SUMMARY

Investigations on heat stress in chicken were conducted at the Institute of Animal Breeding and Genetics of the Georg-August-University Göttingen, Germany. Three experiments were performed to test heat stress reactions of commercial and parent stocks of slow growing broilers. The experiments were purposed to describe a method for evaluating thermotolerance at short-term heat stress, to test the influence of long-term heat stress on short-term heat adaptation (carry-over effect) and to measure the reproductive performances of birds kept under long-term heat stress.

The first experiment was designed to develop a suitable method for evaluation of thermotolerance by a short-term heat stress and to evaluate the differences between genotypes with regard to heat stress reaction. A total of 102 females from three slow growing broiler hybrids (Hubbard ISA I657, S757N and I957) were maintained from hatching until 5 weeks of age in 3 different pens under a room temperature of 30°C starting from 3 weeks until 5 weeks of age. Water and feed was available *ad libitum* (starter crumbled feed until 3 weeks of age and 2 mm pellets afterwards). Twenty four experimental birds of each genotype were individually exposed for 15 minutes to a short-term heat test at 30°C (control) and at 35°C at 3, 4, and 5 weeks of age. Before (T_0) and after heat exposure rectal temperature (T_1) was measured and latency until panting was recorded. Additionally, infrared pictures of the birds were recorded every minute, resulting in 16 pictures per bird and test. Body surface temperatures were analysed by an integrated software. Differences between strains were significant for body weight, daily weight gain and relative growth rate ($P<0.001$). Rectal temperatures after short-term heat stress differed significantly between strains ($P<0.001$). Body surface temperature was significantly affected by strain, temperature and age ($P<0.001$). In *Nana* birds (S757N), the neck temperature was significantly higher whereas the beak and eye temperatures were significantly lower compared to other strains. Strain and the level of heat stress temperature significantly influenced latency until panting ($P<0.001$). Chi-square analyses revealed significant influences of the level of heat and of the strain on the frequency of birds panting ($P<0.001$). After short-term heat exposure at 30°C, strain differences were not significant for frequency of panting, but it was significant when birds were exposed to 35°C.

The short-term heat challenge test was suitable to detect clear differences between genotypes. White birds (I957) showed higher growth rates which correlated with higher metabolic heat generation resulting in higher rectal temperatures and earlier panting. Of all tested birds, naked-neck birds showed the highest adaptability and thermotolerance to high ambient temperature.

The second experiment was aimed to evaluate the effect of long-term heat stress on productive traits and on the adaptation of the birds to short-term heat stress. A total of 120 JA57 female and 12 I66 male birds from broiler parents (Hubbard ISA, France) were reared in France until 138 days of age and were then transferred to Göttingen. The birds were assigned at random to 4 floor pens (9.60 m^2/pen). In two pens, the room temperature was kept at 20°C (control) and in two others at 28°C (heat stress). One pen housed 30 females and 3 males (3.44 birds/m^2). All birds were wing banded. The birds were restrictively fed with pellets (18.66% CP and 12.97 MJ/kg ME). At the age of 30, 34 and 38 weeks, 12 females and 12 males were randomly chosen and individually exposed to a short-term heat test at 28°C or 32°C for 10 minutes. Recording of infrared pictures, for analysing of body surface temperature, measuring of rectal temperature and latency until panting were determined as in experiment 1. Housing temperature differences had a significant effect on egg weight, internal and external egg quality ($P<0.001$), egg fertility in incubation trials ($P<0.03$), fertility and quality of hatching eggs ($P<0.001$), body surface temperature ($P<0.001$), rectal temperature ($P<0.05$), latency until panting ($P<0.001$) and frequency of birds panting ($P<0.001$). However, body weight, growth rate, feed intake and feed conversion ratio was not significantly different between housing temperatures. Birds subjected to the heat stress procedure started panting later, had lower egg weight, lower internal and external egg quality, higher body surface temperatures, higher T_0 and T_1 but lower temperature increment (T_c).

Under high ambient temperature, the productive traits were reduced. Egg quality as well as fertility and hatchability decreased. Heat stressed birds, however, showed a higher adaptive capacity to high ambient temperatures, which was reflected by the higher heat radiation from body surfaces, lower rectal temperatures, later onset and lower frequency of panting during short-term heat stress.

The third experiment was designed to evaluate the influence of the previous parent treatment on the development of their progeny (carry-over effect) and the influence of long-term heat stress on short-term heat adaptation. The experiment involved 393 I657 offspring chicks from experiment 2. The chicks were kept from hatch until 10 weeks of age. Birds were wing numbered and randomly distributed and separately kept according to parent and broiler treatments (CC, CH, HC, HH) in 8 pens (9.60 m^2/pen) resulting in a 2 factorial design. One pen housed 48-50 birds (5.21 birds/m^2). The initial room temperature of 34-35°C was gradually reduced to 20°C (control) in 4 pens (2 rooms) and to 28°C (heat stressed) in the other 4 pens (2 rooms) starting with week 5 until the end of the experiment. Birds were fed *ad libitum* crumbled starter feed (24.04% CP and 11.92 MJ/kg ME) up to 5 weeks of age and from then on pelleted starter feed (23.06% CP and 12.13 MJ/kg ME) until the end of the trial. Water was freely available. From each treatment 8 experimental female birds were randomly chosen and repeatedly exposed to a 10 minutes short-term heat stress (28°C or 32°C) at the age of 5, 7 and 9 weeks. Recording of infrared pictures for analyses of body surface temperature, measuring of rectal temperature and latency until panting were conducted as in the previous experiments. At the end of the experiment, all birds were slaughtered and a total of 320 blood samples from 10 male and 10 female birds per pen were collected to determine the thyroid hormone concentrations. The body weight was significantly affected by parent and broiler temperature treatment and sex ($P<0.05$). A significant difference between broiler treatments could be observed for body surface temperature ($P<0.001$), rectal temperature T_1 and T_C ($P<0.001$), latency until panting ($P<0.01$), frequency of panting ($P<0.04$), carcass traits ($P<0.05$) and thyroid hormones concentration ($P<0.001$). Carcass weight and thyroid hormones concentration differed significantly between sexes ($P<0.05$ and $P<0.001$, respectively).

Heat stressed broilers from control and heat stressed parents had lower productive performances. They showed lower concentration of triidothyronine, depressed feed intake resulting in lower weight gain and lower meat yield. However, broilers originating from heat stressed parents kept under high ambient temperature had better productive performances and lower rectal temperature, they also started panting later, compared to birds originating from parents not subjected to heat stress.

This study showed that subjecting birds to a short-term heat stress is a simple and appropriate alternative to evaluate thermotolerance in birds. The results of the study also underline the influence and importance of long-term heat exposure (acclimatisation) to short-term heat adaptation. It seems that a carry-over effect exists between the parent and the progeny to cope with heat stress.

1 Introduction

High ambient temperature in warm and hot climate regions such as in the tropics remain a major constraint in raising poultry. Heat stress in broilers and broiler parents results in significant losses in production performances such as reduced growth rate, feed intake, egg production, egg quality, egg hatchability and increased mortality (McDaniel *et al*.,1995; Butcher and Miles, 1996; Yalcin *et al*., 1997).

During exposure to high ambient temperatures, body temperature is controlled by balancing heat loss against heat production to maintain a near constant body core temperature at approximately 40°C to 41°C (Schmidt-Nielsen, 1997; van Kampen, 1974). Because broilers do not have sweat glands, they transfer within the thermoneutral zone their body heat to the environment through sensible heat loss from body surfaces such as wattles, combs, shank and unfeathered areas e.g. under the wings (Anderson and Carter, 1993; Kenneth and Thomas, 1993; Schmidt-Nielsen, 1997). When the environmental temperature rises above the thermoneutral zone, heat loss mechanisms begin to shift to an evaporative process (Schmidt-Nielsen, 1997).

Heat stressed broilers have an elevated body temperature and pant rapidly. Elevated body temperature occurs as the sum of metabolic heat production and heat gain from the environment (Francis *et al*., 1990). Once the ambient temperature rises above 27°C, it causes heat stress and birds show hyperventilation or panting which would normally occur when the ambient temperature is near or above 30°C (Richards, 1976; Webster and King, 1987; Marder and Arad, 1989; Anderson and Carter, 1993; Kenneth and Thomas, 1993).

Broilers have difficulties in dissipating heat through the feather coverage. Insulation by the feathers plays a major role in minimising irritation by high ambient temperatures (Scholander *et al.,* 1950). Reduced feather coverage, either by decreased number or by modified shape, may help broilers to dissipate internal heat more efficiently (Hertwig, 1933; Yunis and Cahaner, 1999). Reducing 20 to 40% of feather coverage in naked neck broilers may enhance heat dissipation (Bordas *et al*., 1978).

Another important factor affecting heat loss capacity in broilers is the growth intensity of the birds. A large contribution to heat production occurs via metabolic heat production that increases as the body weight of the bird progresses. Broilers selected for rapid growth rates eat more and generate more metabolic heat per unit of time, causing a higher body temperature, and may therefore become more sensitive to high ambient temperatures. Contrarily, slow growing broilers with lower growth intensity generate less heat and may have advantages in dissipating body heat to the environment. Heat tolerance of broiler strains selected for rapid growth is significantly lower than for slow growing broilers (WASHBURN *et al*., 1980).

Fast growing broilers were developed in moderate climates. Although these broilers are less heat tolerant, they are mainly used in the tropics as the local breeds are very poor in production performances. Commercial genetic selection for heat tolerance has not been widely practised because of the negative correlation with growth rates. Rapid growing broilers were divergently selected for low or high body temperature to alter their heat tolerance genetically, but the realised heritability was very low (EL-GENDY and WASHBURN, 1995).

Concerning the adverse effect of higher growth intensity to heat tolerance under high ambient temperatures, slow growing broilers become a suitable alternative for the tropics. Improved heat tolerance could be achieved by genetically reducing the body insulation and increasing heat dissipation through reduced feather coverage. Sufficient acclimatisation to high ambient temperatures or the previous history of the birds was also able to modify and enhance the heat tolerance in birds (DURHAM, 2002).

Only few data have been published for slow growing broilers. In most studies, the effects of high ambient temperatures on production performances and thermoregulation efficiency were evaluated in conventional broilers, layers and in naked-neck birds and effects of temperature conditioning were estimated under short-term heat stress (MACLEOD and HOCKING, 1993; YAHAV and HURWITZ, 1996;. ZHOU and YAMAMOTO, 1997; LI *et al*., 1992; CAHANER *et al*., 2003)

To test the suitability of slow growing strains for tropical conditions, three experiments were carried out in a closed poultry house at the Institute of Animal Breeding and Genetics, Georg-August-University Göttingen, Germany. The first experiment was designed to develop a suitable method to measure the reactions of broilers towards heat stress and to evaluate differences between genotypes of slow growing broilers with regard to heat stress reactions. The second experiment was conducted to study the effects of long-term heat exposure on heat adaptation responses and reproductive performances of slow growing broiler parents. The third experiment had the purpose to evaluate the influence of the previous parent treatments of the parents on the offspring of slow growing broilers with regard to their adaptation to heat.

2 Literature

2.1 Thermoregulation

Birds are homeothermic or warm-blooded animals that usually maintain a high body temperature (SCHMIDT-NIELSEN, 1997). The recommended average ambient temperature for younger broilers up to 16 days is 31°C and 20-22°C for older birds (CHARLES, 1986).

Birds gain heat from the environment and their metabolism. They regulate the balance between heat production and heat loss to maintain their deep body temperature at approximately 40°C. Birds transport the generated heat to the body surface to allow sensible heat losses from surfaces such as wattles, combs, shanks, and unfeathered areas i.e. under wings to the surrounding environment because they do not have sweat glands (ANDERSON and CARTER, 1993).

Sensible heat loss is effective when the environmental temperature is below or within the thermoneutral zone ranging from 13 to 24°C (SCHMIDT-NIELSEN, 1997). Heat loss mechanism begins to shift to panting when the environmental temperature reaches more than 25°C. Birds have to increase their evaporative losses to maintain body temperature and therefore start to breath more rapidly (VAN KAMPEN, 1974) and panting (hyperventilation) normally occurs at about 30°C (ANDERSON and CARTER, 1993).

2.2 Adaptation responses to heat stress

2.2.1 Ontogenetic adaptation

Influence of incubation temperature

The prenatal period is important in thermoregulation of poultry. Temperature during pre-incubation and incubation influenced hatchability and thermoregulatory ability and stress susceptibility of the chicks (DECUYPERE and MICHELS, 1992; YALCIN *et al.*, 2005). The central nervous control mechanisms of thermoregulation are functionally active during the prenatal period (TZSCHENTKE and BASTA, 2000; NICHELMANN *et al.*, 2001, NICHELMANN and TZSCHENTKE, 2002). Incubation temperature may change physiological responses of poultry to high ambient temperature. Thermal conditioning or prehatch exposure to high temperature resulted in decreased mortality (IQBAL *et al.*, 1990) and improved the capability of broilers to cope with stress at later ages by decreasing circulating T_3 levels under heat stress (MORAES *et al.*, 2003) when they were exposed to short-term acute heat stress at later age. YALCIN *et al*. (2005) reported that incubation of eggs from younger parents at high ambient temperature might reduce deleterious effects of heat stress on body weight at slaughter age in their progeny.

Influence of early rearing temperature

Thermal adaptation might also develop during the early postnatal period. Stress which occurs early in life, whereas many systems of the chicks are still developing, may have a long-lasting impact and could possibly modify the expression of their genetic potential (GROSS, 1983). Early age temperature conditioning by exposure of chicks to heat stress within the first 5 days improved thermotolerance by improving the ability to reduce T_3 concentration and heat production (ARJONA *et al*., 1988; YAHAV and HURWITZ, 1996; YAHAV and MCMURTRY, 2001).The previous history of the animal may modify their heat tolerance. Chicks kept at higher than normal temperatures in their early life after hatching showed improved performance and heat tolerance as well as reduced mortality (DURHAM, 2002). Proper acclimation to heat exposure resulted in a general maintenance to physiological homeostasis during exposures to high ambient temperatures (ARAD and MARDER, 1983).

2.2.2 Behavioural and physiological adaptation

Within the thermoneutral zone, birds do not have to change their normal behavioural pattern, feed intake or metabolism drastically (SCHMIDT-NIELSEN, 1997). During heat stress periods, broilers dispose of adaptive control mechanisms to re-establish heat balance with their surrounding to prevent death from heat exhaustion. They start panting as a response of excessive heat or heat load in the body (HALES and BROWN, 1974). Behavioural responses occur by changes in orientation, posture and activity. Broilers rest more and their wings are usually spread away from the body to promote cooling by reducing body insulation (BUTCHER and MILES, 1996). In hot environment the body fluid pH increases and broilers reduce feed intake and increase water consumption as a part of physiological adaptation (BUTCHER and MILES, 1996). Body growth is usually retarded and reproduction is generally less successful in broiler parents (PAGOT, 1993).

2.2.3 Genetic adaptation

The sensitivity of commercial broilers to heat increased along with the genetic improvement of their growth rate. Fast growing broilers consumed a higher rate of feed and increased metabolism and the internal body heat (CAHANER *et al*., 2003). The authors introduced the recessive mutation *scaleless* to New Hampshire breed resulting in lower body weight and slow growth rate than the current broiler stocks. DAHLKE *et al*. (2005) described that slow growing broilers consumed less feed, demonstrated lower body temperatures and showed high heat tolerance.

Commercial genetic selection for heat tolerance has not been practised widely because of the negative correlation with growth rate. Rapid growing broilers were divergently selected for low or high body temperature to alter their heat tolerance genetically, but the realised heritability was very low (EL-GENDY and WASHBURN, 1995). The authors suggested that improved heat tolerance without negatively affecting growth rate could be achieved by genetically reducing the body insulation and increasing heat dissipation through reduced feather coverage.

Plumage condition

Feathers contain about 80% protein (CAHANER *et al*., 2003) and begin to grow at around day 5 of incubation and cover at most 75% of the skin surface and have function to protect the skin and underlaying tissues (LEESON and WALSH, 2004a). The naked neck gene is related to heat tolerance. Naked neck as a morphological trait is characterised by a reduction of feather coverage mainly in the neck and breast region (CRAWFORD, 1976). The naked neck birds tended to gain more weigh at high ambient temperature and had better capacity to maintain body temperature at high ambient temperatures compared to their fully-feathered counterparts (YAHAV *et al*., 1998). The better feed efficiency, growth and meat yield in birds carrying the *Na* gene at high ambient temperatures were widely reported (HORST and RAUEN, 1986; MERAT, 1986; HORST, 1987; HAAREN-KISO *et al*.,1988; CAHANER *et al*., 2003).

2.2 Body temperature

2.3.1 Rectal temperature

Broilers raised in a hot environment have higher deep body temperature. Exposure of broilers to heat stress (38 ± 1°C) at 35 days of age resulted in an increase in rectal temperatures (ALTAN *et al*., 2000). Heat stressed birds showed a significant hyperthermia, which might have resulted from the limited capacity for evaporative heat loss and additional heat load by feed intake (LI *et al*., 1992). The body temperature of normal birds was 41.20°C and rose up to 42.53°C in hyperthermia birds who showed rapid panting (ARAD and MARDER, 1993).