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The Performance of Naked Neck and Their F_1 Crosses with Lohmann White and New Hampshire Chicken Breeds under Long-Term Heat Stress Conditions

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Abstract

An experiment was conducted on 48 forty-eight female chicks from each of the five genotypes (*Angete-Melata*, Naked neck [Na]; New Hampshire [NH]; Lohmann White [LW]); and F_1 crosses (New Hampshire crosses [Na × NH]; Lohmann White crosses [Na × LW]) to assess the effect of long-term heat stress on performance traits. The female chicks were randomly divided into two groups and raised on floor pens in normal (18-20°C) and high (30-32°C) ambient temperatures up to the 20th week of age, after which they were transferred to a three-tiered system of individual cages in temperature-regulated houses and maintained in the same ambient temperatures up to the age of 68 weeks. The results revealed highly significant differences between Na and both F_1 crosses in performance traits under heat stress conditions. Accordingly, the F_1 crosses were superior to local Na hens for body weight, egg production, egg mass output, egg weight and feed efficiency. Age at sexual maturity for F_1 crosses was significantly shorter than Na but comparable to the average of pure lines. The body weight of heat stressed F_1 crosses was generally larger than Na and comparable to the average of pure lines. Percentage hen-day, hen-housed egg production and total egg number for F_1 crosses under elevated temperature did not significantly differ from the control group indicating their capability to tolerate long-term heat exposure. The present findings suggest that the F_1 crosses could be preferable to the local Na for improved egg production in hot regions.

Keywords: F_1 crosses, heat stress/high temperature, naked neck, performance traits, pure lines

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Introduction

Stress due to high environmental temperature is widely recognised as one of the primary problems in poultry production, especially in tropical and subtropical areas. High environmental temperature is the most important inhibiting factor to poultry production in hot regions (Horst, 1982), apparently because chickens cannot dissipate the heat produced following meals fast enough, which subsequently leads to reduced feed intake and lower weight gain and/or egg production (Washburn and Eberhart, 1988; Cahaner and Leenstra, 1992).

As a result of natural selection, “survival” rather than “product offtake” genes have been accumulated in local chicken strains resulting in poor growth and production. Most of indigenous chickens are, thus, non-descript, unimproved and are usually characterised by small body size, late maturity, low yield in egg number and egg weight, small clutch sizes, long laying pauses and an instinctive inclination to broodiness (Horst, 1989). Nevertheless, associated with low productivity are special desirable characteristics of local chickens such as their low input requirements, adaptability to the harsh conditions, and ability to produce special product qualities (pigmentation, taste, etc.) that are highly valued by the local producers and consumers (Horst and Mathur, 1992; Gueye, 1998).

Among the local chicken strains found in Ethiopia, the *Angete-Melata* (means Naked neck) strain is well known for better performance compared to other strains. Teketel (1986) and G/Yohannes (1997) reported that the *Angete-Melata* strain had significantly larger body weights, higher egg production associated with heavier egg weights and higher egg mass outputs, which were all significantly different from other local chicken strains. The reduction in feathering intensity through the naked neck gene may enhance the insensible heat loss through exposed body surface.

The genetic value of local chickens may be exploited through crossbreeding with exotic chickens to improve productive adaptability and product qualities. Because of the genetic distance between indigenous and exotic chickens, a higher degree of heterosis in some productive performance traits and adaptation to environmental stress would be expected (Horst and Mathur, 1992). This approach would further help to combine the adaptability of the indigenous chicken with the productivity of the exotic improved stock with additional advantage of the heterosis effects, which are expected to be higher under unfavourable environmental conditions (Barlow, 1981; Cunningham, 1982).

In a crossbreeding study carried out at Assela, Ethiopia, involving the exotic Yarkon chicken breed with unidentified local chickens (Brannang and Persson, 1990), F_1 crosses produced 129 eggs per year, which is far better than eggs produced by local hens. The annual egg production of F_1 crosses was 146 eggs per hen at Debre-Zeit Agricultural Research Centre, Ethiopia, (Alemu, 1995). Moreover, crossing with exotic egg type chickens had significant effects on egg numbers, egg weight, and total egg mass (Nwosu, 1992). The general purpose of the present study is, thus, to assess the heat tolerance capacity of *Angete-Melata* chickens and their F_1 crosses with Lohmann White and New Hampshire layer breeds as measured by their productive performance under long-term heat stress conditions.

Materials and Methods

Experimental animals

Two different experiments were conducted at Martin-Luther University Halle-Wittenberg, Germany between April 1997 and September 1999. In the first experiment (April 1997-May 1998), a total of 240 hens from five different pure breeds were used to test adaptability potential to long-term heat stress (30-32°C). The required five commercial chicken breeds were reared at Merbitz Livestock Research Centre of Martin-Luther University (MLU), where both experiments were conducted. The White Leghorn lines and New Hampshire were obtained from Merbitz Research Station, while both day old chicks of Lohmann White and Lohmann Brown were purchased from a commercial enterprise (Lohmann Company Ltd.) in Germany. Finally, on the basis of their performance and adaptability to heat exposure, both LW and NH breeds among the five were identified and eventually crossed with male cocks of *Angete-Melata* (Na) strain to produce the F_1 crossbreed population. To this effect, fertile eggs of *Angete Melata* strains were collected at Poultry Section of Awassa College of Agriculture and transported to Germany. The eggs were incubated and hatched at MLU of Germany.

The 2^{nd} experiment was conducted between May 1998 and October 1999. Artificial insemination was employed for all populations. Female chicks of each genotype were then identified and randomly divided into control and experimental groups and raised on the floor pen up to the 20^{th} week of age under normal (18-20°C) and high (30-32°C) ambient temperatures, respectively. Thereafter, 120 pullets from each group were moved to a three-tiered system of individual cages in temperature regulated layer houses with the respective ambient temperatures as indicated in Table 1.

All the birds had *ad libitum* access to feed and water during the entire experiment. Standard starter (11.4 MJ/kg and 18% CP) and grower rations (11.4 MJ/kg and 15% CP) were provided to all growing chicks and pullets, respectively. All hens maintained in individual laying cages, were fed on commercial laying feed with 11.4 MJ/kg energy and 17% crude protein contents. Hens were fed in-groups *ad libitum* (4 hens/feed pan). Water was supplied with individual nipple drinkers. The dimension of each individual cage was 1000 cm^2 (20 cm width x 50 cm length).

A Tinytalk™ II Data Logger device was used to measure the pen temperature and relative humidity during the course of the experiment. The device was loaded and unloaded at 72 days interval and was adjusted to record the pen temperature at two-hour intervals. The collected data were then converted to conventional data sets by Tinytalk™ PC software for Windows for further analysis.

Measurement of performance traits

Hens were weighed individually at the beginning (20th weeks of age) and end (68th weeks of age) of the experiment. Eggs were collected daily and egg production was calculated on a hen-day and hen-housed basis. Feed intake and egg weight were determined at 28-day intervals. Egg mass was calculated as a factor of egg weight and egg production. Feed efficiency ratio (feed consumed/egg mass) was calculated as grams of feed: grams of egg mass output. Heat stress index or change in performance to control group for performance traits was calculated by using the following formula:

$$\text{Heat stress index} = \frac{\text{Performance in high temperature} - \text{Performance in normal temperature}}{\text{Performance in normal temperature}} \times 100$$

Statistical analysis

Data were analysed using the General Linear Models Procedure of SAS® (SAS Institute, 1996). All performance parameters were analysed in a complete 2x5 factorial design (2 normal and high temperatures; 5 genotypes). Egg number, body weights and percentage data of egg production were analysed following logarithmic transformation to account for the skewed distribution. When significance differences in ANOVA were detected, comparisons of multiple means were made by using Tukey's HSD test. All statements of statistical differences were based on P<0.05 unless noted otherwise.

Results

Egg production traits

Percent fertility and hatchability of eggs for different genotypes is presented in Table 2. Rate of egg fertility was higher for LW and their F_1 cross, but lower for Na chicks. Conversely, hatchability of fertile eggs was higher for NH, but lower for Na × NH chicks. The same trend was also observed for the hatchability of total eggs set. In general, the NH breed showed better hatchability. Among F_1 crosses, the Na × LW was superior to Na × NH for egg fertility and hatchability.

Sexual maturity for exotic breeds (LW and NH) and F_1 crosses was not significantly affected by high temperature although it was slightly shorter by 3 days when compared to the control group. On the other hand, a significant difference in sexual maturity was noted between genotypes exposed to longterm high environmental temperature. Accordingly, age at first egg for F_1 crosses was significantly shorter compared to local Na strain but was comparable to that of exotic breeds.

Exposure to prolonged heat stress at the age of 20 weeks, which corresponds with sexual maturity, resulted in body weight loss of 9.4% in all genetic groups except in Na × LW crosses (Table 3). The body weight depression for individual genotypes was 14.1, 7.8, 13.7 and 12.6% for Na, LW, NH and Na × NH, respectively. Conversely, no significant effect of heat stress on body weight was found at the 68th week of age for all genotypes, except for the NH line, which showed a significant body weight loss of 16.6%. The body weight of Na × LW (1189 g) at 20 weeks of age was comparable to LW (1248 g), but significantly larger than the Na strain (818 g) and Na × NH hens (1101g).

The effect of long-term high temperature on egg production, egg weight and egg mass output is presented in table 4. The effect of ambient temperature and genotype on egg weight and production was highly significant (P<0.001). The ambient temperature by genotype interaction was found to be significant as well. Egg production, as expressed in percentage hen-day and hen-housed, and total egg number for LW and NH exotic breeds were significantly affected by high temperature, while the effect remained insignificant for both F_1 crosses and local Na strains. As a result, percentage hen-housed egg production reduced by 10.8 and 9.7% for LW and NH breeds, respectively; and percentage hen-day egg production by 10.8 and 5.5%, for NH and LW breeds, respectively. There was no significant difference between NH, Na × LW and Na × NH genotypes in hen-day egg production under heat stress conditions.

On the other hand, significant differences between experimental and control groups were found in egg weight resulting in a 10% depression for all genotypes. The decline in egg weight due to heat stress followed the same trend as in egg production and was comparatively larger for NH (15.2%) and LW (11.7%) but smaller for Na × LW (6.0%) and Na (7.4%) compared to the control group. The depression in egg weight for Na × NH crosses was intermediate with 9.5%. The F_1 crosses at high temperature produced eggs with significantly heavier weights than the local Na strain.

The magnitude of heat stress effect on total egg mass output was larger ($p<0.001$) for both breeds (LW and NH) as well. The individual egg mass depression, as measured by heat stress index, for NH and LW was 25 and 21%, respectively (figure 1). However, the heat stress index for daily egg mass output for Na and Na × LW was insignificant. The difference in daily egg mass output between NH and Na × LW at high temperature was insignificant. The daily egg mass output for F_1 crosses was much better than local Na strain but comparable to both pure breeds as illustrated in figures 2 and 3.

Feed intake and efficiency

The effect of heat exposure on feed intake and efficiency for individual genotypes is presented in Table 5. The effect of ambient temperature and genotype on feed intake was highly significant ($P<0.001$). The temperature by genotype interaction effect for feed intake was highly significant as well. However, the effect of ambient temperature on feed efficiency and the temperature by genotype interaction was not significant. The feed intake in all genotypes was significantly depressed resulting in a general decline of 20.4% for pure breeds (NH and LW) and 14.5% for F_1 crosses. The heat stress index of feed intake for individual genotype was 22.7, 18.2, 17.8, 17.1 and 11.9% for NH, LW, Na, Na × NH and Na × LW, respectively (Figure 1).

The difference in feed intake between NH, Na × LW and Na × NH exposed to long-term heat stress was insignificant. The feed efficiency per kg egg mass for both F_1 crosses was comparable to that of the pure breeds, but significantly ($p<0.001$) better than the *Angete Melata* strain as shown in figure 4. The pattern of feed intake in the experimental group increased with age up to 50 weeks of age and declined slightly thereafter, while it increased consistently in the control group. On the other hand, feed efficiency increased constantly with age at both ambient temperatures.

Data for egg production, egg weight, daily egg mass output, feed efficiency, sexual maturity and body weight obtained at high temperature for F_1 crosses were compared to data with local Na hens (Table 6), In general, the performance of local Na strain significantly improved as a result of crossing with pure layer breeds. Accordingly, percentage hen-day egg production and egg weight were significantly higher for Na × LW and Na × NH crosses compared to Na strain (39.3%; 41.4g). The individual daily egg mass output showed similar pattern and improved by 113% and 91.4% for Na × LW and Na × NH, respectively, compared to Na hens. Age at sexual maturity was shorter by 7.2% and 4.2% for Na × LW and Na × NH, respectively. On the other hand, local Na hens consumed over 30% more feed than F_1 crosses and proved to be very poor feed converters.

As far as the performance efficiency for both F_1 crosses under heat stress conditions is concerned, the Na × LW cross was found to be significantly better in most performance parameters than Na × NH as shown in table 7. The Na × LW cross was superior to Na × NH for egg fertility, hatchability and daily egg mass output by 10, 18 and 11%, respectively. Moreover, egg weight and body weight at sexual maturity were significantly higher for Na × LW compared to Na × NH. Among the genotypes exposed to heat stress, the LW breed had a higher mortality rate of 11.1 and 16.7% before and after sexual maturity, respectively. During the laying period, no losses were observed for Na × LW crossbreed combination at high environmental temperature.

Discussion

The F_1 crosses between Ethiopian local chicken strains and White Leghorn raised at tropical environment reached their sexual maturity at 167 days (Mekonnen, 1998), which was comparatively longer by 13 and 8 days for Na × LW (154 d) and Na × NH (159 d), respectively. According to the same author, age at first egg of F_1 crosses was not significantly different from that of the White Leghorn.

On the other hand, the average depression in body weight due to prolonged heat exposure at adult stage was low (5.6%) compared to that at sexual maturity (9.4%), which is in agreement with the reports of Renden and McDaniel (1984) and Proudfoot and Hulan (1987). This might partly be explained that hens at the stage of sexual maturity not being fully adapted to the heat stress, while the tolerance has been improved with age resulting in a slight reduction of body weight at adult stage. The most interesting result in this experiment is that long-term heat stress did not depress the body weight of Na × LW crossbreed combination; instead, there was an increase of 1.7 and 2.9% at sexual maturity and adult stage, respectively, suggesting a gradual adaptation to prolonged heat exposure with age for this particular trait. This could be explained by the small body size of the Na × LW cross contributed by the genetic background of their LW parents, which accounts for better heat tolerance. This finding is supported by Squibb and Wogen (1960), who reported that light bodied breeds are affected less by heat stress. Moreover, the body weight of F_1 crosses in warm temperature was larger than Na, but comparable to the average of pure breed lines, which is in accordance with previous findings by Nwosu (1992).

In this data, a great diversity among the effects of the environments is evident by drastic depressions due to constant heat exposure in all investigated productivity traits confirming the findings of Pech-Waffenschmidt (1992) and Da Cruz-Lopes (1999). The average depression in egg production was 2.7 and 8.1% for F_1 crosses and pure breeds, respectively. This indicates that the F_1 crosses have showed better performance without being severely affected by long-term heat stress suggesting their suitability for egg production in hot climates. This is certainly due to the presence of the Na gene in the F_1 crosses, which is associated with reduced feathering of the Na allele that eased the heat-induced suppression of performance traits.

The significant reduction in egg weight due to prolonged heat stress is in agreement with Vo *et al.* (1980), Sauveur and Picard, (1987), Balnave and Muheereza (1997). All of these investigators compared 21°C with either 29, 31or 35°C and found a considerable depression in egg weight in various chicken lines. Eggs of Na × LW and Na × NH were 25.1 and 16.9% heavier than eggs laid by Na hens, which agrees with Nwosu (1992), who reported an increase of 14.9% in egg weight for F_1 crosses over local chickens. In an experiment conducted in Ethiopia, Mekonnen (1998) reported that the performance of local birds was significantly inferior to that of the White Leghorn and its crosses with local chicken. In the results of this study, the egg production of the local Na hens under heat stress conditions was comparatively lower than reported by Teketel (1986), but comparable to that reported for indigenous birds in Nigeria (Nwosu, 1979, as cited by Horst, 1989). Nevertheless, the egg production of F_1 crosses at high temperature in this study was higher than reported by Brannang and Persson (1990) and Mekonnen (1998) under a tropical environment in Ethiopia

The depression in egg production due to heat stress at the peak phase for F_1 crosses and pure breeds was 5.4 and 6.9%, respectively. The corresponding figure at the end of the experiment was 1.6 and 7.3% for F_1 crosses and pure breeds, respectively, which indicates that the F_1 crosses were very much less susceptible to constant heat stress with increasing age suggesting improved adaptability over time. This tendency was supported by the performance of the local Na, whose egg production rate was significantly depressed at peak (7.4%) but slightly (1.3%) at the end of the experiment.

Minimum voluntary feed intake and poorest performance were obtained with birds kept at long-term hot temperature (Kyarisima and Balnave, 1996). Moreover, reduced feed consumption along with depressed body weight at high temperatures was reported by De Andrade *et al*. (1977) and Balnave (1996). A progressive decline in body weight and feed intake was observed as the ambient temperature increased from 18 to 35°C (Yahav *et al.,* 1996a). In this study, the average feed intake for both pure NH and LW was significantly depressed by 21.7%, which is comparable to earlier findings by De Andrade *et al*. (1977), who reported a decline of 26.5% at 31°C in White Leghorns. Moreover, Kabo (1986) found a reduction of feed intake by 18.5% in young hens maintained at 32°C. In another experiment conducted on medium heavy hybrids, Chima (1975) found a reduction of 28% in feed intake at 34°C. The feed intake for F_1 crosses in this study depressed by 16.3%, which is comparatively lower than pure lines (21.7%).

Conclusion

The results of this study reveals that the F_1 crosses were by far better in all performance traits over the native *Angete-Melata* chickens and comparable to both exotic pure breeds under prolonged heat stress conditions. The Na × LW cross have particularly proved to be the best crossbreed combination for better performance at high temperature. The present findings suggest that the F_1-crosses could be preferred over local Na for improved egg production in hot regions. The crossbreeding approach should be, however, supported by selection of highly productive local Na birds for a better result. Moreover, the performance of F_1 crosses should further be evaluated under tropical environmental conditions. On the other hand, the LW breed at high temperature was found to be much better in most performance traits than NH and could, thus, be recommended for crossbreeding purposes to upgrade the low performance of native chickens under hot climates.

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Table 1. Genetic structure and size of the experimental and control chicken genotypes

Ambient temperatures	**F_1 crosses**		**Local Na and pure lines**		
	Na × LW	**Na × NH**	**Na**	**LW**	**NH**
Normal (Control group, 18-20 °C)	24	24	24	24	24
High (Experimental group, 30-32 °C)	24	24	24	24	24
Total	48	48	48	48	48

Table 2. Egg fertility and hatchability for local Na, pure breed chicks and their F_1 crosses (in %)

Traits	**Na**	**LW**	**NH**	**Na × LW**	**Na × NH**
Egg fertility	86.6	97.5	96.6	97.0	88.2
Hatchability of total eggs set	70.7	89.9	92.3	74.4	60.0
Hatchability of fertile eggs	81.7	92.2	95.6	79.9	68.0

Table 3. Effect of elevated environmental temperature on body weight and survival of local Na, exotic chicken breeds and their F_1 crosses (mean ± s.d.)

Body weight	**Temp.**	**Na**	**LW**	**NH**	**Na × LW**	**Na × NH**
At 20 weeks of age (g)	N	$952^{aE}\pm124$	$1353^{aB}\pm126$	$1574^{aA}\pm166$	$1169^{aD}\pm150$	$1259^{aC}\pm136$
	H	$818^{bD}\pm156$	$1248^{bB}\pm143$	$1360^{bA}\pm130$	$1189^{aB}\pm95$	$1101^{bC}\pm140$
At 68 weeks of age (g)	N	$1273^{aD}\pm214$	$1594^{aBC}\pm193$	$2031^{aA}\pm200$	$1581^{aC}\pm245$	$1719^{aB}\pm257$
	H	$1230^{aB}\pm206$	$1548^{aA}\pm279$	$1694^{bA}\pm304$	$1626^{aA}\pm224$	$1643^{aA}\pm281$
Mortality rate (%)	N	None	8.3	None	None	None
	H	4.2	16.7	4.2	None	4.2

$^{A-E}$Means between genotypes within a row with different superscript differ significantly (p<0.05)

^{a,b}Means between temperatures within each genotype and body weight category with different superscripts differ significantly (p<0.05) Temp.= Temperature N= Normal temperature H = High temperature

Table 4. Effect of high environmental temperature on total egg number, laying rate, egg weight and daily egg mass output of Na, pure breeds and their F_1 crosses (mean $\pm$ s.d.)

Performance traits	**Temp.**	**Na**	**LW**	**NH**	**Na $\times$ LW**	**Na $\times$ NH**
Hen-day Production (%)	N	$39.2^{aD}\pm10.3$	$87.8^{aA}\pm15.4$	$73.5^{aB}\pm11.6$	$67.2^{aC}\pm11.2$	$67.6^{aC}\pm9.38$
	H	$39.3^{aC}\pm10.0$	$83.0^{bA}\pm14.4$	$65.6^{bB}\pm11.4$	$66.9^{aB}\pm10.5$	$64.3^{aB}\pm7.74$
Hen-housed Production (%)	N	$39.2^{aD}\pm10.2$	$85.3^{aA}\pm11.6$	$70.5^{aB}\pm11.6$	$66.8^{aC}\pm11.1$	$67.6^{aC}\pm9.41$
	H	$38.4^{aC}\pm10.7$	$76.1^{bA}\pm13.1$	$63.6^{bB}\pm14.9$	$66.9^{aB}\pm10.5$	$63.0^{aB}\pm9.82$
Egg weight (g)	N	$44.7^{aE}\pm4.98$	$62.6^{aA}\pm4.53$	$64.0^{aB}\pm5.87$	$54.9^{aC}\pm5.04$	$53.5^{aD}\pm4.92$
	H	$41.4^{bD}\pm4.17$	$55.7^{bA}\pm6.13$	$54.4^{bA}\pm5.67$	$51.8^{bB}\pm5.29$	$48.4^{bC}\pm5.45$
Daily egg mass Output (g)	N	$17.5^{aD}\pm5.18$	$54.9^{aA}\pm10.6$	$47.1^{aB}\pm7.98$	$36.8^{aC}\pm6.22$	$36.0^{aC}\pm4.90$
	H	$16.2^{aD}\pm4.42$	$46.3^{bA}\pm9.7$	$35.7^{bB}\pm9.19$	$34.5^{aB}\pm5.66$	$31.0^{bC}\pm4.86$

$^{A-E}$Means between genotypes within a row with different superscripts differ significantly ($p<0.05$)

^{a,b}Means between temperatures within each genotype and trait with different superscripts differ significantly ($p<0.05$) Temp.= Temperature

N= Normal temperature H= High temperature

Table 5. Voluntary feed intake and feed efficiency as affected by prolonged high temperature in local Na, exotic pure breeds and their F_1 crosses (mean $\pm$ s.d.)

Parameter	**Temp.**	**Na**	**LW**	**NH**	**Na $\times$ LW**	**Na $\times$ NH**
Feed intake (g/hen/d)	N	$77.0^{aC}\pm4.94$	$121^{aA}\pm7.66$	$116^{aA}\pm6.09$	$101^{aB}\pm5.05$	$105^{aB}\pm5.12$
	H	$63.3^{bC}\pm3.60$	$98.8^{bA}\pm8.11$	$89.7^{bB}\pm5.09$	$88.8^{bB}\pm5.41$	$87.3^{bB}\pm6.28$
Feed efficiency (kg/kg egg mass)	N	$5.29^{aA}\pm1.22$	$2.28^{aC}\pm0.30$	$2.49^{aBC}\pm0.23$	$2.94^{aB}\pm0.56$	$2.89^{aB}\pm0.31$
	H	$5.00^{Aa}\pm2.13$	$2.23^{aD}\pm0.25$	$2.44^{aDC}\pm0.26$	$2.80^{aBC}\pm0.41$	$2.88^{aB}\pm0.31$

$^{A-E}$Means between genotypes within a row with different superscript differ significantly ($p<0.05$)

^{a,b}Means between temperatures within each genotype and parameters with different superscript differ significantly ($p<0.05$) Temp.= Temperature N= Normal temperature H= High temperature

Table 6. Comparison of major performance traits between local Na and their F_1 crosses with exotic breeds under high environmental temperature (Change to Na, %)

Performance traits	**Na**	**Na $\times$ LW**	**Na $\times$ NH**
Egg production (% hen-day)	44.9^{b}	$68.3\ (+52.1)^{a}$	$65.5\ (+45.9)^{a}$
Egg weight (g)	41.4^{c}	$51.8\ (+25.1)^{a}$	$48.4\ (+16.9)^{b}$
Egg mass (g/hen-day)	19.3^{c}	$36.1\ (+87.0)^{a}$	$32.0\ (+65.8)^{b}$
Feed efficiency (kg/kg egg mass)	5.00^{b}	$2.80\ (-44.0)^{a}$	$2.88\ (+-42.2)^{a}$
Age at first egg (d)	166^{a}	$154\ (-07.2)^{c}$	$159\ (-04.2)^{b}$
Body weight at 20th weeks of age (g)	818^{c}	$1189\ (+45.4)^{a}$	$1102\ (+34.7)^{b}$
Body weight at 68th weeks of age (g)	1230^{b}	$1626\ (+32.2)^{a}$	$1643\ (+33.6)^{a}$

$^{a-c}$Means within a row with different superscript differ significantly ($p\leq0.05$)

Table 7. Performance comparison between Na x LW and Na x NH crossbreed combinations under high environmental temperature

Performance traits	**Na × LW**	**Na × NH**	**Difference to Na × NH (%)**
Egg fertility (%)	97.0[a]	88.2[b]	10.0
Hatchability (%)	80.0[a]	68.0[b]	17.6
Age at first egg (d)	154[a]	159[b]	-3.1
Body weight at sexual maturity (g)	1189[a]	1102[b]	7.9
Egg weight (g)	51.8[a]	48.4[b]	7.0
Egg mass (g/hen/d)	34.5[a]	31.0[b]	11.3

[a,b] Means within a row with different superscript differ significantly (p<0.05).

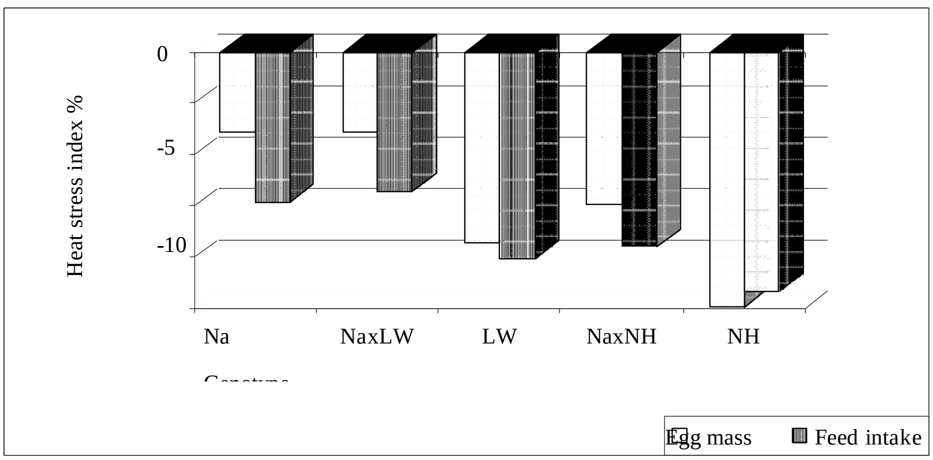

Figure 1. The magnitude of long-term heat stress effect on egg mass and feed intake of all genotypes as measured by heat stress index

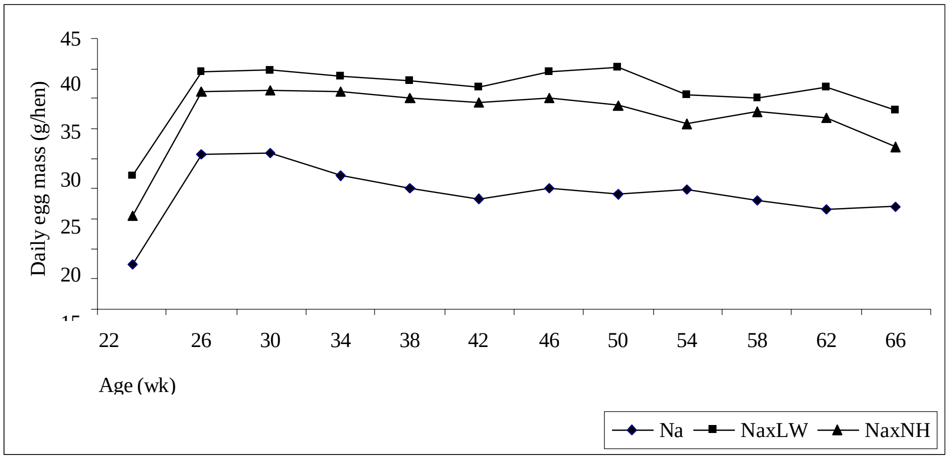

Figure 2. Trend of daily egg mass production for *Angete-Melata* and F_1 crosses in relation to age under heat stress conditions

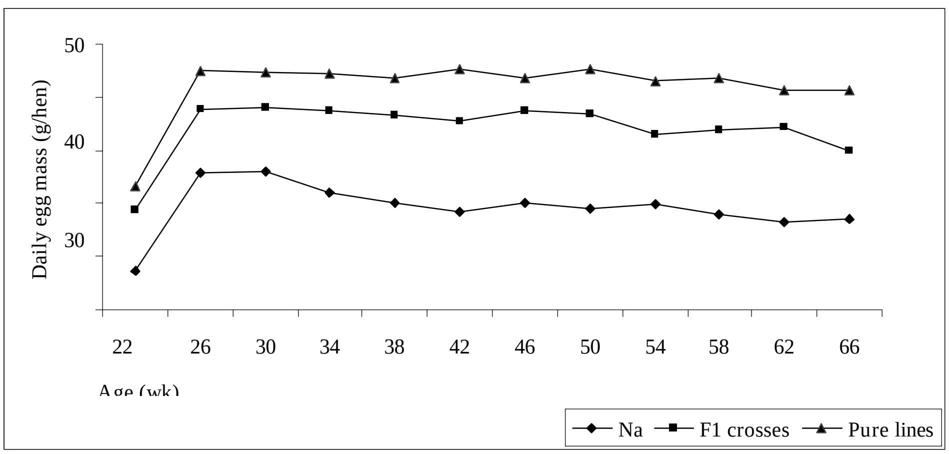

Figure 3. Tendency of daily egg mass production with age for local Na, F_1 crosses and pure breeds under high environmental temperature

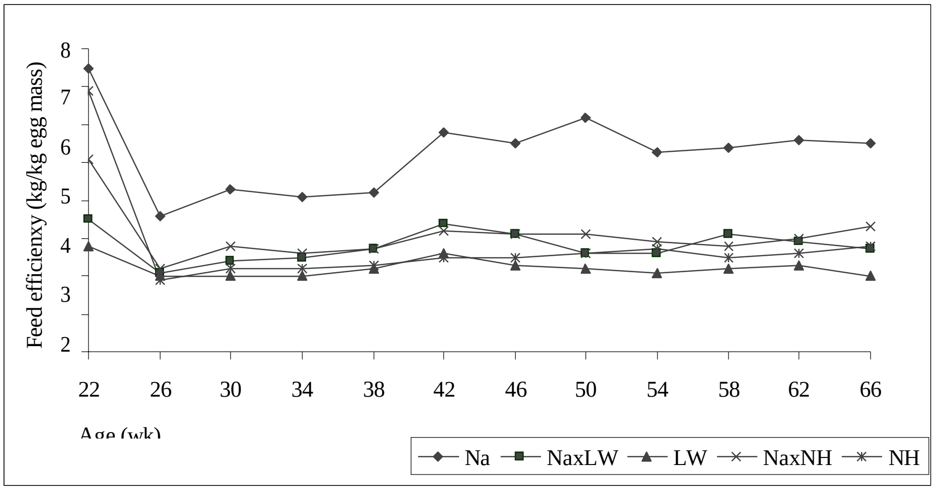

Figure 4. Comparison of feed efficiency between local *Angete Melata*, pure breeds and their F_1 crosses maintained at high environmental temperature

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