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ASSESSING THE THERMO-TOLERANCE POTENTIALS OF FIVE COMMERCIAL LAYER CHICKEN GENOTYPES UNDER LONG-TERM HEAT STRESS ENVIRONMENT AS MEASURED BY THEIR PERFORMANCE TRAITS

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Assessing the thermo-tolerance potentials of five commercial layer chicken genotypes under long-term heat stress environment as measured by their performance traits

This study was conducted to test the thermo-tolerance ability of five commercial chicken genotypes (Lohmann Brown, LB; Lohmann White, LW; New Hampshire, NH; White Leghorn selected for low feed expenditure, WL-FE and White Leghorn with sex-linked dwarf gene, WL-dw) under long-term heat exposure. Two-hundred forty female chickens were assigned to a completely randomized design in a 5 × 2 factorial arrangements (five genetic groups and two ambient temperatures [thermo-neutral, 18–20 °C; heat stress, 30–32 °C]). Individual eggs were collected on daily basis while egg weight and feed intake were determined on individual and group basis at 28-days intervals, respectively. Shell quality traits were determined at 25, 40 and 56 weeks age. No Genotype × ambient temperature interactions were found except for body weight and egg deformation. Chickens at thermo-neutral temperature produced significantly heavier eggs than those of heat-exposed (60 g vs. 54 g). Hen-housed egg production of chickens in thermo-neutral temperature was significantly higher than those of heat-stressed (76.8 % vs. 66.2 %). Daily egg mass production at thermo-neutral and heat stressed chickens was 46 g and 35.8 g, respectively. Feed consumption in heat-stressed and thermo-neutral chickens was 109 and 80.8 g, respectively. Shell thickness, breaking strength and Haugh unit values were significantly reduced in heat-stressed chickens. Among heat-exposed chickens, the NH had the highest body weight while the LW produced 10 % more eggs than the group average. The heat-induced effect on shell quality traits was lowest in LW chickens. The results indicated that the magnitude of heat stress was breed dependent in which the LB showed poor adaptability to heat stress while both NH and LW genotypes demonstrated better thermo-tolerance ability.

Key words: poultry / laying hens / egg quality / egg production / heat stress / genotype

Ocena tolerančnega potenciala petih komercianih genotipov kokoši nesnic na osnovi proizvodnih lastnosti pod pogoji dolgotrajnega toplotnega stresa

V študiji smo testirali toplotno toleranco petih komercialnih genotipov kokoši (Lohmann Brown, LB; Lohmann White, LW; New Hampshire, NH; beli leghorn, selekcioniran na nizko porabo krme, WL-FE in beli leghorn s spolno vezanim genom za pritlikavost, WL-dw) pod pogoji dolgotrajne izpostavljenosti visokim temperaturam. Za naključno zasnovan 5 × 2 faktorski poskus (pet genetskih skupin in dve ambientalni temperaturi [termo nevtralna, 18–20 °C; toplotni stres, 30–32 °C]) smo uporabili 240 kokoši. Jajca smo zbirali individualno vsak dan, poraba krme pa je bila ocenjena individualno in za posamezne skupine v 28-dnevnih intervalih. Kakovost jajčne lupine smo ocenili pri starosti 25, 40 in 56 tednov. Med genotipi in okoljskimi temperaturami nismo našli interakcij, razen za telesno maso in deformacije jajc. Kokoši so v termo nevtralnem okolju proizvajale statistično zančilno težja jajca (60 g) kot kokoši pod toplotnim stresom (54 g). Proizvodnja jajc kokoši v termo nevtralnem okolju je bila statistično značilno višja (76,8 %) kot pod pogoji toplotnega stresa (66,2 %). Dnevna proizvodnja jajčne mase je bila višja v termonevtralnem okolju (46 g) kot pod pogoji toplotnega stresa (35,8 g). Poraba krme v termo nevtralnem okolju je bila nižja (80,8 g) kot pod pogoji toplotnega stresa (109 g), debelina jajčne lupine, trdnost lupine in vrednosti v Haughovih enotah so bile statistično značilno zmanjšane pri kokoših v pogojih toplotnega stresa. Med kokošmi pod toplotnim stresom je imel genotip NH najvišjo telesno maso, genotip LW pa je proizvedel 10 % več jajc kot je bilo povprečje skupine. Najmanj opazen je bil vpliv okoljske temperature na kakovost lupine pri genotipu LW. Naši rezultati kažejo, da je stopnja toplotnega stresa odvisna od genotipa, pri čemer ima LB najslabšo prilagodljivost na toplotn stres, medtem ko sta genotipa NH in LW pokazala boljšo toleranco za povišano okoljsko temperaturo.

Ključne besede: perutnina / kokoši / nesnice / jajca / kakovost / proizvodnja / toplotni stres / genotip

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1 INTRODUCTION

Poultry production is one of the most important sectors of animal production throughout the world, particularly in tropical countries where it is considered as affordable source of animal protein to populations lacking access to cheap consumable products. Although the indigenous breeds performed better under higher levels of management than under village situations, they still do not perform competitively under commercial conditions (Wondmeneh *et al.,* 2011). Modern specialised breeds and lines have been developed since the 1950s in developed countries to produce high output in major performance traits. Breeding goals were directed to achieve high performance in meat and/or egg production traits. Attempts of developing countries to build up their own breeding industry have been impeded by two factors: competition with international poultry breeding companies and the lack of local poultry breeds suitable for modern commercial production (Hoffmann, 2005).

Recently there have been efforts to establish poultry farming as an industry in many tropical areas using commercial chicken breeds (Wondmeneh *et al.,* 2011; Islam *et al.,* 2002; Bekele *et al.,* 2010). It has been observed that some commercial chicken breeds have shown better performance under tropical environments as compared with unimproved local chickens and even their crossbreds (Forsido, 1986; Alewi *et al.,* 2011). However, most commercial chicken populations are obtained from breeding farms with a controlled environment and are delivered to production farms with variable environments across the world. As a consequence, genotype × environment interactions may occur (Falconer and McKay, 1996).

Heat tolerance of laying hens is particularly an important issue for the adverse effect of genotype × environment interactions on egg production because the productive period is long and the impact of heat stress increases with the hens' age (Bordas and Mérat, 1992). In such situations, the use of unsuitable genotypes in hot regions may result in large economic losses due to decreased performance, reduced protein gain, and higher mortality. Accordingly, testing the adaptation potential of various commercial chicken breeds to a particular stressful environment should be the strategy of choice when genotype by environment interactions significantly affects economically important traits (Hartmann, 1990). This study was thus conducted to test the adaptive responses and thermo-tolerance ability of five commercial chicken genotypes to long-term heat exposure and identify those with improved thermo-tolerant ability for further breeding purposes.

2 MATERIALS AND METHODS

2.1 EXPERIMENTAL ANIMALS AND THEIR MANAGEMENT

Forty-eight chickens from each genotype of White Leghorn with sex-linked dwarf gene (WL-dw), White Leghorn selected for low feed expenditure (WL-FE), New Hampshire (NH) Lohmann White (LW) and Lohmann Brown (LB) were used to test their thermo-tolerance ability and adaptive responses to long-term heat stress. The chicks were hatched at the same time and divided in two groups in which 24 birds from each genotype were kept in thermo-regulated houses at 18–20 °C (thermo-neutral) whilst the remaining 24 at 30–32 °C (heat stress) (Table 1). The brooding temperature for those chicks kept in thermo-neutral temperature was adjusted as follows: for day old chicks, 35 °C; for the first week, from 34 °C to 33 °C; for the second week, from 30 °C to 28 °C and for the third week from 28 °C to 23 °C. Those chicks exposed to heat stress were reared in the same environmental temperature (30–32 °C) right after hatching. All chicks were raised on floor pens in the respective temperatures up to 20 weeks age. Thereafter, they were transferred to battery cages with the respective ambient temperatures (thermo-neutral 18–20 °C; heat stress 30–32 °C) and kept in temperature regulated conventional individual layer cages (1000 cm^2 per hen) to the end of the experimental period (56 weeks).

Table 1: *Levels of ambient temperatures and the genetic composition of commercial chicken genotypes*
Preglednica 1: *Okoljske temperature in genetsko ozadje komercialnih linij nesnic*

	Commercial layer genotypes				
Ambient temperatures	LW	LB	NH	WL-dw	WL-FE
Thermo-neutral (18–20 °C)	24	24	24	24	24
Heat stress (30–32 °C)	24	24	24	24	24
Total (N) = 240					

LW = Lohmann White; LB = Lohmann Brown; NH = New Hampshire; WL-dw = White Leghorn with sex-linked dwarf gene; WL-FE = White Leghorn selected for low feed expenditure

Ambient temperature and relative humidity of the pen was measured at 2 hours interval using a digital Tinytalk™ II Data Logger device. Relative humidity could not be controlled but was monitored continuously and ranged from 50 to 75 % and 65 to 85 % in the experimental and thermo-neutral houses, respectively. The hens were kept under 12-h light program, which corresponds to the natural conditions in the tropics.

During the growing period, the birds kept on the floor pen had *ad libitum* access to feed and water. Standard starter (11.4 MJ/kg and 18 % crude protein) and grower rations (11.4 MJ/kg and 15 % crude protein) were provided to all growing chicks and pullets, respectively. The adult hens were fed on commercial laying feed with 11.4 MJ/kg energy and 17 % crude protein contents. The adult hens kept in individual cage were fed in-group *ad libitum* (4 hens/feed pan) and supplied with water using individual nipple drinkers.

2.2 DATA COLLECTION PROCEDURES

Body weights were measured at 20 weeks age and end of the experiment (56 weeks). Mortality was recorded as it occurred. The age at first egg was used to determine the sexual maturity of birds. Eggs were collected from individual hens once daily and egg weight was determined at 28-d intervals. Feed consumption was measured every week by a weigh-back of feed residues in group feed troughs (4 birds/feeding trough). Egg quality traits were determined for all birds at 25, 40 and 56 weeks age using conventional methods. Percentage hen-housed production, egg mass production, feed conversion ratio (FCR), Haugh units (HU) and yolk index were calculated using standard methods.

2.3 STATISTICAL ANALYSIS

All performance parameters were analysed in a complete 2 × 5 factorial design (2, thermo-neutral and heat stress ambient temperatures; 5, genotypes). Analysis of variance (ANOVA) was performed using the SAS GLM procedure (SAS, 2004) with the model including the main effects of genotype and ambient temperature with one-way interaction. Comparisons of multiple means were made using Duncan Multiple Range Test.

Table 2: *Effect of genotype, ambient temperature and their interactions on sexual maturity and body weight of commercial layer hens*
Preglednica 2: *Učinek genotipa, okoljske temperature in njunih interakcij na spolno zrelost in telesno maso komercialnih linij nesnic*

Ambient temperature (T)	Genotype (G)	Age at sexual maturity (wks)	Body weight (kg) 20 wks age	Body weight (kg) 56 wks age
Thermo-neutral	LW	21.3^{b}	1.336^{b}	1.791^{b}
	LB	21.9^{b}	1.556^{a}	2.190^{a}
	NH	22.4^{b}	1.487^{a}	2.138^{a}
	WL-dw	22.4^{b}	1.001^{c}	1.451^{c}
	WL-FE	24.4^{a}	1.069^{c}	1.548^{c}
Heat stress	LW	21.3^{b}	1.270^{b}	1.321^{c}
	LB	21.4^{b}	1.514^{a}	1.663^{b}
	NH	22.0^{b}	1.494^{a}	1.802^{a}
	WL-dw	21.3^{b}	0.987^{d}	1.201^{c}
	WL-FE	23.7^{a}	1.075^{c}	1.225^{c}
Sources of variations		P-values		
T		0.009	0.187	<0.0001
G		<0.0001	<0.0001	<0.0001
T × G		0.558	0.549	0.022

^{a,b,c,d} Column means across each ambient temperature with different superscript letters are significantly (P < 0.05) different
LW = Lohmann White; LB = Lohmann Brown; NH = New Hampshire; WL-dw = White Leghorn with sex-linked dwarf gene; WL-FE = White Leghorn selected for low feed expenditure

3 RESULTS

3.1 SEXUAL MATURITY AND BODY WEIGHT

As shown in Table 2, the effect of ambient temperature and genotype on sexual maturity of birds was significant ($P < 0.05$). Among heat-exposed genotypes, age at sexual maturity was significantly delayed in WL-FE than other genotypes. Body weight at 20 weeks age did not significantly differ between heat-stressed and thermo-neutral chickens, which correspond the anticipated age of sexual maturity (Table 2). However, significant differences were noted in body weight between genotypes in heat stress magnitude in which the LW showed the highest heat-induced depression values while the LB and WL-dw the lowest (Table 4). The heat-induced depression values for body weight at 20 weeks age were positive for NH and WL-FE genotypes. At 56 weeks of age, the body weight in all heat-exposed genotypes was reduced ($P < 0.001$) with a significant genotype × environment interactions compared with those in thermo-neutral temperature. The magnitude of heat stress induced depression in body weight at 56 weeks age was significantly ($P < 0.05$) higher for LW and LB breeds than NH and WL-dw genotypes (Table 4). Among heat-exposed chickens, the body weight at 56 weeks was higher ($P < 0.05$) in NH than the rest four genotypes.

3.2 EGG PRODUCTION TRAITS AND FEED UTILIZATION

Although the effect of genotype × ambient temperature interactions was not significant ($P > 0.05$), the effect of ambient temperature and genotype was highly significant ($P < 0.001$) for egg weight, egg production and egg mass production (Table 3). In the current study, egg production has been presented in laying rate and expressed as percentage of hen-housed production. As presented in Table 4, hen-housed egg production was significantly ($P < 0.001$) decreased in all heat-stressed genotypes compared with those at thermo-neutral environment. The highest heat-induced reduction in hen-housed egg production was observed in LB (18.9 %) and the lowest in WL-dw (8.7 %) which differed significantly from other genotypes (Table 4). Among heat-exposed genotypes, the hen-housed egg production was significantly ($P < 0.05$) different in LW (76.5 %) compared with the rest of four genotypes and produced 10 % more eggs than the group average.

On the contrary, the WL-dw and WL-FE had the lowest hen-housed egg production and were significant-

Table 3: *Effect of genotype, ambient temperature and their interactions on performance traits of commercial layer hens reared at thermo-neutral and heat stress ambient temperatures*
Preglednica 3: *Učinek genotipa, okoljske temperature in njunih interakcij na proizvodne lastnosti komercialnih linij nesnic v termo nevtralnem okolju in pot pogoji toplotnega stresa*

Temperature (T)	Thermo-neutral					Heat stress					Pooled	Source of variations		
Genotype (G)	LW	LB	NH	WL-dw	WL-FE	LW	LB	NH	WL-dw	WL-FE	SEM	T	G	G × T
HH egg production (%)[1]	86.5^{a}	87.4^{a}	74.3^{b}	65.4^{c}	70.4^{bc}	76.5^{a}	70.9^{b}	64.1^{c}	59.7^{c}	59.8^{c}	2.189	<0.001	<0.001	0.188
Egg weight (g)	59.5^{b}	61.5^{a}	59.3^{b}	59.0^{b}	59.3^{b}	52.1^{c}	56.1^{a}	54.3^{b}	53.2^{bc}	53.9^{b}	0.827	<0.001	<0.001	0.272
Egg mass (g/hen/d)	51.2^{a}	53.9^{a}	44.1^{b}	38.6^{c}	42.0^{b}	39.9^{a}	39.8^{a}	35.2^{b}	31.7^{b}	32.3^{b}	1.324	<0.001	<0.001	0.087
Feed intake (g/d/hen)	120^{a}	123^{a}	115^{a}	88.9^{b}	98.6^{b}	85.9^{b}	90.4^{a}	87.8^{ab}	66.2^{d}	73.7^{c}	2.438	<0.001	<0.001	0.124
FCR (kg/kg egg mass)[2]	2.42^{b}	2.48^{b}	2.98^{a}	2.52^{b}	2.34^{b}	2.29^{b}	2.29^{b}	3.00^{a}	2.15^{b}	2.15^{b}	0.192	0.506	0.004	0.658

[a,b,c,d] Row means across each ambient temperature with different superscript letters are significantly ($P < 0.05$) different
[1] HH = Hen-housed; SEM = Standard error of the mean; [2] FCR = Feed conversion ratio (kg feed/kg egg mass); LW = Lohmann White; LB = Lohmann Brown; NH = New Hampshire; WL-dw = White Leghorn with sex-linked dwarf gene; WL-FE = White Leghorn selected for low feed expenditure

Table 4: *Response of individual genotypes to heat exposure as expressed by heat stress-induced depression in performance traits*
Preglednica 4: *Odziv različnih genotipov na toplotni stres, ocenjen na osnovi zmanjšanja proizvodnje*

Performance traits	LW	LB	NH	WL-dw	WL-FE
Body weight at 20 wks					
Thermo-neutral	1.336^{A}	1.336^{A}	1.336^{A}	1.336^{A}	1.336^{A}
Heat stress	1.270^{A}	1.270^{A}	1.270^{A}	1.270^{A}	1.270^{A}
Heat-induced depression, %[1]	-4.94^{a}	-2.70^{b}	$+0.47^{c}$	-1.40^{b}	$+0.56^{c}$
Body weight at 56 wks					
Thermo-neutral	1.791^{A}	1.791^{A}	1.791^{A}	1.791^{A}	1.791^{A}
Heat stress	1.321^{B}	1.321^{B}	1.321^{B}	1.321^{B}	1.321^{B}
Heat-induced depression, %	-26.2^{a}	-24.1^{a}	-15.7^{b}	-17.2^{b}	-20.9^{ab}
Hen-housed egg production, %					
Thermo-neutral	86.5^{A}	87.4^{A}	74.3^{A}	65.4^{a}	70.4^{a}
Heat stress	76.5^{A}	70.9^{B}	64.1^{B}	59.7^{B}	59.8^{B}
Heat-induced depression, %	-11.6^{b}	-18.9^{a}	-13.7^{b}	-8.70^{c}	-15.1^{ab}
Egg weight (g)					
Thermo-neutral	59.5^{A}	61.5^{A}	59.3^{A}	59.0^{A}	59.3^{A}
Heat stress	52.1^{B}	56.1^{B}	54.3^{B}	53.2^{B}	53.9^{B}
Heat-induced depression, %	-12.4^{a}	-8.80^{b}	-8.40^{b}	-9.80^{b}	-9.10^{b}
Egg mass production (g/d/hen)					
Thermo-neutral	51.2^{A}	53.9^{A}	44.1^{A}	38.6^{A}	42.0^{A}
Heat stress	39.9^{B}	39.8^{B}	35.2^{B}	31.7^{B}	32.3^{B}
Heat-induced depression, %	-22.1^{b}	-26.2^{a}	-20.2^{bc}	-17.9^{c}	-23.1^{b}
Feed consumption (g/d/hen)					
Thermo-neutral	120^{A}	123^{A}	115^{A}	88.9^{A}	98.6^{A}
Heat stress	85.9^{B}	90.4^{B}	87.8^{B}	66.2^{B}	73.7^{B}
Heat-induced depression, %	-28.4^{a}	-26.5^{a}	-23.7^{b}	-25.5^{ab}	-25.3^{ab}
Feed conversion ratio (kg/kg egg mass)					
Thermo-neutral	2.42^{A}	2.48^{A}	2.98^{A}	2.52^{A}	2.34^{A}
Heat stress	2.29^{A}	2.29^{A}	3.00^{A}	2.15^{A}	2.15^{A}
Heat-induced depression, %	-0.54^{c}	-7.70^{b}	$+0.70^{c}$	-14.7^{a}	-8.10^{b}

$^{A, B}$ Column means between ambient temperatures with different superscript letters are significantly (P < 0.05) different
$^{a, b, c}$ Column means between genotypes with different superscript letters are significantly (P < 0.05) different
[1] Calculated from: (Heat stress – Thermo-neutral) / (Thermo-neutral)*100
LW = Lohmann White; LB = Lohmann Brown; NH = New Hampshire; WL-dw = White Leghorn with sex-linked dwarf gene; WL-FE = White Leghorn selected for low feed expenditure

ly different (P < 0.05) from LW and LB genotypes. As shown in Table 3, the effect of heat stress on egg weight was highly significant (P < 0.001) in all genotypes resulting in a general depression of 9.7 % compared to those kept at thermo-neutral temperature. As shown in Table 4, the LW genotype had that highest heat-induced egg weight depression and differed significantly from other genotypes.

In heat-exposed genotypes, the egg mass production was significantly (P < 0.001) different to that of thermo-neutral temperature (Table 3). Among heat-exposed genotypes, the egg mass production was significantly (P < 0.05) larger in LW and LB genotypes. However, the heat-induced egg mass reduction was significantly higher for LB than other genotypes (Table 4). No significant (P > 0.05) differences were found in egg mass production between NH, WL-FE and WL-dw genotypes reared at high ambient temperature. At thermo-neutral environment, however, the WL-dw genotype produced significantly (P < 0.05) lower egg mass than other genotypes.

During the entire experimental period, mortality in heat-stressed birds was generally lower in WL-FE (4.2 %), but higher in LB and NH genotypes having the same mortality rate of 8.3 %. No mortality was observed in heat-stressed LW and WL-dw genotypes. In thermo-neutral environment, however, the mortality rate was equally higher for both LW and WL-dw genotypes (8.3 %).

As shown in Table 3, the effect of ambient temperature and genotype on feed consumption was highly significant ($P < 0.001$), but not their interactions. Compared with thermo-neutral birds, the overall feed consumption reduced in heat-stressed birds by about 26 %, the highest and the lowest values being observed in LW and NH genotypes, respectively (Table 4). Amongst heat-stressed genotypes, the daily feed consumption per hen was highest in LB (90.4 g) and lowest in WL-dw (66.2 g) genotypes. Although FCR reduced in heat-exposed genotypes, the effect of ambient temperature was insignificant. However, significant differences in FCR were noted in the magnitude of heat-induced depression between genotypes in which the WL-dw genotype showed the highest and the LW the lowest values (Table 4). The NH breed was the only genotype among others which showed a positive heat stress induced depression in FCR.

3.3 EGG QUALITY TRAITS

As presented in Table 5, except for yolk index, the effect of heat stress on all egg quality traits was significant ($P < 0.05$). A highly significant ($P < 0.001$) genotype effect was also observed on all investigated egg quality traits. However, the effect of genotype × temperature was only significant ($P < 0.05$) for egg deformation. Shell thickness was negatively affected by heat stress in all genotypes, with the smallest effect observed in LW genotype. Similarly, heat stress did not affect ($P > 0.05$) breaking strength and yolk index in LW genotype.

The highest depression in HU (albumen quality) was noted in LB and NH, while the lowest in WL-FE genotype. However, yolk index increased ($P > 0.05$) in all heat-stressed genotypes except in WL-dw. Among heat-exposed genotypes, the LW and LB produced eggs with the lowest deformation, while the WL-dw with the highest deformation. With advancing age, egg production, shell quality traits, yolk index and HU decreased whereas egg deformation increased.

Table 5: *Effect of genotype, ambient temperature and their interactions on egg quality traits at 25, 40 and 56 weeks of age*
Preglednica 5: *Učinek genotipa, okoljske temperature in junih interakcij na kakovost jajc v starosti 25, 40 in 56 tednov*

Ambient temperature (T)	Genotype (G)	Shell thickness (µm)	Breaking strength (N)	Egg deformation (µm)	Haugh units	Yolk index (%)
Thermo-neutral	LW	376^{bA}	41.2^{aA}	56.1^{bA}	83.7^{aA}	43.7^{bA}
	LB	385^{aA}	41.9^{aA}	56.6^{bA}	81.3^{aA}	46.5^{aA}
	NH	369^{cA}	41.4^{aA}	62.4^{aA}	75.2^{bA}	46.4^{aA}
	WL-dw	364^{cA}	38.0^{bA}	59.5^{abA}	76.8^{bA}	44.2^{bA}
	WL-FE	365^{cA}	38.2^{bA}	56.7^{bA}	71.6^{cA}	44.4^{bA}
Heat stress	LW	371^{aA}	41.2^{aA}	55.6^{cA}	81.5^{aA}	45.6^{abA}
	LB	369^{aB}	40.6^{abA}	58.2^{bcA}	77.0^{bB}	47.3^{aA}
	NH	362^{bA}	39.2^{abA}	60.7^{bA}	71.4^{cB}	46.6^{aA}
	WL-dw	354^{cA}	34.6^{cB}	67.0^{aB}	74.3^{bcA}	43.9^{cA}
	WL-FE	358^{bA}	36.7^{bcA}	60.0^{bA}	71.7^{cA}	44.8^{bcA}
Pooled SEM		3.99	1.234	1.438	1.164	0.609
Sources of variations		P-values				
T		0.0007	0.031	0.03	0.0003	0.166
G		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T × G		0.701	0.756	0.02	0.342	0.340

[a,b,c] Column means across each ambient temperature with different lower case superscript letters are significantly ($P < 0.05$) different
[A,B] Means between ambient temperatures within each genotype with different upper case superscript letters are significantly ($P < 0.05$) different
LW = Lohmann White; LB = Lohmann Brown; NH = New Hampshire; WL-dw = White Leghorn with sex-linked dwarf gene; WL-FE = White Leghorn selected for low feed expenditure; SEM = Standard error of the mean

4 DISCUSSION

4.1 SEXUAL MATURITY AND BODY WEIGHT

In the present study, age at sexual maturity was reduced in all heat-exposed genotypes. Heat stress is well known to reduce the reproductive performance of laying hens by interrupting egg production, an effect caused not only by a reduction in feed intake but also by a disruption of hormones responsible for ovulation and a decrease in responsiveness of granulose cells to luteinizing hormone (Donoghue *et al.,* 1989; Novero *et al.,* 1991). The depression in body weight due to heat exposure was only significant at 56 weeks age ranging from 15.7 to 26 % compared to those of non-heat-exposed birds. In the present study it has been thus demonstrated that the extent of the effect of hyperthermia on body weight was much greater in the older birds which is most likely attributable to relative differences in the birds' body sizes, surface areas, and geometries as reported by Sandercock *et al.* (2001). These findings further agree with those of Mashaly *et al.* (2004) who found that body weight of laying hens were decreased when exposed to high temperature possibly due to a reduction in feed consumption and feed conversion efficiency. Exposure to high ambient temperature with increasing age resulted in body weight reduction in LW and LB genotypes.

The heat-induced depression values for body weight at 20 weeks age were positive for NH and WL-FE genotypes indicating better thermo-tolerance ability of these breeds as compared to other genotypes. The NH is a dual-purpose chicken, which was developed by specialized selection out of the Rhode Island Red breed for rapid growth, fast feathering, early maturity and vigour. The observed poor thermo-tolerance in commercial layer hens may be attributable to a decreased ability to lose heat as reported by MacLeod and Hocking (1993).

4.2 EGG PRODUCTION AND FEED UTILIZATION

Although the effect of interaction genotype × environment was not significant ($P > 0.05$), hen-housed egg production was significantly ($P < 0.01$) affected by heat stress in all five genotypes. These results agree with those of Muiruri and Harrison (1991) and Kirunda *et al.* (2001), who reported that egg production in layer hens decreased when they were exposed to high environmental temperature. The decrease in egg production in the present and previous works of other scholars was most likely due to the decrease in feed consumption, reducing the available nutrients for egg production. Heat stress not only reduces feed intake but also has been reported to reduce digestibility of different components of the diet (Bonnet *et al.,* 1997). Furthermore, Zhou *et al.* (1998) reported that exposure to high temperature decreased plasma protein concentration, which is an essential component of egg protein. Similarly, Wallis and Balnave (1984) found that the digestibility of amino acids was decreased by high environmental temperature in broilers. Hai *et al.* (2000) reported that the activities of trypsin, chymotrypsin and amylase decreased significantly at a temperature of 32 °C.

The differential effect of heat stress on egg production was most pronounced in LB hens, least severe in WL-dw and LW hens and intermediate in the NH and WL-FE hens. Accordingly, the LW hens appeared to be better in thermo-tolerant among the three normal body sized genotypes. These results, with no mortality in LW are the primary explanation for the assertion that this genotype might be physiologically more thermo-tolerant than the LB or WL-FE genotypes which showed more heat-induced depression in most performance traits. Moreover, the heat-induced egg mass reduction was significantly higher for LB than other genotypes which may suggest poor thermo-tolerance ability of this specific line. Genotypic variation in response to heat stress has been shown to exist among breeds (Fox, 1980). The differences in the degree of induced hyperthermia may reflect variations in thermo-tolerance in the investigated genotypes, possibly attributable to differing efficiencies of heat loss mechanisms (Sandercock, 1995). The physiological characteristics involved in the conveyance of thermo-tolerance are not clear, but heat stress proteins (HSP), especially HSP70, may be involved (Maak *et al.,* 2003; Franco-Jimenez *et al.,* 2007).

It has been reported that birds with lighter body weight have a greater tolerance to high temperatures than heavier body weight stocks (Altan *et al.,* 2000). Although the relative advantage of dwarf hens in hot conditions is not consistent in literature (Mérat, 1990), there is evidence that a small body is associated with a lower heat load and faster heat dissipation (Gowe and Fairfull, 1995; Sandercock *et al.,* 2006). However, the WL-dw hens in the present study did not demonstrate this ability under constant heat stress environment when compared to those at thermo-neutral environment apparently due to insufficient feed intake as suggested by Garcês *et al.* (2001) and Galal *et al.* (2007).

The feed intake reduction in response to heat stress is in agreement with earlier findings (Muiruri and Harrison, 1991; Kirunda *et al.,* 2001; Mashaly *et al.,* 2004; Lu *et al.,* 2007). In order to minimise heat storage in the body (which otherwise results in the increase of body temperature) the bird reduces its feed intake. Consequently, by reducing the feed intake the bird is able to reduce the amount of heat associated with the metabolization of nutrients, controlling the amount of heat produced and reducing the thermal burden, allowing for a better control of the bird's body temperature. The reduced feed consumption and subsequent undersupply of needed nutrients quickly affect the productivity of the flock (Grieve, 2003). Larbier *et al.* (1993) found that chronic heat exposure significantly decreased protein digestion and Bonnet *et al.* (1997) reported that the feed digestibility of the different components of the diet (proteins, fats, starch) decreased with exposure of broiler chickens to high temperatures. On the other hand, the NH breed showed a positive heat stress induced depression in FCR indicating better feed utilization under heat stress situations.

4.3 EGG QUALITY TRAITS

The adverse effect of high environmental temperature on eggshell quality traits has been well documented (Odom *et al.,* 1986; Mahmoud *et al.,* 1996; Balnave and Muheereza, 1997). Exposure of hens to high temperatures resulted in a significant decrease in egg weight, shell strength, shell thickness and HU. However, in agreement with the results of Franco-Jimenez *et al.* (2007), there were no genotype × temperature interactions in egg weight and HU. The decrease in egg weight due to heat stress is in line with those of Balnave and Muheereza (1997) and Kirunda *et al.* (2001). They compared 21 °C with either 29 °C, 31 °C or 35 °C and found a considerable depression in egg weight in various chicken breeds. The decline in egg weight is directly associated with reduced feed consumption of birds.

The primary explanation for decreased eggshell quality traits might be due to reduction in the availability of nutrients, more specifically low calcium level. During heat stress, calcium intake was reduced as a direct consequence of reduced feed intake and this stimulates bone resorption resulting in hyperphosphataemia, which inhibits the formation of calcium carbonate in the shell gland of layers (Rama and Nagalakshmi, 1998). Moreover, the decrease in shell quality in the current study may be partially due to a reduction in free ionized calcium in the blood plasma as suggested by Odom *et al.* (1986). Furthermore, Mahmoud *et al.* (1996) reported that plasma calcium level was significantly decreased in laying hens when the birds were exposed to high temperatures. In addition, it has been shown that calcium use (Odom *et al.,* 1986) and calcium uptake by duodenal epithelial cells (Mahmoud *et al.,* 1996) are decreased by exposure to high environmental temperatures. Heat stress has also reduced the activity of carbonic anhydrase, an enzyme which results in the formation of bicarbonate that contributes the carbonate to the eggshell (Balnave *et al.,* 1989).

Shell thickness was negatively affected by heat stress in all genotypes, with the smallest effect observed in LW genotype. Similarly, heat stress did not affect($P > 0.05$) breaking strength and yolk index in LW genotype. Hence, this finding suggests that this particular genotype appeared to sustain a higher level of egg production and egg equality under heat stress environment than the other four genotypes.

A number of studies have shown that eggshell quality decreases as birds grow older (Roberts and Ball, 2004). There is some evidence that the inability of the hen to produce an increased amount of eggshell with age is related to the activity of 25-hydroxycholecalciferol-1-hydroxylase, an enzyme involved in calcium homeostasis (Elaroussi *et al.,* 1994). In agreement with the present findings, Kirunda *et al.* (2001) reported that HU of eggs from heat-stressed birds were reduced after heat exposure. In contrary, Mashaly *et al.* (2004) reported that HU of eggs from heat-stressed birds were significantly higher than those birds in thermo-neutral environment. The decline in albumen quality (HU) with bird's age in the present study agrees with those of Roberts and Ball (2004).

5 CONCLUSIONS

These results suggest that there are notable differences in thermoregulatory responses to heat stress in all five genotypes, possibly due to differences in their overall genetic background attributable to differing efficiencies of heat loss mechanisms. The New Hampshire chicken showed the lowest heat stress induced depression in feed consumption, feed utilization, body weight and egg weight parameters suggesting better thermo-tolerance ability as compared to other genotypes. Moreover, the Lohmann White chickens showed enhanced thermo-tolerance as demonstrated by their improved hen-housed egg production and egg quality traits under heat stress situations. The highest heat stress induced depression was observed in Lohmann Brown indicating poor thermo-tolerance ability of this genotype.

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