 293 seconds), no trend was be established. Red blood cell count ranged from 2.52 to 2.77 $\times 10^6/mm^3$ during prestress for both trials. In both trials, a low red blood cell count due to hemodilution was observed during the 37.8 C treatment beginning at 14 days of stress and continued throughout poststress which indicates that a prolonged period of time is necessary to produce or alleviate hemodilution due to heat stress. The 32.2 C ambient environment caused hemodilution in 28 days of stress in trial 2 as compared to the 10.0 and 21.1 C groups. At 21 days of stress, the 10.0C group showed signs of hemoconcentration which declined within 14 days of postress. The red blood cell count returned to prestress values between 7 and 14 days of postress for the 32.2, 21.1 and 10.0 C groups. Prestress values of hematocrit ranged 40 to 47.5% for both trials. Hemodilution occurred in both trials, as indicated by the low hematocrit values for the 37.8 C treatment, and continued throughout stress and postress. Hematocrit values for the 37.8 C group at 21 days of postress for trial 1 and 2 were 34 and 33%, respectively. In trial 2 the 32.2 C group appeared to show a slight hemodilution, which was particularly true over time. Hematocrit values obtained for the 32.2, 21.1 and 10.0 C treatments did not significantly vary from prestress values. Huston (1965) reported that chickens grown in cooler environments had a higher hematocrit while those exposed to heat stress had lower hematocrit values. Hemoglobin values were obtained only for trial 2 and prestress values ranged from 12.6 to 14.0 g/dL. A decreased hemoglobin concentration in the 37.8

C group beginning at day 1 of stress indicated hemodilution; values remained low throughout the trial; however, the 32.2, 21.1 and 10.0 C treatments did not significantly differ from each other. Hemodilution and decreased hemoglobin levels were noted by Subaschandran and Balloun (1967) when birds were exposed to heat stress of 38 C. Prestress values of sedimentation rate for trial 2 ranged 9.6 to 11.4 mm/hr. In both trials, a significant increase in sedimentation rate was noted at 14 days of stress for the 37.8 C treatment and continued until day 21 of postress in trial 2. The 32.2 C group had a slightly higher sedimentation rate as compared to the 21.1 and 10.0 C treatments. Buchanan (1958) indicated that sedimentation rate can be influenced by ambient temperature.

Kohne and Jones (1975a) reported venous blood pH, PO_2 (partial pressure of oxygen), PCO_2 (partial pressure of carbon dioxide) and plasma Na, Cl, total Ca, Mg and inorganic P values for 20 non-laying Broad Breasted White (Nicholas strain) hens at 42 weeks of age. Measurements were obtained as ambient temperature was increased from 21(prestress) to 49C(heat stress). As temperature increased from 21 to 49C, venous pH increased from 7.40 to 7.69, venous PO_2 decreased from 48.3 to 43.4 mm Hg and venous PCO_2 decreased from 54.5 to 16.3 mm Hg. Plasma K (14.0 to 18.4 mg%) significantly increased as temperature increased. Plasma Cl (116.5 to 117.8) did not change significantly. Plasma Na (343.0 to 318.6 mg%), total Ca (12.2 to 11.0 mg%), Mg (2.0 to 1.6 mg%) and inorganic P (5.4 to 4.4 mg%) declined as ambient temperature increased. They concluded that acute hyperthermia has a large effect on blood gases and plasma electrolyte concentrations.

Kohne and Jones (1975b) also reported blood pH, PCO_2, PO_2 and plasma Na, K, total Ca, Mg, Cl and inorganic P values for 90 Broad Breasted White (Nicholas strain) laying hens at 33 weeks of age. The study was designed to determine if increasing ambient temperature (21 to 35C) would affect certain physiological parameters in the egg producing turkey; and further, if dietary Ca level would influence blood acid-base balance,

plasma electrolyte levels or production by the turkeys. Dietary Ca level had no significant influence on the variables measured which supports the observations of Sullivan and Gehle (1962) that dietary Ca levels of 1.8, 2.8, 3.8 and 4.8% did not significantly affect serum calcium levels. As ambient temperature increased from 21 to 35 C the following significant differences were noted: venous PCO_2 decreased from 58.2 to 53.7 mm Hg, plasma Na decreased from 342.2 to 332.2 mg%, total Ca decreased from 24.0 to 14.7 mg%, Mg decreased from 3.3 to 2.8 mg%, inorganic P decreased from 4.6 to 3.7 mg% and potassium increased from 12.4 to 13.2 mg%. Increasing ambient temperature did not significantly affect venous PO_2 (50.8-52.2 mm Hg), pH (7.4), or plasma Cl (118.2-117.9 mEq/l). The slow increase in ambient temperature to 35C did not produce a change in the acid-base balance of the blood as did an acute exposure to increasing ambient temperature (Mueller, 1966). However, plasma electrolytes were affected by a slow increase in ambient temperature in the same way they are by a fast increase in temperature.

Krista et al. (1979) reported blood pressure, hematocrit and hemoglobin values of hypertensive and hypotensive strains of turkeys (Broad White variety) 15-22 weeks of age within 4 ambient temperature environments. Constant temperature treatments consisted of ambient (control), 15.7, 26.8 and 37.8 C. Systolic blood pressure values ranged from 248 to 351 mm Hg in the hypertensive group and from 140 to 248 mm Hg for hypotensive strain at the ambient environment. The lowest average blood pressures were noted in the 37.8 C chamber; both the high and low blood pressure strains showed overall decreases in blood pressure of 28 and 14%, respectively. No consistent changes in hematocrit and hemoglobin values due to environment were noted. Mean hematocrit values were 39.1 and 38.0% for the hypertensive and hypotensive strains respectively, while hemoglobin values were 11.8 and 12.2 g/dL.

Total serum protein of three turkey strains (White, Red and Black) fifty weeks of age were measured under different seasonal conditions by Al-Heeti et al. (1985). Total serum protein was significantly influenced by strain (6.00, 6.15 and 6.28 g/100ml for

White, Red and Black, respectively) and sex (6.02 and 6.26 g/100ml for males and females, respectively). Highest levels (6.52 g/100ml) were obtained under moderate seasonal conditions (22.3 C and 55% RH) and lowest (5.85 g/100ml) with high temperature and low humidity (35.2 C and 37% RH). No significant interactions of strain × sex and sex × season were detected; however the strain × season interaction was significant. Highest levels of albumin were noted in Black and Red strains (3.28 g/100ml). Sex and season had no significant effects; only the strain × season interaction was significant.

Donaldson and Christensen (1991) examined the effects of feeding diets with various carbohydrate levels to poults for 24 hours immediately post-hatch on hepatic glucose-6-phosphatase activity and blood glucose levels and to monitor blood glucose levels in poults fasted for 24 hours post-hatch. British United (BUT) and Nicholas strains were examined. The poults were of mixed sex because previous work (unpublished observations) had shown the sexes did not differ for the variables being investigated. Effects of a 24 hour holding period on blood glucose levels in fasted poults at 21 and 37 C were examined at 0, 1 and 24 hours. At 21 C, blood glucose concentrations (mg/dL) for BUT poults were 194, 253 and 183 at 0, 1 and 24 hours, respectively, and glucose concentrations for Nicholas poults were 224, 263 and 257 at 0, 1 and 24 hours, respectively. At 37 C, blood glucose concentrations (mg/dL) for BUT poults were 185, 224 and 228 and for Nicholas poults were 198, 224 and 251 at 0, 1 and 24 hours, respectively. Significant time effects were observed at 37 C, whereas significant strain, time and strain × time effects were detected at 21 C. The processes of wingbanding and of obtaining a drop of blood by wing vein puncture was sufficient to cause a increase in blood glucose concentration of 13% in Nicholas and 21% in BUT poults after 1 hour at 37 C. The same processes caused a blood glucose increase of 17% in Nicholas and 30% in BUT poults after 1 hour at 21 C. Even a mild stress such as blood sampling can cause

blood glucose to rise in poults, and the effect of additional stress (e.g., lower ambient temperature) is additive.

Basal Metabolic Rate

According to Brody (1945), basal heat production is convenient as a baseline for measuring various energy increments, such as the heat increments of muscular work, of feeding, of lactation, of gestation and of keeping warm in cold weather. Basal heat production, energy metabolism, post-absorptive metabolism or standard metabolism, is defined as heat production during complete rest in a thermoneutral environment in the post-absorptive condition. Basal heat production per unit body weight in homeotherms decreases as weight increases. Consequently, body weight alone is not suitable as a reference base for metabolism.

According to the laws of Newton and Stefan - Boltzmann, the rate of cooling (heat loss) from a sphere is proportional to its surface area. Over a century ago, Sarrus and Rameaux (1837) suggested that either surface area, the square of the radius or the diameter or its equivalent, the 2/3 power of weight, could be used as a reference base for heat production and dissipation. In equation form, surface area, heat loss, heat production and oxygen consumption, Y, all should be proportional to the square of linear size, L: $Y=L^2$ or to the 2/3 power of volume, or to the 2/3 power of weight, W (if the specific gravity and shape is constant), as indicated by the equation: $Y=aW^{2/3}$. In 1932, Kleiber reported that the 3/4 power of weight was useful as a reference base across species for adult animals. At about the same time, Brody published results reporting that the 0.73 power of weight was ideal as a cross-species reference base. The Conference on Energy Metabolism in 1935 tentatively adopted the 0.73 power of body weight as a reference base for energy metabolism.

Brody determined the basal metabolism of four groups of mature Rhode Island Red fowls, normal and bantam (small) varieties. When both varieties were included, the exponent ranged from 0.70 to 0.74. However, when only the larger variety was used (omitting the bantams), the slope ranged from 0.30 to 0.54. This may be because larger birds of the larger variety were fatter.

Smaller, growing turkeys usually have exhibited higher heat production values than large turkeys, both per unit weight and per unit of metabolic body size ($W^{.75}$) (Afifi, 1975; Buffington et al., 1974; MacLeod et al., 1980; Nichelmann et al., 1976). MacLeod et al. (1985) stated that $W^{.75}$ is unlikely to be the most suitable scaling factor for turkeys at different stages of growth, even though it seems adequate over a narrower weight range in the domestic fowl.

Buffington et al. (1974) suggested that most of the early research conducted to measure the heat and moisture loss by animals was based on basal metabolic rate. However, BMR is a physiological state that is only rarely attained by animals living under natural conditions. Buffington stated that when designing a building and its environmental modification system, an engineer requires an accurate estimate of heat produced by active, not sedentary, animals.

Thermobalance

Heat production of turkeys or other homeotherms increases during heat distress; this is characterized by an elevated body temperature and occurs when heat production exceeds the homeotherm's ability to dissipate the heat. The most common strategy for reducing heat gain or increase heat loss is by providing a suitable environmental modification. An additional strategy is to exploit biological relationships for reducing bird heat production and/or increasing heat loss extent and/or efficiency of heat dissipation.

Turkey thermobalance is determined by summing heat produced and heat lost. Homeotherms must maintain a relatively constant deep body temperature over a wide range of ambient temperatures (Meltzer, 1987). Under most practical conditions, heat from the bird flows to the environment by radiation, convection, conduction and water evaporation; the importance of these routes varies with environmental conditions (Freeman, 1971).

Bird thermobalance can be estimated as: heat production (HP) = evaporative heat loss (EHL) ± nonevaporative heat loss (NHL) ± change in bird heat content (HC) (Sturkie, 1986). The amount of stored heat (HC) depends upon body temperature and specific heat of the body. The quantity of heat gain or loss is estimated as: $S = \Delta T$ x body mass x 3.5, where S = heat content change (kJ), ΔT = body temperature change (C), and 3.5 = mean specific heat of the body tissues [kJ/kg x C].

How heat content changes with environment is not known. However, heat content is important as a thermoregulatory mechanism, especially during high ambient temperature, where a fever increases the temperature difference between the bird and its environment and thereby increases heat loss from the body (Sturkie, 1986). Nonevaporative heat loss (sensible heat loss) includes heat losses through radiation, convection, and conduction. Evaporative heat loss (insensible heat loss) includes heat loss through respiratory and cutaneous water evaporation.

Heat Production

Turkey heat production (HP) can be estimated by indirect calorimetry in which HP = 16.18 x liters oxygen consumed + 5.02 x liters carbon dioxide produced (Brouwer, 1965); no correction for methane and urinary nitrogen is included. Rominjn and Lockhorst (1961, 1966) indicated that the error resulting from the omission of methane and urinary nitrogen is ≅0.2 % and should not exceed 1.5 % even at a high rates of protein catabolism. Buffington et al. (1974) determined that the error incurred in calculating the

HP of active, growing Wrolstad White turkeys (50 to 80 days of age) from indirect calorimetric data as a result of neglecting urinary nitrogen excretions was of 1.12 %.

Indirect calorimetric heat production measurements has been used to determine feed energy availability for growth and maintenance (Shannon and Brown, 1969; Burlacu et al., 1970 a,b) as well as to estimate energy requirements under specific conditions. The bird's energy use for maintenance and production has been reported to be affected by environmental temperature (van Kampen, 1974; Farrell and Swain, 1977b), nutrient deficiencies (Kleiber, 1945), diseases (Sykes, 1970) and the dietary ratio of protein to energy (Davidson et al., 1968).

Under normal conditions, animals make maximum efficiency of energy for growth when heat losses are minimal. Heat production values usually are expressed per unit metabolic body weight (kg $BW^{.75}$) (Luiting, 1990) to minimize differences in metabolic rate between large and small birds and to make values largely independent of body weight. The thermoneutral zone (TN) is the temperature range over which heat production of an animal is minimal. Generally, the TN zone is inversely related to bird age (Meltzer, 1983). Heat production is related linearly to caloric intake (Luiting, 1990), feed consumption (van Kampen, 1974; Wiernusz and Teeter, 1993), deep body temperature (van Kampen and Romijin, 1970; Farrell and Swain, 1977) extending over a range of -5 to 40 C (Romijin and Vreugdenhil, 1969). Male broilers have been reported to have a 24 % greater heat production per unit of body weight than females (Meltzer, 1983). Heat production is inversely related to ambient temperature (van Kampen, 1974, 1981a: Williamson et al., 1985: Chwalibog et al., 1985); this may be attributed to reduced feed consumption at elevated temperatures. Broilers exposed to an increasing ambient temperatures exhibit a decreasing oxygen consumption and carbon dioxide production; this apparent reduction of heat production during heat distress may be due to decreased gas exchange between the blood and the air (Chwalibog and Eggum, 1989). Heat

production is elevated by low ambient temperature so that the homeotherm maintains body temperature.

Nonevaporative Heat Loss

Nonevaporative (sensible) heat loss is the body heat loss via radiation, convection, and conduction. Nonevaporative heat loss (NHL) = heat production - evaporative heat loss - body heat content change (Sturkie, 1986). Poultry utilize NHL as their major means of heat dissipation when housed below and within the thermoneutral temperature environments (Arieli et al., 1980; van Kampen, 1981b). NHL represents ≅75 % of total heat loss at the thermoneutral environment (Romijin and Lokhorst, 1966). Heat loss from the head appendages has been estimated as 9.3 to 25.6 % of total heat loss at environmental temperatures from -5 to 40 C (van Kampen, 1974). When the ambient temperature falls below the lower critical temperature, heat loss may exceed production; this forces the bird to increase metabolic rate in order to prevent a decline in body temperature (Freeman, 1971).

Decreased water consumption and therefore decreased urinary output during cold distress helps to conserve body heat (van Kampen, 1981a). Physical thermoregulatory mechanisms of the bird include covering the legs by sitting and fluffing out feathers to increase insulatory protection: these minimize heat loss during cold. The quantity of feathering is an important determinant of heat production at thermoneutral temperatures (O'Neill et al., 1971). At 20 C, a fully feathered bird has half the heat production rate as a non-feathered bird; therefore, feathered birds are more efficient in feed utilization at low temperatures. Arterial vasoconstriction decreases heat loss from the extremities; therefore, a reduction in countercurrent heat exchange occurs (van Kampen, 1981b). Cardiovascular modifications under cold distress may reduce the sensible heat loss from the head and legs by 15 to 20 %. Heat production increases via shivering if other responses prove inadequate (Freeman, 1988).

When the ambient temperature increases, the temperature gradient between the bird and the environment declines. This reduces nonevaporative heat loss which leads to a reversal of the responses reported during cold distress. Thermal insulatory effectiveness of the feathers is enhanced by posturally increasing effective surface area (Freeman, 1971). Vasodialation during high ambient temperature distress increases nonevaporative heat loss by reducing peripheral resistance to the viscera; this shunts more blood and core body heat to the peripheral tissues (Bottje and Harrison, 1984). Increased blood flow to the wattles and comb is an important mechanism for dissipating body heat (Michael and Harrison, 1987). A less important means of nonevaporative cooling is increased urine production. Elevated water loss is compensated by an increased water consumption; when consumed water has a lower temperature than the bird, this dissipates heat. Sensible heat efficiency decreases as ambient temperature increases due to a decreased temperature differential between the bird and ambient temperature (van Kampen, 1974; Wiernusz and Teeter, 1993). Consequentially, as ambient temperature inclines, the bird resorts increasingly to dissipating excess heat by evaporating water.

Evaporative Heat Loss

Evaporative heat loss is estimated by multiplying the grams of water evaporated (respiratory plus cutaneous water) by the latent heat of vaporization. Water evaporation is one route for fowl to control body temperature. Water has a high latent heat of vaporization; for every gram of water which evaporates, approximately 2.4 KJ of heat are lost. Evaporative heat loss of animals takes place both through the body surface and the respiratory tract. Because the fowl has no sweat glands, evaporative heat loss is primarily via the moist surface layer of the respiratory tract. Inspired air is 'saturated' with water vapor at body temperature (Kerstens, 1964). Hence, the rate of evaporative heat loss is directly proportional to respiratory rate.

Although evaporative heat loss at lower temperatures is minimal, it increases dramatically from 26 to 35 C where it may contribute up to 80 % of the total heat loss

from the body (Kerstens, 1964; van Kampen, 1981; Wiernusz and Teeter, 1993). A bird's dependency upon evaporative heat loss increases sharply when the temperature exceeds the upper critical temperature. Below the lower critical temperature, heat loss by evaporation of water from the skin also occurs but it represents only a small proportion (van Kampen, 1971; Richards, 1976). Cutaneous water loss increases in absolute terms as ambient temperature increases, but still only represents only 40% once panting is initiated (van Kampen, 1971) and declines to 15 % of total heat loss when the bird is panting actively (van Kampen, 1974).

During exposure to high temperature, respiration rate increases (Michael and Harrison, 1987). This increases the quantity of water that is evaporated from the mucous membranes lining of the upper respiratory tract and provides the water loss for evaporation. Also, during this time, blood flow through the carotid artery which serves the upper respiratory tract is enhanced (Freeman, 1984). Thereby, panting is the main route for heat dissipation during high ambient temperature distress. Heat distressed birds dissipate over 80 % of their heat production via evaporative heat loss (van Kampen, 1974; Weirnusz and Teeter, 1993). Respiratory water loss is minimal until ambient temperature surpasses the thermoneutral zone. At temperature of 34 C and relative humidity (RH) of 40 %, an adult hen dissipates over 80 % of total heat by evaporative heat loss; however, this was reduced to only 39 % when the RH increased to 90 %, under these conditions, birds becomes hyperthermic (Romijin and Lockhorst, 1966).

Respiratory evaporative heat loss is linearly related to respiration rate which in turn can perturb acid base balance. Broilers under heat distress have been reported to have elevated blood pH and reduced HCO_3^- and PCO_2 (Marder et al., 1974; Arad and Marder, 1983; Bottje and Harrison, 1985; Teeter et al., 1985; Branton et al., 1986). Respiratory alkalosis is associated with a myriad of physiological changes associated with electrolyte changes. Respiratory alkalosis has been reported to increase potassium excretion by over 600 % in broilers (Smith and Teeter, 1987) and by 45 % in layers

(Deetz and Ringrose, 1976) this reduces plasma sodium and potassium (Edens, 1977; Deyhim and Teeter, 1990). As intercellular potassium and HCO3- are replaced by hydrogen ions, this leads to intercellular acidosis (Gary, 1989). Because optimal enzymatic activity for protein synthesis (Stryer, 1981) and nutrient transport (Mongin, 1981) require a narrow and stable pH, hyperventilation with elevations in pH of blood and possibly other tissues may reduce bird productivity.

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CHAPTER III

FEED ACCESS EFFECTS ON SERUM METABOLITES OF HYBRID LARGE WHITE MALE TURKEYS

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ABSTRACT

A study was conducted utilizing Hybrid Large White male turkeys at 6 wk of age to evaluate feed access effects on various serum metabolite concentrations. Birds deprived of feed for 16 h had lower ($P < .05$) serum calcium (7.3 vs 8.1mg/dL), magnesium (2.7 vs 3.2 mEq/L) and triglycerides (45.8 vs 66.6 mg/dL) than birds with *ad libitum* access to feed. Serum values not impacted ($P > .1$) by the 16-h feed withdrawal include hematocrit, sodium, potassium, chloride, phosphorus, iron, glucose, total protein, blood urea nitrogen, creatinine, lactate dehydrogenase, aspartate aminotransferase, albumin, uric acid, and unsaturated iron-binding capacity.

(Key words: turkeys, nutrition, hematocrit, serum metabolites)

INTRODUCTION

Serum blood chemistries are potentially useful in the diagnosis and prognosis of turkey diseases and nutritional status. However, knowledge of "normal" blood chemistries are required before interpretation of such data may be made. Although serum chemistry values have been published for different avian species, information for commercial turkey strains are lacking. Of additional concern is the impact of bird feeding history on serum analyte concentration. Serum analytes impacted by feeding history would be of less diagnostic value where feed consumption history is unavailable. Several reports suggest that feed deprivation impacts hematocrit and plasma protein (3-d deprivation of 2-wk-old Diamond White poults; Augustine, 1982), plasma glucose, albumin, uric acid, blood urea nitrogen, and total protein (3-d deprivation of newly-hatched Hybrid poults; Moran, 1989), plasma triacylglyceride (12-h deprivation of 2 strains of turkeys at 16 to 20-wk-old; Bacon *et al.*, 1989), plasma glucose (24-h deprivation of newly-hatched BUT and Nicholas poults; Donaldson and Christensen, 1991; Donaldson *et al.*, 1991). Additional information is needed that examines variables simultaneously under practical conditions using a commercial turkey strain. The following study was conducted to evaluate feed access effects on hematocrit and 17 serum chemistries in 6-wk-old Hybrid Large White turkeys.

MATERIALS AND METHODS

Hybrid Large White male poults were obtained from a commercial hatchery and raised on rice hull litter under brooder stoves to 5 wk of age. Birds received a prestarter ration to 5 wk of age, at which time they were switched to a grower ration (Table 1). All birds were allowed *ad libitum* access to feed and water throughout the production period. On Day 42, nine birds were deprived of feed for 16 h and nine birds continued with *ad libitum* access to feed; however, feed intake was not recorded. On Day 43, all birds were individually weighed and two blood samples collected from the ulnaris vein as described

by Dein (1986) using a 3-mL syringe. The ambient temperature was 25 C at blood collection time. One sample of whole blood was used to determine hematocrit in duplicate. Sodium, potassium, calcium, magnesium, chloride, phosphorus, iron, glucose, triglycerides, total protein, blood urea nitrogen, creatinine, lactate dehydrogenase, aspartate aminotransferase, albumin, uric acid, and unsaturated iron-binding capacity were determined on serum samples using: Roche kits[3] for chloride (No. 44029), lactate dehydrogenase (No. 43623), aspartate aminotransferase (No. 44645), magnesium (No. 44169), triglycerides (No. 44120), uric acid (No. 44124), creatinine (No. 44905), glucose (No. 44557), blood urea nitrogen (No. 44568), total protein (No. 44903), albumin (No. 44902), calcium (No. 44033), and phosphorus (No. 44031) and Sigma kits[4] for unsaturated iron-binding capacity (No. 565B) and iron (No. 565B). In all instances, serum variables were measured using a Cobas Mira wet chemistry analyzer[5] with sodium and potassium values assayed via sodium and potassium selective electrode module (No. 44498) of the Cobas Mira. An ANOVA was performed using the General Linear Models procedure of the SAS Institute (1982). The unpaired *t* test procedure was used to separate treatment means (Steele and Torrie, 1960).

RESULTS AND DISCUSSION

All experimental results are displayed in Table 2. Although the fed birds had a 2.0% greater body weight than the feed-deprived turkeys, presumably attributable to their continued feed consumption, the difference was not significant. The SEM for the fed group was 21% higher than the deprived treatment, which likely reflects the varying feed contents in the birds' gastrointestinal tract. Nonetheless, bird mean body weight was similar to NRC (1984) projections for large turkeys.

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[3] Hoffman-LaRoche, Nutley NJ 07042

[4] Sigma Diagnostics, St. Louis, MO 63178-9916.

[5] Roche Diagnostics Systems Inc., Montclair, NJ 07042-5199

No feeding history effect was detected for hematocrit, sodium, potassium, chloride, phosphorus, iron, glucose, total protein, blood urea nitrogen, creatinine, lactate dehydrogenase, aspartate aminotransferase, albumin, uric acid, and unsaturated iron-binding capacity, suggesting that they may be used to diagnose disease-nutritional status of 6-wk-old Hybrid Large White turkeys without regard for feeding history. These values are in general agreement with data presented by others (Augustine, 1982; Moran, 1989; Donaldson and Christensen, 1991) for similar bird types (turkey poults) and varying dietary histories (fed vs feed-restricted). As such, these analytes have particular advantage for evaluating random sample analysis of bird populations in the field consuming similar ration types. In contrast, triglyceride, calcium and magnesium concentrations were significantly reduced ($P < .05$) in birds that were deprived of feed, making analyte interpretation without knowledge of feeding history uncertain.

Serum triglycerides were reduced ($P < .01$) by 31% (45.8 vs 66.6 mg/dL) with a 61% lower SEM (2.13 vs 5.48 mg/dL) in the feed-restricted birds. These data are in agreement with those of Bacon *et al.* (1989), who reported that blood plasma triacylglycerides of two turkey strains, at 16 to 20 wk of age, declined ($P < .05$) during an overnight period (12 h) of feed withdrawal. Naito (1987) indicated that a withdrawal period sample (12 to 24 h) is essential for triglyceride analysis of human patients, gecause triglyceride concentration increase at 2 h postprandially and reach a maximum at 4 to 6 h; furthermore, samples drawn from patients that are eating are not suitable for analysis. Whether the evaluated triglyceride SEM reflects variation in feed consumption extent or feeding pattern is not known.

Feed access effects on serum calcium and magnesium were similar to bird's triglyceride response pattern. Feed-restricted birds had lower ($P < .05$) serum calcium (7.3 vs 8.1 mg/dL) and magnesium (2.7 vs 3.2 mEq/L) than those that consumed feed *ad libitum*. The SEM for magnesium was greater in the fed birds but the calcium was lower. The calcium response was similar to McMurtry *et al.* (1984), in which the total calcium

levels of Large White turkey poults (4-wk-old) significantly increased at 6, 8, and 48 h of feed deprivation. Lewandowski *et al.* (1986), reported that serum calcium ranges from 8 to 12 mg/dL and further that it will frequently rise when birds consume higher protein rations. Farrell (1987) indicated that human infants have the same serum concentrations of magnesium as adults, and there is no difference between fasting and fed magnesium levels.

In summary, this study estimates the "normal range" for 15 serum chemistries that may be used as an aid to evaluate the health of 6-wk-old Hybrid Large White Turkeys where birds have access to and have consumed feed within 16 h of sampling. Further, the results of the study indicate that short-term feed restriction profoundly impacts serum concentrations of triglycerides, calcium, and magnesium, which limits their utility in disease diagnosis and nutritional status judgment in cases in which feed consumption is questionable. The values reported in this study are, to the authors' best knowledge, the first in which the 18 analytes evaluated were done simultaneously.

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TABLE 1. Composition of turkey rations

Ingredients and analysis	Prestarter[1]	Grower[1]
	(%)	
Soybean meal (48.5% CP)	49.44	37.09
Ground corn (8.7% CP)	43.96	56.42
Dicalcium phosphate	2.80	2.64
Tallow	1.50	2.35
Calcium carbonate	1.20	.60
Salt	.40	.30
Hoffman vitamin mix[2]	.40	.40
Methionine	.20	.10
Trace mineral premix[3]	.10	.10
Calculated analysis		
CP	28.00	23.00
ME, kcal/kg	2,811.60	2,998.60
Ca	1.26	.96
Na	.18	.14
K	1.08	.88
P (available)	.67	.62
Mg	.06	.08
Fe, mg/kg	427.76	501.84

[1]Rations supplemented with .04% monensin and .0002% selenium 60.

[2]Mix supplied per kilogram of diet: vitamin A, 15,840 IU (retinyl acetate); vitamin E, 52.8 IU (dl-α-tocopheryl acetate); cholecalciferol, 4,400 IU; vitaminK, 5.33 mg; thiamin, 3.16 mg; riboflavin, 10.56 mg; niacin, 70.4 mg; pantothenic acid, 17.6 mg; choline, 799.04 mg; pyridoxine, 6.34 mg; folacin, 1.76 mg; biotin, .176 mg; vitamin B_{12}, 17.6 μg.

[3]Mix supplied per kilogram of diet: Ca, 160 mg; Zn, 100 mg; Mn, 120 mg; Fe, 75 mg; Cu, 10 mg; I, 2.5 mg.

TABLE 2. Serum blood chemistries (x ± SEM) of 6 wk Hybrid Large White male turkeys fed or deprived of feed

Analyte[1]	Deprived of feed[2]	Fed	Mean	$P > F$
Weight, g	1966.67 ± 47.08	2006.78 ± 57.17	1986.72	.5955
Hct. %	33.39 ± .51	34.11 ± .48	33.75	.3175
Na, mEq/L	149.13 ± 2.52	151.25 ± 4.70	150.19	.6963
K, mEq/L	3.39 ± .17	3.64 ± .25	3.51	.4278
Ca, mg/dL	7.30 ± .30[b]	8.14 ± .25[a]	7.72	.0445
Mg, mEq/L	2.66 ± .12[b]	3.23 ± .22[a]	2.94	.0321
Cl, mEq/L	118.67 ± 1.83	120.67 ± 3.55	119.67	.6236
P, mg/dL	7.66 ± .11	8.06 ± .31	7.86	.2455
Fe, µg/dL	385.43 ± 93.50	383.14 ± 108.60	384.29	.9875
Gluc, mg/dL	278.11 ± 6.16	285.11 ± 8.54	281.61	.5158
Trig, mg/dL	45.78 ± 2.13[b]	66.56 ± 5.48[a]	56.17	.0028
TP, g/dL	2.86 ± .10	2.94 ± .10	2.90	.5391
BUN, mg/dL	1.23 ± .12	1.43 ± .14	1.33	.2996
Crea, mg/dL	0.21 ± .01	0.20 ± .00	.21	.3322
LDH, U/L	732.22 ± 29.45	653.63 ± 36.06	695.24	.1092
AST, U/L	286.11 ± 10.89	267.78 ± 17.31	276.94	.3833
Alb, mg/dL	1.16 ± .04	1.17 ± .06	1.16	.8775
Uric, mg/dL	4.57 ± .25	4.52 ± .29	4.54	.9028
UIBC, µg/dL	75.33 ± 9.77	68.44 ± 10.37	71.89	.6352

[a-b] Means ± SEM in a row with no common superscript differ significantly ($P < .05$).

[1]Hct = hematocrit, Gluc = glucose, Trig = triglycerides, TP = total protein, BUN = blood urea nitrogen, Crea = creatinine, LDH = lactate dehydrogenase, AST = aspartate aminotransferase, Alb = albumin, Uric = uric acid, UIBC = unsaturated iron-binding capacity.

[2]Turkeys deprived of feed for 16 h.

CHAPTER IV

SERUM CHEMISTRY VALUES OF 6, 12, 18, 24, AND 30-WK-OLD HYBRID LARGE WHITE MALE TURKEYS DEPRIVED OF FEED FOR 16 H

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ABSTRACT

One study was conducted using 6, 12, 18, 24 and 30-wk-old Hybrid Large White male turkeys to evaluate age-weight effects on serum metabolites following a 16-h feed deprivation. As age and (or) weight increased, increases ($P < .01$) were detected in hematocrit, sodium, calcium, total protein, creatinine, lactate dehydrogenase, aspartate aminotransferase, uric acid and unsaturated iron-binding capacity. Age and (or) weight were negatively correlated ($P < .01$) with potassium, magnesium, and phosphorus. Age but not weight was positively correlated ($P < .01$) with blood urea nitrogen, chloride, and albumin. Weight was negatively correlated ($P < .01$) with triglycerides but age was not ($P = .07$). Neither age or weight were significantly correlated with iron or glucose concentrations in serum. Prediction equations based on age, weight, and the age-weight interaction were calculated.

(*Key words*: Turkeys, feed deprivation, hematocrit, serum metabolites,)

INTRODUCTION

Serum chemistries are used widely for the diagnosis of turkey diseases and nutritional status. Feed consumption has been reported to have variable effects on serum chemistry values (Augustine, 1982; Moran, 1989; Bacon *et al.*, 1989; Donaldson and Christensen, 1991; Donaldson *et al.*, 1991; Cason and Teeter, 1994). Consequently, short-term feed deprivation may be useful as a tool to reduce variation. However, knowledge of "normal" blood chemistries are needed in order to interpret serum chemistry values. Reference ranges for serum chemistries have been published for a variety of avian species, but relatively little information is available describing serum chemistries of short-term fasted male turkeys of various body sizes.

Serum chemistry values can be affected by many variables, these include species, sex, age, physiological condition, nutritional status, geological location and time of day (or year) when the sample is taken (Dein, 1986). Andreasen *et al.* (1989) determined chicken and turkey plasma and serum protein concentrations by refractory (with human and veterinary refractometers) and by the biuret method. Turkey and chicken protein was lower in serum than in plasma for both species according to both methods; this led authors to conclude that plasma and serum values are not comparable in each species and further that methods for protein determination, comparing plasma to serum values may result in erroneous conclusions (Lumeij and de Bruijne, 1985).

The first published report concerning serum blood chemistries of male turkey blood was by Scott *et al.*, (1933). Mean plasma calcium values reported by Scott and his associates were 11.1 mg/dL for 10 females and 11.66 mg/dL for 5 males. Neilson and Madsen (1940) reported mean serum calcium levels of 13.15 mg/dL for 28-wk-old normal Bronze toms and hens; this was higher than the plasma calcium levels reported by Scott *et al.* (1933). Rhian *et al.* (1944) have published information on the blood of normal Bronze turkeys (16 hens and 4 toms) at different dates. They found that the blood plasma composition of vitamins A and C, carotene, calcium, phosphorus, glutathione, sugar,

hemoglobin, hematocrit, and plasma protein from toms was the same as from hens. Whole blood hematocrit values reported for the toms ranged from 35.5 to 45% with a mean of approximately 42%. Paulsen *et al.* (1950) made further studies of blood plasma chemistries on Broad-Breasted breeding turkeys (20 hens and 4 toms) at 4 wk intervals during 1944 and 18 hens during 1945 and found that differences in blood chemistries (hemoglobin, calcium, phosphorus, carotene, and vitamin A) existed between males and females.

Serum values of sodium, potassium, and calcium from normal adult (42 to 72-wk-old) White Holland turkeys were published by Kirshner *et al.* (1951). Mean serum values for sodium (5 toms) was 155 mEq/L and for potassium (3 toms) was 6.4 mEq/L. No differences between hens and toms for sodium and potassium average values were significant. Mean calcium values for 5 toms was 23.9 mEq/L for whole blood, being lower than for hens (34.5 mEq/L).

Lynch and Stafseth (1953) reported that in normal Broad-Breasted Bronze turkey toms (16 to 24-wk-old), serum total protein ranged from 3.96 to 4.91 g/dL and serum albumin ranged from 60.24 to 72.08 percent of serum protein. Serum total protein and albumin values have been reported for Beltsville White turkeys (6-wk-old) infected with *Histomonas meleagridis* by Clarkson (1966). The sex of the turkeys were not mentioned in his report. Measurements were recorded daily for 14 d post-infection. Serum total protein was reduced significantly on days 5 through 8 (2.3 g/100 mL), but then returned to the control value (3.3 g/100 mL). The main changes associated with histomoniasis are reduced albumin and increased γ-globulin. Approximate albumin values ranged from 1.5 to 1.3 g/dL on Day 1 and from 2.1 to 0.3 g/dL on Day 14 for control and infected turkeys, respectively. The rapid decline occurred before the development of liver lesions, which is the sole organ responsible for albumin production (Miller and Bale, 1954; Mandel *et al.* 1947).

Hematocrit values of 56 Broad-Breasted Bronze and Broad-Breasted White male turkeys (36 and 43-wk-old, respectively) at 10, 21.1, 32.2, and 37.8 C were published by Parker and Boone (1971). No significant differences due to bird strain were detected; therefore, the data reported were combined. Two trials were conducted and blood was analyzed during prestress, stress, and poststress. Hemodilution occurred in both trials, as indicated by the low hematocrit values for the 37.8 C treatment, and continued throughout stress and postress. Hematocrit values for the 37.8 C group at 21 days of postress for trials 1 and 2 were 34 and 33%, respectively. In trial 2, the 32.2 C group appeared to show a slight hemodilution, which was particularly evident with stress. Hematocrit values obtained for the 32.2, 21.1, and 10.0 C treatments did not significantly vary from prestress values. Huston (1965) reported that chickens exposed to cooler environments had a higher hematocrit than birds exposed to heat stress. Hematocrit and plasma levels of glucose and total protein were determined for eastern wild turkeys over a 13 month period (Lisano and Kennamer, 1977). Mean hematocrit values for males was 41.4%, plasma total protein was 4.7 g/100 mL. and plasma glucose was 336.2 mg/100 mL. All of the values were not significantly different when comparing sexes across the 13-month study period.

The following study was conducted to determine age-weight effects on hematocrit and serum sodium, potassium, calcium, magnesium, chloride, phosphorus, iron, glucose, triglycerides, total protein, blood urea nitrogen, creatinine, lactate dehydrogenase, aspartate aminotransferase, albumin, uric acid and unsaturated iron-binding capacity of Hybrid male turkeys differing in age and body weight following a 16 h of feed deprivation but without deprivation of water.

MATERIALS AND METHODS

Thirty Hybrid Large White male poults were obtained from a commercial hatchery in intervals to produce 5 populations at 6 wk intervals. Poults were raised on rice hull litter under brooders and fed a prestarter ration (Table 1) to the fourth week. At 5 wk of age, birds were switched to a grower ration (Table 1) which they received until they were 30 wk of age. Birds had *ad libitum* access to feed and water throughout the production period. Birds were deprived of feed overnight (16 hours) and 10 birds per age group (50 birds total) were selected randomly, weighed and two blood samples were collected from the ulnaris vein as described by Dein (1986) using a 3 mL syringe. The ambient temperature was 25 C when blood was collected. One sample of whole blood was used to determine hematocrit in duplicate. Sodium, potassium, calcium, magnesium, chloride, phosphorus, iron, glucose, triglycerides, total protein, blood urea nitrogen, creatinine, lactate dehydrogenase, aspartate aminotransferase, albumin, uric acid and unsaturated iron-binding capacity were determined on serum samples using: Roche kits[3] for Chloride (No. 44029), lactate dehydrogenase (No. 43623), aspartate aminotransferase (No. 44645), magnesium (No. 44169), triglycerides (No. 44120), uric acid (No. 44124), creatinine (No. 44905), glucose (No. 44557), blood urea nitrogen (No. 44568), total protein (No. 44903), albumin (No. 44902), calcium (No. 44033), and phosphorus (No. 44031) and Sigma kits[4] for unsaturated iron-binding capacity (No. 565B) and iron (No. 565B). In all instances, serum variables were measured using a Cobas Mira wet chemistry analyzer[5] with sodium and potassium values assayed via sodium and potassium selective electrode module (No. 44498) of the Cobas Mira. An ANOVA was performed using the General Linear Model procedure of the SAS Institute (1982). The unpaired *t* test procedure was used to separate treatment means (Steele and Torrie, 1960) and regression analysis was used for estimating predictive equations. The predictive equations were estimated using backward-

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elimination technique of the SAS Institute (1982) and variables include age, age^2, weight, weight^2, and age x weight interactions. All variables that remained in the model produced F statistics significant at the 0.1 level.

RESULTS AND DISCUSSION

Mean body weights and mean serum chemistry values are displayed in Table 2. Though weight was positively correlated ($P < .01$) with age ($r = .94$) it increased through 24 weeks after which it plateaued, creating quadratic relationship. The predictive equation determined from our data: Weight (g) = -3963.56 + 1017.08(age) - 10.68(age)^2 where r =.81.

Mean hematocrit increased ($P < .01$) by 45% during the 6 to 30 wk age intervals (33.4 to 48.6%). Cecil and Bakst (1991) reported hematocrit values of Hybrid Large White breeder male turkeys, ranging from 8 to 46 wk of age, rose from 33 to 41%, respectively. The authors reported further that hematocrit increased (16-wk-old) 1 wk after spermatozoa were first detected in the seminiferous tubules and suggested that hematocrit could be used to predict spermatozoal maturation in testes, sexual maturity and the start of semen production in the male breeder turkey. Results of the study herein are in agreement in that hematocrit differences were noted first at 18 wk of age. However, whether this effect is restricted to males is uncertain. The predictive equation (Table 3) detected both age and weight in a quadratic relationship.

Normal birds (differing avian species) have been reported to have a serum glucose between 200-500 mg/dl with values dependent on age, time of day and state of captivity (Lewandowski *et al.*, 1986). In this study, glucose averaged 280.8 mg/dL, and was not correlated significantly with bird age or weight. Though age was not correlated ($P = .07$) with triglyceride; weight was negatively correlated ($P < .01$) with serum triglycerides (r = -.42). Mean serum triglyceride concentration exhibited a 27.6% decrease ($P < .01$) from 1967 to 16798 g (45.78 to 33.13mg/dL); however, there were no significant differences (P = .56) between 1967 and 15890 g. The predictive equation determined from our data

(Table 3): Serum triglycerides (mg/dL) = $41.2 + 2.9x10^{-3}(wt) - 1.9x10^{-7}(wt)^2$, where weight unit = g.

Age and weight were both correlated (r = .55 and .45, respectively; $P < .01$) with serum total protein and albumin. Total protein increased ($P < .01$) from 6 to 30 wk of age and from 1.97 to 15.89 kg by 2.9 to 4.4 g/dL, while albumin increased from 1.2 to 1.4 mg/dL. Because total protein and albumin continued to increase with age, following the body weight plateau at 24 weeks, they appear to be more closely related to age than to weight. Lewandowski *et al.* (1986) reported the normal value of total protein varies with species of birds but generally is in the 3 to 5 g/dL range; furthermore that values can be affected by age, seasonal changes, captive status and by egg production. Galvin (1980) reported that albumin is the largest individual protein fraction in avian serum and the decline of plasma protein in disease states usually is due to a decline in the albumin. However, the total protein prediction equation (Table 3) included age alone while the equation for albumin included both age and weight coefficients.

Age and weight both were correlated ($P < .01$) with serum uric acid (r = .67 and .54, respectively) and creatinine (r = .61 and .54, respectively). Uric acid increased ($P < .01$) from 6 to 30 wk of age and from 1.97 to 15.89 kg by 4.6 to 8.5 mg/dL, while creatinine increased 0.2 to 0.3 mg/dL. Although weight was not correlated with blood urea nitrogen (BUN), age was correlated ($P < .01$) with BUN (r = .43). Serum BUN concentrations increased ($P < .01$) by 73.2% between 6 and 30 wk of age (1.2 to 2.1mg/dL). The prediction equations (Table 3) for uric acid, creatinine and BUN included age and weight as coefficients. Lewis *et al.* (1979), reported that mean plasma values of 7 female turkeys (4.54 to 5.45 kg.) were 6.7g/dL for uric acid, 0.5mg/dL for creatinine, and ≤2.2g/dL for BUN. Lewandowski *et al.*, (1986) reported normal ranges for uric acid (2-15mg/dL) and of creatinine (< 0.2mg/dL) and suggested that because birds are uricotelic and thereby produce uric acid instead of urea as the major nitrogenous end product, BUN

is not useful as a test of renal function in birds. Whether this is true for all forms of renal disease, however, is uncertain.

Age and weight both were correlated ($P < .01$) with lactate dehydrogenase ($r = .65$ and .70, respectively) and aspartate aminotransferase ($r = .83$ to .84, respectively). Lactate dehydrogenase (LDH) increased ($P < .05$) from 6 to 30 weeks and from 1.97 to 15.89 kg by 732.2 to 1087.5 U/L while aspartate aminotransferase (AST) increased 235.8% ($P < .01$) from 286.1 to 960.8 U/L. Enzyme levels from 20 Nicholas turkeys (15 kg) were reported by Bognin *et al.*, (1976). Their mean enzyme levels in serum (milliunits per mL of serum) were 960 of LDH and 446.0 of glutamate-oxaloacetate transaminase (GOT) which now is known as AST. These results suggest that enzyme patterns were distinctively different from those of other fowl (Cornelius, 1961; Rivetz and Bognin, 1974; Rivetz *et al.*, 1975; Fowler, 1970; Bognin and Israeli, 1976) and require further study. Lewandowski *et al.*, (1986) reported that AST varies with sex, age, time of year and breeding activity and that season can affect LDH. The LDH equation (Table 3) included weight alone while the AST equation included both age and weight coefficients.

Age and weight were not correlated ($P = .23$) with iron nor were differences ($P = .14$) found between all ages. Mean iron value was 279.9 μg/dL. However, age and weight were correlated ($P < .01$) with unsaturated iron-binding capacity (UIBC) with correlation coefficients of .68 and .58, respectively. UIBC increased ($P < .01$) 200% from 6 to 30 wk of age and from 1.97 to 15.89 kg by 75.3 to 225.7 μg/dL. Age and weight coefficients both were included in the UIBC predictive equation (Table 3). Perrotta (1987) observed that the unsaturated iron-binding capacity of transferrin (UIBC) denotes the available iron-binding sites of serum whereas the amount of iron that serum transferrin can bind when completely saturated is the total iron-binding capacity (TIBC). Because it is not possible to diagnose the cause of chronic iron deficiency or anemia from serum iron alone, TIBC determination is useful.

Age and weight were positively correlated ($P < .01$) with serum sodium ($r = .63$ and .53, respectively) and with calcium ($r = .50$ and .45, respectively). However, age and weight were negatively correlated ($P < .01$) with potassium ($r = -.54$ and -.51, respectively), with magnesium ($r = -.46$ and -.47, respectively) and with phosphorus ($r = -.80$ and -.79, respectively). Weight was not correlated ($P = .09$) with chloride; whereas age was ($P < .05$; $r = .32$). Significant increases from 6 to 30 wk and from 1.97 to 15.98 kg were as follows: sodium = 10.3% (149.1 to 164.4 mEq/L) and calcium = 34.7% (7.3 to 9.8 mg/dL). Significant decreases from 6 to 30 wk and from 1.97 to 15.89 kg were as follows: potassium = -23.6% (3.4 to 2.6 mEq/L), magnesium = -22.9% (2.7 to 2.1 mEq/L) and phosphorus = -25.7% (7.7 to 5.7 mg/dL). Although mean serum chloride increased 5.7% from 6 to 30 wk (118.7 to 125.4 mEq/L), this increase was not significant ($P = .15$). Sodium, magnesium, and phosphorus predictive equations (Table 3) included age and weight coefficients, potassium and chloride included age coefficients, whereas calcium included only weight coefficients. Lewandowski *et al.* (1986) reported normal ranges of the following analytes for birds were: sodium = 130-170 mEq/L, calcium = 8-12 mg/dL, potassium = 2.5-6.0 mEq/L and phosphorus = 2-6 mg/dL. Kohne and Jones (1975a) reported plasma Na, Cl, total Ca and Mg values for 20 non-laying Broad-Breasted White (Nicholas strain) hens at 42 wk of age. Analyte values at 21 C were as follows: Na = 343.0 mg%, Cl = 116.5 mEq/L, total Ca = 12.2 mg% and Mg = 2.0 mg%. Kohne and Jones (1975b) also reported plasma Na, K, total Ca, Mg and Cl values for 90 Broad-Breasted White (Nicholas Strain) laying hens at 33 wk of age. Analyte values at 21 C were as follows: Na = 342.2 mg%, K = 12.4 mg%, total Ca = 24.0 mg%, Mg = 3.3 mg% and Cl = 118.2 mEq/L.

Our data indicate that serum chemistry analytes exhibit profound changes with both age and weight in Large White male turkeys ranging from 6 to 30 weeks of age and 1.97 to 15.89 kg. Proper interpretation of serum chemistry for male must consider weight

and (or) age. The effect of feed consumption has been to primarily impact triglycerides, calcium, and magnesium (Cason and Teeter, 1994). Consequently, this study utilized short-term feed restriction to remove variation. Predictive equations for serum analytes were established using age, age^2, weight, weight^2, and age x weight variables. Variables were excluded that did not add a significance above the 0.1 level. The values reported in this study are the first to simultaneously examine 18 serum analytes and 5 different age-weight combinations of male turkeys. These values should serve as an aid for refining standard serum values.

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TABLE 1. Composition of turkey rations

Ingredients and analysis	Prestarter[1]	Grower[1]
	(%)	
Soybean meal (48.5% CP)	49.44	37.09
Ground corn (8.7% CP)	43.96	56.42
Dicalcium phosphate	2.80	2.64
Tallow	1.50	2.35
Calcium carbonate	1.20	.60
Salt	.40	.30
Hoffman vitamin mix[2]	.40	.40
Methionine	.20	.10
Trace mineral premix[3]	.10	.10
Calculated analysis		
CP	28.00	23.00
ME, kcal/kg	2,811.60	2,998.60
Ca	1.26	.96
Na	.18	.14
K	1.08	.88
P (available)	.67	.62
Mg	.06	.08
Fe, mg/kg	427.76	501.84

[1]Rations supplemented with .04% monensin and .0002% selenium 60.

[2]Mix supplied per kilogram of diet: vitamin A, 15,840 IU (retinyl acetate); vitamin E, 52.8 IU (dl-α-tocopheryl acetate); vitamin D-3, 4,400 IU; vitaminK, 5.33 mg; thiamin, 3.16 mg; riboflavin, 10.56 mg; niacin, 70.4 mg; pantothenic acid, 17.6 mg; choline, 799.04 mg; pyridoxine, 6.34 mg; folacin, 1.76 mg; biotin, .176 mg; vitamin B-12, 17.6 mcg.

[3]Mix supplied per kilogram of diet: Ca, 160 mg; Zn, 100 mg; Mn, 120 mg; Fe, 75 mg; Cu, 10 mg; I, 2.5 mg.

TABLE 2. Age effects on serum blood chemistries (x ± SEM) of Hybrid Large White male turkeys deprived of feed for 16 h

Analyte	Age (wk) 6	12	18	24	30	Mean	$P > F$
Weight, g	1966.67 ± 47.08 [d]	6879.22 ± 132.68 [c]	8856.13 ± 242.74 [b]	16798.00 ± 433.26 [a]	15890.00 ± 671.93 [a]	9660.39	.0001
Hct. %	33.39 ± .51 [c]	33.28 ± .76 [c]	33.00 ± .64 [c]	41.44 ± .97 [b]	48.58 ± 1.16 [a]	37.28	.0001
Na, mEq/L	149.13 ± 2.52 [c]	150.38 ± 2.63 [c]	152.71 ± 2.15 [bc]	158.00 ± 1.94 [ab]	164.43 ± 3.23 [a]	154.74	.0001
K, mEq/L	3.39 ± .17 [a]	3.34 ± .11 [a]	2.86 ± .17 [b]	2.67 ± .18 [b]	2.59 ± .31 [b]	2.99	.0005
Ca, mg/dL	7.30 ± .30 [b]	9.70 ± .39 [a]	9.84 ± .55 [a]	9.54 ± .44 [a]	9.83 ± .31 [a]	9.17	.0012
Mg, mEq/L	2.66 ± .12 [a]	1.75 ± .06 [c]	1.78 ± .02 [c]	1.98 ± .05 [b]	2.05 ± .08 [b]	2.10	.0070
Cl, mEq/L	118.67 ± 1.83 [ac]	114.13 ± 3.08 [bc]	113.71 ± 2.67 [c]	121.38 ± 2.52 [ab]	125.43 ± 3.98 [a]	118.62	.0453
P, mg/dL	7.66 ± .11 [a]	7.71 ± .25 [a]	7.27 ± .25 [a]	6.09 ± .17 [b]	5.69 ± .28 [b]	6.89	.0001
Fe, µg/dL	385.43 ± 93.50	220.43 ± 37.95	253.50 ± 37.32	270.20 ± 32.07	257.00 ± 30.85	279.93	.2387
Gluc, mg/dL	278.11 ± 6.16	283.00 ± 6.22	285.14 ± 10.16	280.13 ± 7.41	277.86 ± 8.16	280.80	.9226
Trig, mg/dL	45.78 ± 2.13 [a]	53.38 ± 4.42 [a]	50.50 ± 3.94 [a]	33.13 ± 4.06 [b]	43.71 ± 3.99 [ab]	45.08	.0707
TP, g/dL	2.86 ± .10 [d]	3.41 ± .22 [bc]	3.53 ± .39 [acd]	3.65 ± .28 [ab]	4.41 ± .33 [a]	3.53	.0003
BUN, mg/dL	1.23 ± .12 [ab]	.98 ± .08 [b]	1.16 ± .09 [ab]	1.20 ± .11 [ab]	2.13 ± .45 [a]	1.30	.0091
Crea, mg/dL	.21 ± .01 [c]	.24 ± .02 [bc]	.25 ± .02 [abc]	.28 ± .02 [ab]	.33 ± .03 [a]	.26	.0001
LDH, U/L	732.22 ± 29.45 [b]	737.88 ± 35.52 [b]	754.43 ± 40.61 [b]	1095.60 ± 96.97 [a]	1087.50 ± 111.40 [a]	850.77	.0001
AST, U/L	286.11 ± 10.89 [cd]	303.89 ± 14.95 [c]	254.57 ± 17.36 [d]	810.00 ± 28.62 [b]	960.75 ± 42.43 [a]	461.25	.0001
Alb, mg/dL	1.16 ± .04 [c]	1.29 ± .04 [a]	1.55 ± .13 [ab]	1.25 ± .05 [ac]	1.44 ± .06 [b]	1.31	.0110
Uric, mg/dL	4.57 ± .25 [bc]	4.39 ± .22 [c]	4.59 ± .21 [bc]	6.07 ± .63 [ab]	8.50 ± .96 [a]	5.40	.0001
UIBC, µg/dL	75.33 ± 9.77 [c]	143.50 ± 16.44 [b]	183.71 ± 15.46 [ab]	161.33 ± 22.06 [ab]	225.67 ± 32.23 [a]	150.94	.0001

[a-d] Means ± SEM in a row with no common superscript differ significantly ($P < .05$).

Hct = hematocrit, Gluc = glucose, Trig = triglycerides, TP = total protein, BUN = blood urea nitrogen, Crea = creatinine, LDH = lactate dehydrogenase. AST = aspartate aminotransferase, Alb = albumin, Uric = uric acid, UIBC = unsaturated iron-binding capacity.

TABLE 3. Serum blood chemisty predictive equations using age[1] and/or weight[2] in male turkeys 6 to 30 weeks of age

Analyte	Predictive equation	RMSE[3]	R^2
Hct, %	$40.52 - 1.68(age) + 6.83x10^{-4}(wt) + 5.23x10^{-2}(age)^2$	4.41	.90
Na, mEq/L	$147.96 - 9.00x10^{-8}(wt)^2 + 8.31x10^{-5}$(age x wt)	43.99	.44
K, mEq/L	$3.65 - 3.80x10^{-2}(age)$	.26	.30
Ca, mg/dL	$6.00 + 7.37x10^{-4}(wt) - 3.00x10^{-8}(wt)^2$	1.08	.53
Mg, mEq/L	$3.08 - 2.60x10^{-4}(wt) - 2.73x10^{-3}(age)^2 + 1.17x10^{-5}$(age x wt)	.06	.67
Cl, mEq/L	$125.12 - 1.46(age) + 5.02x10^{-2}(age)^2$	60.19	.23
P, mg/dL	$7.99 - 2.43x10^{-2}(age)^2 - 7.00x10^{-8}(wt)^2 + 7.81x10^{-5}$(age x wt)	.28	.74
Fe, µg/dL	279.93	21345.37	.00
Gluc, mg/dL	280.80	411.14	.00
Trig, mg/dL	$41.15 + 2.90x10^{-3}(wt) - 1.90x10^{-7}(wt)^2$	99.08	.35
TP, g/dL	$2.97 + 1.52x10^{-3}(age)^2$	.54	.30
BUN, mg/dL	$1.64 - 9.80x10^{-2}(age) + 5.68x10^{-3}(age)^2 - 3.50x10^{-6}$(age x wt)	.24	.42
Crea, mg/dL	$2.15x10^{-1} - 1.76x10^{-3}(age)^2 - 1.00x10^{-8}(wt)^2 + 6.38x10^{-6}$(age x wt)	.00	.46
LDH, U/L	$686.82 + 1.48x10^{-6}(wt)^2$	22331.81	.56
AST, U/L	$704.53 - 101.82(age) + 6.02x10^{-2}(wt) - 7.57x10^{-6}(wt)^2 + 9.14x10^{-3}$(age x wt)	3079.05	.97
Alb, mg/dL	$7.19x10^{-1} + 1.01x10^{-1}(age) - 5.97x10^{-5}(wt) - 1.52x10^{-3}(age)^2$	.02	.46
Uric, mg/dL	$7.39 - 1.02(age) + 1.09x10^{-3}(wt) + 4.40x10^{-2}(age)^2 - 5.24x10^{-5}$(age x wt)	1.01	.73
UIBC, µg/dL	$35.74 + 1.94x10^{-2}(wt) + 4.68x10^{-1}(age)^2 - 1.14x10^{-3}$(age x wt)	2470.03	.54

[1]Age term units = wk posthatch.

[2]Weight term units = g.

[3]RMSE = Root mean square error.

Hct = hematocrit, Gluc = glucose, Trig = triglycerides, TP = total protein, BUN = blood urea nitrogen, Crea = creatinine.
LDH = lactate dehydrogenase, AST = aspartate aminotransferase, Alb = albumin, Uric = uric acid.
UIBC = unsaturated iron-binding capacity.

CHAPTER V

EFFECTS OF AMBIENT TEMPERATURE ON BASAL METABOLIC RATE AND THERMOBALANCE OF 2, 8, AND 14-WK-OLD MALE HYBRID LARGE WHITE TURKEYS.

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ABSTRACT

Turkeys exposed to high ambient temperature generally exhibit reduced weight gain, feed efficiency, and survivability. Survivability during heat distress (HD) depends upon physiological processes controlling thermobalance. A replicated experiment was conducted utilizing birds fasted for 36 h to evaluate the effects of ambient temperature (25, 37 C) on 2, 8, and 14-wk-old Hybrid Large White male turkeys. The 11 h experimental period was divided into 3 intervals exposing birds to 24, 24-37, and 37 C. Measurements included: body temperature, oxygen consumption, carbon dioxide production, water consumption, bird water production, heat gain, heat production, evaporative cooling, nonevaporative cooling, respiration rate, respiration efficiency, and respiratory quotient. Age effects were detected for every measurement except body temperature, respiration rate, and respiratory quotient. Effects of heat were noted for every measurement except oxygen consumption, respiration efficiency, and respiratory

quotient. Age by heat interactions were noticed for water production and evaporative cooling. The best exponent for converting body weight to metabolic body weight (thermoneutral temperature) was .71 ± .04 for the .217 to 7.439 kg turkeys. The data reported indicated that as Large White turkeys are exposed to increased ambient temperatures, nonevaporative cooling declines which forces the bird to rely on evaporative cooling to maintain body temperature.

(Key words: Turkeys, heat distress, thermobalance, respiration, metabolic body weight)

INTRODUCTION

Basal metabolic rate is defined as the heat produced during complete rest in a thermoneutral environment in the post-absorptive condition (Brody, 1945). Basal heat production per unit body weight in homeotherms decreases as weight increases. Consequently, body weight is not suitable as a reference base for metabolism. According to the laws of Newton and Stefan - Boltzmann, heat loss is proportional to surface area. Over a century ago, Sarrus and Rameaux (1837) suggested that the square of linear size or the 2/3 power of weight could be used as a reference base for heat production. This is based simply on the area/volume relations for a sphere ($SA = 4\pi r^2$; $V = 4/3\pi r^3$). In equation form, heat loss should be proportional to the 2/3 power of weight (W) if the specific gravity is constant and the shape is a cube, as indicated by the equation: $aW^{2/3}$. In 1932, Kleiber reported that the 3/4 power of weight was more precisely employed as a reference base across species for adult animals. At about the same time, Brody published results reporting that the 0.73 power of weight was the ideal cross-species reference base. The Conference on Energy Metabolism in 1935 tentatively adopted the 0.73 power of body weight as a reference base for energy metabolism.

Brody (1945) determined the basal metabolic rate for four groups of mature Rhode Island Red fowls, normal and bantam (small) varieties. When both varieties were included, the exponent ranged from 0.70 to 0.74. However, when only the larger variety

was used (omitting the bantams), the slope ranged from 0.30 to 0.54. This may have been a result of the larger birds of the larger strain being fatter.

Historically, turkey basal metabolic rate has been expressed as $wt^{.75}$. However MacLeod et al. (1985), expressed concern over the suitability of this value for turkeys at different stages of growth. Smaller, growing turkeys usually have higher heat production values than large turkeys, both per unit weight and per unit of metabolic body size ($wt^{.75}$) (Afifi, 1975; Buffington et al. 1974; MacLeod et al. 1980; Nichelmann et al. 1976). MacLeod et al. (1985) stated that $wt^{.75}$ is unlikely to be the most suitable scaling factor for turkeys at different stages of growth even though it may be adequate over the narrow weight range domestic fowl.

A thorough understanding of energy metabolism of turkeys is required for profitable poultry meat production. The capacity of the turkey at different ages to lose heat at different ambient temperatures needs to be quantified (Emmans, 1989). Emmans (1989) suggested that hot, rather than cold, environments need emphasis.

Morris (1989), stated that fast growing male turkeys in the 8-16 wk stage usually become too hot to eat the amount of feed needed to reach their full growth potential. The 8 to 16-wk-old male turkey needs an environmental temperature of 9-12 C in order to lose all the heat produced during growth; hence, its potential for growth is not achieved at higher temperatures.

Jurkschat et al. (1989), studied female turkeys ranging in age from 10 to 50 d exposed to ambient temperatures of 5 to 40 C. Both age and ambient temperature influenced rectal temperature and heat production. Over this wide range of ambient temperature; rectal temperature increased and heat production decreased as age advanced.

Malhotra (1967) partitioned the heat losses of mature turkeys and concluded that as ambient temperature increased from 10 to 35 C, radiant heat loss decreased, the percent of sensible heat loss by radiation increased, and the latent heat loss increased. Radiant heat loss is directly proportional to the weight of the bird but inversely proportional to the

ambient temperature. At lower temperatures, sensible heat loss constitutes the major portion of the total heat loss (by radiation). Malhotra (1967) stated that partitional heat loss was not strongly dependent upon the age of the bird and time after feeding.

Numerous physiological responses can be manipulated to enhance broiler productivity. Such responses include heat production, evaporative and nonevaporative cooling, respiration rate, and apparent respiration efficiency. However, data is lacking regarding base line values for the turkey. Although thermobalance values have been published for different avian species, information for commercial turkey strains are lacking. Additional information is needed that examines thermobalance values simultaneously under fasted conditions using a commercial turkey strain. The following study was conducted to evaluate ambient temperature effects (25 to 37 C) on basal metabolic rate and thermobalance of 2, 8, and 14-wk-old Hybrid Large White male turkeys fasted for 36 h.

MATERIALS AND METHODS

Thirty Hybrid Large White male poults were obtained from a commercial hatchery at time intervals to produce 3 populations at 6 wk intervals. Poults were raised on rice hull litter under brooders and fed a prestarter ration (Table 1) until 4 wk of age. Birds received a starter, grower, and developer ration (Table 1) at 5 to 8, 9 to 12, and 13 to 14 wk of age, respectively. Birds had *ad libitum* access to feed and water throughout the production period.

Birds which were 2-wk-old (mean body weight of 0.2 kg.) were placed individually in broiler metabolic chambers (51 x 34x 41 cm). Birds at 8-wk-old and birds at 14 wk of age (mean body weights of 3.0 and 7.2 kg., respectively) were individually placed in 8 turkey metabolic chambers (74 x 53 x 76 cm) at ambient temperature of 25 C with *ad libitum* access to feed and water. Four birds of each age were used. Both the turkey and the broiler metabolic chambers were located in one room to remove effect of

room. After 3 d of adaptation to metabolic chambers, the 8 and 14-wk-old birds were aseptically prepared and abdominally implanted with a radiotelemetry temperature transmitter.[1] Prior to surgery, anesthetic induction and maintenance were achieved by a intramuscular ketamine HCl injection (40 mg/kg of body weight) and halothane oxygen mixture using the Bain none rebreathing system[2] , respectively. After surgery, birds were returned to their metabolic chambers and allowed 2 d to recover with *ad libitum* access to feed and water. After the 2d recovery-adaptation period, birds were deprived of feed for 36 h.

Experiment

The study began after the 36 h feed deprivation. Birds also were deprived of feed during the 11 h duration of the study. The environmental exposure consisted of 3 intervals; during interval 1, the basal metabolic rate was measured for 4 h at 25 C. BMR also was measured during intervals 2 (5 h at 25 to 37 C) and 3 (2 h at 37 C) which represented the thermobalance responses to increased ambient temperature. All three age groups were used in interval 1; only the 8 and 14-wk birds were used in intervals 2 and 3. The trial was replicated for a total of 8 birds per age group. Water was supplied continuously for *ad libitum* consumption and intake was monitored every 1 h by recording disappearance from a graduated cylinder. Bird thermobalance response variables which were quantified included: heat production (H), evaporative heat loss (E), core body temperature (BT), sensible heat loss (S), and respiration rate (RR).

Respiratory Chambers. The 9 (8 test, 1 reference) open circuit turkey respiratory chambers (74 x 53 x 76 cm), constructed of clear acrylic plexiglas (12.7 mm), were equipped with wire mesh floors suspended 9 cm above the excreta collection pan (74 x 53 cm) containing 4 cm of mineral oil. The oil was used to ensure that the excreta was

[1] Mini-Mitter Telemetry System, Sunriver, OR 97707.
[2] Cyprane North America Inc., Tonawanda, NY 14150.

isolated from the chamber environment. Each compartment also contained a 8 cm diameter fan[3] to mix air, and an ambient temperature probe[4] to monitor temperature in each chamber once per minute throughout the experiment. The 5 (4 test, 1 reference) open circuit broiler respiratory chambers (51 x 34 x 41 cm), constructed of clear acrylic plexiglas (6.35 mm), were equipped with wire mesh floors suspended 9 cm above an excreta collection pan (51 x 34 cm) containing 4 cm of mineral oil. Each compartment also contained a 3 cm diameter fan[3] to mix air, and an ambient temperature probe[4] to monitor temperature in each chamber once per minute throughout the experiment. Overall chamber calibration was established by comparing heat production with heat loss by comparative slaughter data (McDonald, 1993) and also by ethanol oxidation according to Misson (1974). Both methods yielded values within 2 and 1% of indirect calorimetry estimates, respectively.

Breathing Air Supply and Analysis. Compressed air dried to a dew point of 4 C was delivered to the birds for respiration through individual 64 mm diameter polyethylene lines. Each line passed through a computer-monitored and controlled heat exchanger such that air reached the desired temperature prior to chamber entry. Independent microvalves were used to regulate chamber air flow (20 ± .005 and 2.7 ± .005 L/min for turkey and broiler chambers, respectively); flow rate was monitored using an electronic mass flow meter.[5] Oxygen, CO_2, and H_2O vapor concentrations were determined five times per hour per chamber using Ametek[6] O_2 (accuracy ± .01%) and CO_2 (accuracy ± 2.0%) analyzers and a Cole Parmer[7] relative humidity probe (accuracy ± 2%), respectively.

Heat Production. Oxygen consumption and CO_2 production were estimated by multiplying chamber air flow rate (20 ± .005 and 2.7 ± .005 L/min for turkey and broiler

[3] Radio Shack cooling fan Catalogue Number 273-244, Radio Shack, Stillwater, OK 74075.
[4] Model ES-060, Omnidata International, Logan, UT 84321.
[5] Omega Engineering, Stanford, CT 06907.
[6] Pittsburgh, PA 15238.
[7] Model Number 37301-70, Chicago, IL 60648.

chambers, respectively) by the difference in gas concentration between incoming and outgoing air of reference and test chambers. Heat production (kilocalories per hour per BW) was estimated from liters of O_2 consumed and liters of CO_2 produced according to Brouwer (1965). No correction was utilized for nitrogen excretion, as the error created by its omission is only about .2% (Romijn and Lokhorst 1961, 1966).

Evaporative heat loss. Production of water vapor was estimated by first converting relative humidity (RH) measurements into grams water per cubic liter for the test and reference chambers (Handbook of Chemistry and Physics, 1987). Total water vapor production (respiratory plus cutaneous) was determined by multiplying test and reference chamber difference in water vapor concentration by the flow rate through the chamber. Evaporative heat loss was estimated by multiplying the grams of water evaporated times the latent heat of vaporization for H_2O at the birds' body temperature.

Body Heat Content. Changes in bird heat content (HC) were monitored by multiplying BT, recorded every 1.5 min, times bird specific heat as described by Sturkie (1986).

Sensible heat loss. Sensible heat loss (kilocalories) was estimated by difference according to Yousef (1985): $S = H - E \pm HC$.

Respiration Rate (RR). Bird RR estimated by monitoring chamber pressure cycles created by an inhale-exhale respiratory cycle, during a 1 min period 7.5 times per hour using a Columbus Instruments respiration monitor.[8]

Data Acquisition System. The chamber environment and all data measurements were controlled and monitored using a Workhorse Data Acquisition and Control System.[9] Gas concentrations (RH, O_2, CO_2), gas flow rates, RR and ambient temperature were recorded once on each of the 12 compartments every 12 min.

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[8] Columbus, OH 43204.
[9] Omega Engineering, Stanford, CT 06970.

Statistical Analysis

Oxygen, CO_2, and water concentration, BT, and RR were regressed against time, time squared and time cubed to establish polynomial equations describing the data. Quantitative estimates for each variable attributed to bird metabolism were made by integrating variable functions over specified time intervals and subtracting the control chamber as appropriate. All integrated values as well as BT and water consumption means were analyzed by ANOVA using the General Linear Model procedure of the SAS Institute (1982). When a significant *F* statistic was noted, treatment means were separated by Duncan's multiple range test (Steel and Torrie, 1960). Regression analysis of the SAS Institute (1982) was used to determine the exponent for converting body weight to metabolic body weight by regressing the log of heat production verses the log of body weight during interval 1.

RESULTS AND DISCUSSION

The ambient temperature of the metabolic chambers was as follows: Interval 1 lasted for 4 h at 25 C; interval 2 lasted for 5 h in which temperature was increased linearly during 5 h from 25 to 37 C; and interval 3 lasted for 2 h at 37 C. Interval 1 represents the basal metabolic rates of the 2, 8, and 14-wk-old turkeys. Interval 2 represents the thermobalance responses to increasing ambient temperature by the 8 and 14-wk-old turkeys. Interval 3 represents the thermobalance responses to constant high ambient temperature by the 8 and 14-wk-old turkeys.

Body Temperature

Body temperature (Table 2) increased ($P < .01$) from intervals 1 to 3 by 2.5 % and 4.0 % for the 8 and 14-wk-old birds, respectively (39.9 to 40.9 and 39.5 to 41.1 C, respectively). Although the 8-wk-old birds had a numerically higher body temperature

than the 14-wk-old birds during intervals 1 and 2, the difference was not significant (P = .28). Body temperatures of the 2-wk-old poults were not monitored. Similar trends in body temperature using White Beltsville female turkeys 10 to 50 days of age have been published by Jurkschat et al. (1989), in which the colonic temperature increased as the ambient temperature increased.

Water Consumption

Water consumption per hour per unit of body weight (Table 2) numerically increased from interval 2 to 3 for the 8-wk-old birds and from intervals 1 to 3 for the 14-wk-old turkeys; however, the increase was not significant (P = .11). No water consumption was detected for the 2-wk-old poults. A significant age effect was noted (P < .01), whereas there were no interval or age by interval interactions (P = .34). During interval 1, the 8-wk-old birds had a 628.6% greater water consumption (P < .01) than the 14-wk-old turkeys (5.61 vs .77 mL/h x wt).

Oxygen Consumption

During interval 1, oxygen consumption per unit of body weight (Table 2) of the 2-wk-old poult was significantly greater (P < .01) than for the 8 or 14-wk-old turkeys by 59.5 and 200%, respectively. A significant age effect was noted (P < .01), whereas there were no heat or age by heat interactions (P = .08). Although oxygen consumption increased numerically in both the 8 and 14-wk-old birds between intervals 1 and 3, this increase was significant only for the 14-wk-old turkeys (P < .05). Similar effects have been noted by Gray and Prince (1988). Adult male wild turkeys did not differ in oxygen consumption (0.423 ml/g x h) between ambient temperature in the range of 15 to 25 C. Also the oxygen consumption for winter juvenile turkeys was significantly higher (18.5 %) than for winter adults (.398 vs .336 ml/g x h, respectively).

Carbon Dioxide Production

Carbon dioxide production per unit of body weight (Table 2) had a similar trend as seen in oxygen consumption. The carbon dioxide production of the 2-wk-old poult was greater ($P < .01$) than for the 8 or 14-wk-old turkeys (.94, .56, and .28 L/min x wt, respectively). A significant age effect was noted ($P < .01$), whereas there were no heat or age by heat interactions ($P = .08$). The 8-wk-old birds had greater carbon dioxide production ($P < .01$) than the 14-wk-old turkeys during intervals 2 and 3.

Water Production

Moisture production of the birds as grams per hour per unit weight (Table 2) had significant age, heat, and age by heat interactions ($P < .01$). The moisture production by the 2-wk-old poult was 243.7 and 583.7% greater ($P < .01$) than by 8 and 14-wk-old birds, respectively, during interval 1. Water production was increased ($P < .01$) by 246.2 and 233.7% for the 8 and 14-wk-old turkeys, respectively, from interval 1 to 3. Also, the 8-wk-old birds had a greater ($P < .01$) water production than the 14-wk-old birds during intervals 1, 2, and 3.

Heat Gain

Heat gain as kilojoules per hour per kg of body weight (Table 2) had age and heat effects ($P < .01$); however, there were no age by heat interactions ($P = .06$). The heat gains for the 8 and 14-wk-old turkeys were similar ($P = .22$) during intervals 1 and 2. However, the 8-wk-old birds had less ($P < .01$) heat gain than the 14-wk-old turkeys (.32 and .79 KJ/h x wt, respectively). The general trend was that heat gained by the bird was greatest during intervals 2 and 3. The heat gain increased ($P < .01$) from -.18 to .79 KJ/h x wt during intervals 1 and 3, respectively, in the 14-wk-old birds. Similarly, there was an increase ($P < .01$) from -.20 to .32 in intervals 1 to 3, respectively, in the 8-wk-old birds.

Heat Production

Heat production as kilojoules per hour per unit of body weight exhibited the same trend as oxygen consumption and carbon dioxide production . Age and heat effects were noted ($P < .01$), whereas the age by heat interaction was not significant ($P = .15$). The 2-wk-old birds averaged 65.0% more ($P < .01$) heat production than the 8-wk-old turkeys (24.9 and 15.1 KJ/h x wt, respectively). Similarly, the 8-wk-old turkeys had 87.7% greater ($P < .01$) heat production than the 14-wk-old turkeys (15.1 and 8.0 KJ/h x wt, respectively). Although the heat production increased from intervals 1 to 3 in the 8 and 14-wk-old birds, the change was significant ($P < .01$) only for the 8-wk-old birds.

Similar heat production values for fasted (3 days) male Broad-Breasted White turkeys have been reported by MacLeod et al. (1980, 1985). He indicated that birds with body weights of .235 and 13.1 kg had heat production values of 29.3 and 10.7 KJ/h x kg. These are in agreement with the heat production values of 24.90, 15.09, and 8.04 (KJ/h x wt) shown in the table for the 2 (.217 kg), 8 (3.018 kg), and 14 (7.439 kg) wk-old birds, respectively, during interval 1.

The general decreases in total heat loss with aging has been published by DeShazer et al., (1974) in which heat production by Large White male turkeys 6 to 36 days of age was similar to the decreased heat production values we observed in heat production per unit weight.

Evaporative Cooling

Evaporative cooling as kilojoules per hour per unit of body weight (Table 2) exhibited the same general trend as seen in water production. There were significant age, heat, and age by heat interactions ($P < .01$). The evaporative cooling by the 2-wk-old poult was 243 and 584.4% greater ($P < .01$) than by the 8 and 14-wk-old birds, respectively, during interval 1. Evaporative cooling increased 245.5 and 216.6 % for the 8

and 14-wk-old turkeys, respectively, from interval 1 to 3. Also, the 8-wk-old birds had greater ($P < .05$) evaporative cooling than the 14-wk-old birds during intervals 2 and 3.

A trend for evaporative cooling to decrease as birds age was published by DeShazer et al., (1974) for Large White male turkeys 6 to 36 days of age. This is similar to the trend of the heat production values we observed. Evaporative cooling parallels broilers in that it increases with temperature.

Nonevaporative Cooling

For nonevaporative cooling as kilojoules per hour per unit weight (Table 2), significant age and heat effects ($P < .01$) were detected; however, the age by heat interaction was not significant ($P = .46$). The 8-wk-old birds had greater nonevaporative cooling (77.8, 129.3, and 196.8%) than the 14-wk-old turkeys during intervals 1, 2, and 3, respectively. Nonevaporative cooling extent decreased 10.9 to 8.4 KJ/h x wt for the 8-wk-old and from 6.2 to 2.8 KJ/h x wt for the 14-wk-old turkeys from intervals 1 to 3, respectively.

A similar trend for nonevaporative cooling at elevated temperatures to increase with age was published by DeShazer et al., (1974) for Large White male turkeys 6 to 36 days of age. This is opposite the effect of age on heat production we observed. DeShazer used a heat of only 5.5 C above recommended temperature, small when compared to the difference we tested. Also, his birds were fed which may alter nonevaporative cooling. With broilers, nonevaporative cooling extent decreases incrementally with increasing ambient temperature which agrees with results of our study.

Respiration Rate

Respiration rate as breaths per minute (Table 2) was altered by heat ($P < .01$), but not by age or an age by interval interaction ($P = .92$). Respiration rate increased from interval 1 to 3 by approximately 200% for both the 8 and 14-wk-old birds.

Apparent Respiration Efficiency

Apparent respiration efficiency as joules per breath exhibited an age response ($P < .01$), but heat and the heat by age interactions were not significant ($P = .11$). During interval 1, the 2-wk-old poults had only 20% ($P < .01$) the apparent respiration efficiency of the 8-wk-old turkeys (1.51 vs 7.91 J/breath); the 8-wk-old birds had only slightly ($P = .55$) lower (10%) apparent respiration efficiency than the 14-wk-old turkeys (7.91 vs 8.77 J/breath.

Respiratory Quotient

Respiratory quotient (RQ) exhibited no treatment, interval, or treatment by interval interactions ($P = .21$). RQ was determined to be $.71 \pm .13$ ($r = .31$). An RQ of .7, the theoretical value for fat, indicates that energy is being obtained only from body fat reserves.

Basal Metabolic Weight

Regression analysis was used to determine the best exponent for converting body weight to metabolic body weight. The log of heat was regressed against body weight during interval 1. The exponent determined from the data ($.71 \pm .04$; $r = .97$) across the 2 (.217 kg), 8 (3.018 kg), and 14 (7.439 kg) wk-old birds, was similar to .67 suggested by Sarrus and Rameaux (1837), and .75 reported by Kleiber (1932) as a useful base across species for adult animals. Brody suggested that the 0.73 power of weight was an ideal cross-species reference base. The Conference on Energy Metabolism (1935) tentatively adopted the 0.73 power of body weight as the reference base for energy metabolism.

Brody (1945) measured the basal metabolic rate of four groups of mature Rhode Island Red fowls, normal and bantam (small) varieties. When both varieties were included, the exponent ranged from 0.70 to 0.74. However, if only the larger variety was

used and bantams were omitted, the slope ranged from 0.30 to 0.54, perhaps because the larger birds of the larger variety were fatter.

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Table 1. Composition of turkey rations

Ingredients and analysis	Prestarter[1]	Starter[1]	Grower[1]	Developer[1]
		(%)		
Soybean meal (48.5% CP)	49.44	44.55	37.09	27.03
Ground corn (8.7% CP)	43.96	49.36	56.42	67.59
Dicalcium phosphate	2.80	3.02	2.64	2.00
Tallow	1.50	1.74	2.35	1.99
Calcium carbonate	1.20	.42	.60	.49
Salt	.40	.31	.30	.30
Hoffman vitamin mix[2]	.40	.40	.40	.40
Methionine	.20	.10	.10	.10
Trace mineral premix[3]	.10	.10	.10	.10
Calculated analysis				
CP	28.00	26.00	23.00	19.09
ME, kcal/kg	2,811.60	2,893.00	2,998.60	3,097.60
Ca	1.26	1.00	.96	.75
Na	.18	.15	.14	.14
K	1.08	1.00	.88	.72
P (available)	.67	.70	.62	.49
Mg	.06	.07	.08	.09
Fe, mg/kg	427.76	511.17	501.84	484.22

[1]Rations supplemented with .04% monensin and .0002% selenium 60.

[2]Mix supplied per kilogram of diet: vitamin A, 15,840 IU (retinyl acetate); vitamin E, 52.8 IU (dl-α-tocopheryl acetate); cholecalciferol, 4,400 IU; vitamin K, 5.33 mg; thiamin, 3.16 mg; riboflavin, 10.56 mg; niacin, 70.4 mg; pantothenic acid, 17.6 mg; choline, 799.04 mg; pyridoxine, 6.34 mg; folacin, 1.76 mg; biotin, .176 mg; vitamin B_{12}, 17.6 mcg.

[3]Mix supplied per kilogram of diet: Ca, 160 mg; Zn, 100 mg; Mn, 120 mg; Fe, 75 mg; Cu, 10 mg, I, 2.5 mg.

Table 2. Ambient temperature effects on thermobalance variables (x ± SEM) of male turkeys 2, 8, and 14 wk of age

Variable	Interval[1]	Age (wk) 2	8	14
Body temperature	1	-	39.85 ± .21 [cd]	39.54 ± .21 [d]
(C)	2	-	40.51 ± .21 [b]	40.37 ± .21 [bc]
	3	-	40.86 ± .21 [b]	41.12 ± .21 [a]
Water consumption	1	-	5.61 ± 1.51 [ab]	.77 ± 1.17 [de]
(mL/hr x wt)	2	-	4.03 ± .99 [ac]	2.36 ± .93 [ae]
	3	-	5.54 ± .93 [bc]	3.17 ± .93 [abd]
Oxygen consumption	1	1.26 ± .05 [a]	.79 ± .05 [b]	.42 ± .05 [d]
(L/m x wt)	2	-	.81 ± .05 [b]	.55 ± .05 [cd]
	3	-	.88 ± .05 [b]	.56 ± .05 [c]
Carbon dioxide production	1	.94 ± .03 [a]	.56 ± .04 [b]	.28 ± .03 [d]
(L/m x wt)	2	-	.62 ± .04 [b]	.36 ± .03 [cd]
	3	-	.66 ± .04 [b]	.38 ± .03 [c]
Water production	1	5.88 ± .29 [a]	1.71 ± .29 [c]	.86 ± .29 [d]
(g/h x wt)	2	-	3.89 ± .29 [b]	1.67 ± .29 [c]
	3	-	5.92 ± .29 [a]	2.87 ± .29 [b]
Heat gain	1	-	- .20 ± .09 [d]	- .18 ± .09 [d]
(KJ/h x wt)	2	-	.46 ± .09 [bc]	.62 ± .09 [ab]
	3	-	.32 ± .09 [c]	.79 ± .09 [a]
Heat production	1	24.90 ± 1.52 [a]	15.09 ± 1.63 [b]	8.04 ± 1.52 [c]
(KJ/h x wt)	2	-	22.05 ± 1.63 [a]	10.27 ± 1.52 [c]
	3	-	23.38 ± 1.63 [a]	10.48 ± 1.52 [c]
Evaporative cooling	1	14.03 ± .69 [a]	4.09 ± .69 [c]	2.05 ± .69 [d]
(KJ/h x wt)	2	-	8.08 ± .69 [b]	3.98 ± .69 [c]
	3	-	14.13 ± .69 [a]	6.49 ± .69 [b]
Nonevaporative cooling	1	-	10.97 ± 1.13 [ab]	6.17 ± 1.05 [c]
(KJ/h x wt)	2	-	13.12 ± 1.13 [a]	5.67 ± 1.05 [cd]
	3	-	8.43 ± 1.13 [bc]	2.84 ± 1.05 [d]
Respiration rate	1	39.36 ± 5.18 [b]	38.69 ± 5.18 [b]	39.06 ± 5.18 [b]
(Breaths/min)	2	-	50.00 ± 5.18 [b]	51.47 ± 5.18 [b]
	3	-	116.36 ± 5.18 [a]	114.03 ± 5.18 [a]
Apparent respiration efficiency	1	1.51 ± 1.04 [c]	7.91 ± 1.04 [ab]	8.77 ± 1.04 [ab]
(J/breath)	2	-	8.10 ± 1.04 [ab]	9.56 ± 1.04 [a]
	3	-	6.07 ± 1.04 [b]	7.41 ± 1.04 [ab]
Respiratory quotient	1	.76 ± .05	.70 ± .05	.71 ± .05
	2	-	.77 ± .05	.65 ± .05
	3	-	.76 ± .05	.69 ± .05

[1]Intervals 1, 2, and 3 = ambient temperatures of constant 25, 25 to 37 (linear increase), and constant 37 C, respectively. Intervals 1, 2, an 3 = 4, 5, and 2 h duration, respectively.

[a-e]Means within each variable within rows and columns with unlike superscripts differ significantly ($P < .05$).

VITA

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