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Chronic heat exposure raises the water-to-feed ratio without altering the growth trajectory of guinea fowl (*Numida meleagris*)

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Abstract

Guinea fowl (*Numida meleagris*) are considered heat tolerant, but it is unknown whether chronic heat changes the shape of their growth curve or the water cost of rearing. We modelled the growth of 96 guinea fowl reared in climatic chambers at 26 or 32 °C (four boxes of 12 birds per temperature) from 28 to 91 days of age. Five nonlinear models were fitted to weekly box-mean body weights. We also assessed flock uniformity, the weekly water-to-feed ratio, the within-age relationship between body weight and thermoregulatory responses, and the economic slaughter age. The logistic model gave the best fit in all boxes ($R^2 = 0.998$). Air temperature did not affect asymptotic weight (1829 vs 1831 g), maturation rate (0.064 vs 0.060 d^{-1}), age at inflection (52.7 vs 53.9 d) or maximum growth rate (29.2 vs 27.4 g d^{-1}) ($P \geq 0.31$). Flock uniformity was also unaffected. In contrast, the water-to-feed ratio was 19% higher at 32 °C (2.29 vs 1.93 mL g^{-1}; $P = 0.021$), with the largest gap at 35 days (3.09 vs 1.65 mL g^{-1}), when evaporative heat loss is highest. Marginal feed conversion rose steeply after 70 days, placing the economic slaughter age at 65–88 days for live-weight/feed price ratios of 4–10. Guinea fowl maintain their growth trajectory under chronic heat, and the cost of heat is paid mainly in water. The water-to-feed ratio is a simple on-farm indicator of heat load.

Keywords: Heat stress; Growth curve; Logistic model; Water intake; Thermoregulation; Slaughter age.

1. Introduction

High air temperature is one of the main constraints on poultry production in tropical regions. Heat stress reduces feed intake and feed efficiency and raises the energy and water cost of keeping body temperature stable (Syafwan et al., 2011; Lara and Rostagno, 2013; Wasti et al., 2020). Fast-growing genotypes are especially sensitive, because high growth rate reduces heat tolerance (Settar et al., 1999). In northeastern Brazil, air temperature often

exceeds the upper limit of the thermal comfort zone of most farm birds, with losses in broiler performance (Oliveira et al., 2006; Baracho et al., 2019). Climate control in these regions raises production costs, so species that tolerate heat with little loss of performance are attractive for small and medium producers. Using adapted genotypes is one of the main strategies to reduce heat stress in tropical livestock (Renaudeau et al., 2012). Unlike commercial broilers, whose efficiency results from intense genetic selection (Havenstein et al., 2003), rustic species can produce in simpler housing.

The guinea fowl (*Numida meleagris*) is a rustic bird of African origin, valued for its meat and for its resistance to hot climates. Meat-type strains have been evaluated for intensive rearing (Nahashon et al., 2009). In earlier work with the same birds, raising air temperature from 26 to 32 °C increased respiratory rate and surface, cloacal and eyeball temperatures (Marques et al., 2023), as well as pupil temperature and dilation (Marques et al., 2021). It also shifted heat loss from sensible to latent forms, cutting sensible heat loss by 53.5% and raising latent heat loss by 82.7% (Marques et al., 2023). Even so, final weight, weight gain, feed conversion and carcass yield did not differ between temperatures (Marques et al., 2023). These results came from phase means compared by analysis of variance. They show whether heat changed performance, but not how it changed the shape of growth over time.

Nonlinear growth models summarise the whole growth trajectory in a few parameters with biological meaning: asymptotic weight, maturation rate and the age at which growth is fastest (Narınç et al., 2017). Because the choice of function changes the estimates, several models should be compared for each data set (Aggrey, 2002). Growth curves are also used to compare genotypes and to identify when growth starts to slow (Santos et al., 2005). In guinea fowl, growth curves have been fitted for pearl gray and French meat-type strains reared under temperate as conditions. The Gompertz model gave the best fit, with maximum growth at about 6 to 7 weeks of age (Nahashon et al., 2006a, 2006b). In broilers, chronic heat reduced

growth in a strain-dependent way (Roushdy et al., 2018), but we found no study on how chronic heat changes the growth curve of guinea fowl. Two flocks can reach similar final weights through different paths, for example slower early growth followed by compensation. These paths matter for the slaughter age and for how long feed is spent on little gain.

Water intake is another sensitive response to heat. Broilers exposed to 35 °C increased water consumption by 78%, and water intake correlated with evaporative cooling (Belay and Teeter, 1993). Water consumption has also been proposed as a health and welfare indicator in broiler flocks (Manning et al., 2007). In guinea fowl, water intake at 32 °C was only 5.6% higher than at 26 °C (Marques et al., 2023). However, water intake rises with feed intake and body size. Expressing water per unit of feed eaten separates the thermoregulatory demand from the effect of growth. To our knowledge, the water-to-feed ratio has not been used to track heat load in guinea fowl over the rearing period.

The objective of this study was to describe the growth trajectory of guinea fowl reared at 26 and 32 °C with nonlinear models. We also assessed flock uniformity and the weekly water-to-feed ratio, explored the link between body weight and thermoregulatory responses, and estimated the economic slaughter age in each thermal environment. We hypothesised that chronic heat would slow the maturation rate and delay the age of maximum growth without changing asymptotic weight, and that it would raise the water-to-feed ratio.

2. Material and methods

2.1. Ethics, animals and housing

The procedures were approved by the Research Ethics Committee of the Federal University of Campina Grande (UFCG), Paraíba, Brazil (protocol CEP nº 020/2019). The study used data from the climatic-chamber experiment described by Marques et al. (2021, 2023), carried out at the Laboratory of Rural Constructions and Ambience of UFCG. Ninety-

six unsexed guinea fowl were housed in eight 1 m² boxes (12 birds per box) inside two climatic chambers. The two chambers were identical in model, dimensions (3.1 × 2.8 × 2.6 m) and climate-control system (EOS® TR-18; Marques et al., 2023). Boxes, feeders, drinkers, stocking density and management were identical in both chambers. Four boxes were kept at 26 °C (thermoneutral) and four at 32 °C (heat stress) from the 4th to the 13th week of life. Water and feed were supplied ad libitum. Diets followed NRC (1994) recommendations, with 3200 kcal kg^{-1} of metabolizable energy and about 23, 20 and 18% crude protein in the initial, growth and final phases. Birds received 23 h of light per day, and vaccination and environmental control followed Marques et al. (2023). Mean air temperature was 26.1 ± 0.5 and 31.8 ± 0.6 °C, and the temperature-humidity index (THI) was 25.0 ± 0.6 and 31.0 ± 0.4, respectively. Relative humidity was set at 65 ± 5% but reached 71.6 ± 2.9% at 32 °C, and wind speed was 0.50 ± 0.03 and 0.52 ± 0.03 m s^{-1} (Marques et al., 2023). No birds died during the experimental period. The box was the experimental unit (n = 4 per temperature) in a completely randomised design.

2.2. Body weight

All birds were weighed weekly from 28 to 91 days of age (10 weighings). The same ringed birds (Marques et al., 2023) were weighed throughout. Because the box was the experimental unit, growth was modelled on box-mean weights (8 boxes × 10 ages), so that repeated weighings of birds sharing a box were not treated as independent replicates (Hurlbert, 1984).

2.3. Growth models

Five nonlinear models were fitted to each box by least squares (Levenberg–Marquardt algorithm): Gompertz, logistic, von Bertalanffy, Brody and Richards. In all models, W is

body weight (g), t is age (d), A is asymptotic weight (g), b is an integration constant, k is the maturation rate (d^{-1}) and m is the Richards shape parameter. Models were ranked by the Akaike information criterion (AIC; Akaike, 1974), the coefficient of determination (R^2) and the residual standard deviation (RSD). The logistic model (Eq. 1) was:

$$W_t = A / (1 + b\, e^{-kt}) \qquad (1)$$

From the logistic fit of each box we derived the age at inflection ($t_i = \ln b / k$), the weight at inflection (A/2) and the absolute growth rate (AGR, g d^{-1}; Eq. 2):

$$AGR_t = k\, W_t\, (1 - W_t / A); \quad AGR_{max} = kA / 4 \qquad (2)$$

Box-level parameters were compared between temperatures with Student's t test (two-stage approach), after checking normality (Shapiro–Wilk) and homogeneity of variances (Levene). Age at inflection at 32 °C departed from normality and was also compared by the Mann–Whitney test. In addition, the 95% confidence intervals (CI) of the differences were reported to judge equivalence. A pooled model with temperature-specific parameters was also compared with a common model by an extra-sum-of-squares F test.

2.4. Flock uniformity

For each box and age, we calculated the coefficient of variation (CV, %) of body weight and the percentage of birds within ±10% of the box mean. The mean CV, the final CV and the weekly rate of change of CV (linear slope) per box were compared between temperatures.

2.5. Water-to-feed ratio

Weekly feed and water intake per box (amount offered minus refusals) were converted to g bird^{-1} d^{-1} and mL bird^{-1} d^{-1}. The water-to-feed ratio (mL g^{-1}) was calculated for each box and week and compared between temperatures for each week and for the whole period. P values of the weekly comparisons were adjusted for multiplicity by the Holm (1979) method. Records for week 6 were identical to those for week 5 in all boxes, indicating a transcription duplicate, and were excluded.

2.6. Body weight and thermoregulatory responses

Each week, four birds per box were weighed and had respiratory rate (RR) and infrared surface temperatures (wing, shank, head and back) measured at the same handling, following Marques et al. (2023). Mean surface temperature was the weighted average of the four regions. To separate body size from age, each variable was expressed as a deviation from its box-week mean, and the within-age slope per 100 g of body weight was estimated for each temperature. Box-level slopes were then compared between temperatures (exploratory analysis; 28–70 days, n = 220 records). Cloacal temperature was not included because its treatment labels were swapped in the source sheet, so its values could not be matched to individual body weights; its treatment means are those reported by Marques et al. (2023).

2.7. Economic slaughter age

Daily feed intake per bird (FI, g d^{-1}) was regressed linearly on age for each box. Marginal feed conversion (mFCR, g feed g^{-1} gain; Eq. 3) was:

$$mFCR_t = FI_t / AGR_t \qquad (3)$$

The economic slaughter age was defined as the age at which mFCR equals the live-weight/feed price ratio (Pw/Pf). Beyond this age, one more day of feeding costs more than the weight it adds. The criterion considers feed cost only. It was solved numerically for each box at price ratios of 4, 6, 8 and 10.

2.8. Statistical analysis

Analyses were performed in Python 3.13 with SciPy 1.18. Data are presented as means ± standard error (SE) of four boxes. Significance was set at $P < 0.05$.

3. Results

3.1. Model selection

The logistic model gave the lowest AIC in every box (mean ΔAIC = 0.05; maximum 0.4) and the smallest residual standard deviation (Table 1). The Richards model converged to a Gompertz-like shape and added no information. Brody fitted worst and overestimated asymptotic weight.

Table 1. Goodness of fit of five nonlinear models describing the growth of guinea fowl from 28 to 91 days of age (means of eight boxes). The logistic model ranked best in all boxes.

Model	AIC	R^2	RSD (g)	ΔAIC, mean (max)	Median A (g)
Logistic	67.4	0.998	24.6	0.05 (0.4)	1818
Gompertz	72.4	0.997	31.0	5.1 (11.6)	2096
Richards	74.4	0.997	31.0	7.1 (13.6)	2096
von Bertalanffy	75.6	0.996	36.0	8.2 (15.3)	2302
Brody	81.7	0.992	48.5	14.4 (21.8)	3808

AIC, Akaike information criterion; R^2, coefficient of determination; RSD, residual standard deviation; ΔAIC, difference from the best model in the same box; A, asymptotic weight.

3.2. Growth curve parameters

Air temperature did not affect any logistic parameter ($P \geq 0.31$; Table 2; Mann–Whitney $P = 0.69$ for age at inflection), and the pooled model with temperature-specific parameters did not improve the fit ($F_{3,74} = 2.25$; $P = 0.09$). The fitted curves stayed within 31 g of observed box means at every age (Fig. 1A). Absolute growth rate peaked at 53–54 days and fell to 8.6 and 9.7 g d^{-1} at 91 days (Fig. 1B).

Table 2. Parameters of the logistic growth model of guinea fowl reared at 26 or 32 °C from 28 to 91 days of age (mean ± SE, n = 4 boxes). Confidence intervals show that large effects of heat can be ruled out.

Parameter	26 °C	32 °C	95% CI of difference (32 − 26 °C)	P
A (g)	1829 ± 61	1831 ± 67	−220 to 225	0.98
b	29.7 ± 3.1	25.6 ± 2.6	—	0.35
k (d^{-1})	0.064 ± 0.003	0.060 ± 0.003	−0.014 to 0.006	0.34
Age at inflection (d)	52.7 ± 0.9	53.9 ± 1.3	−2.8 to 5.2	0.48
Weight at inflection (g)	914 ± 30	916 ± 34	—	0.98
AGRmax (g d^{-1})	29.2 ± 0.7	27.4 ± 1.5	−5.7 to 2.1	0.31

A, asymptotic weight; b, integration constant; k, maturation rate; AGRmax, maximum absolute growth rate; CI, confidence interval.

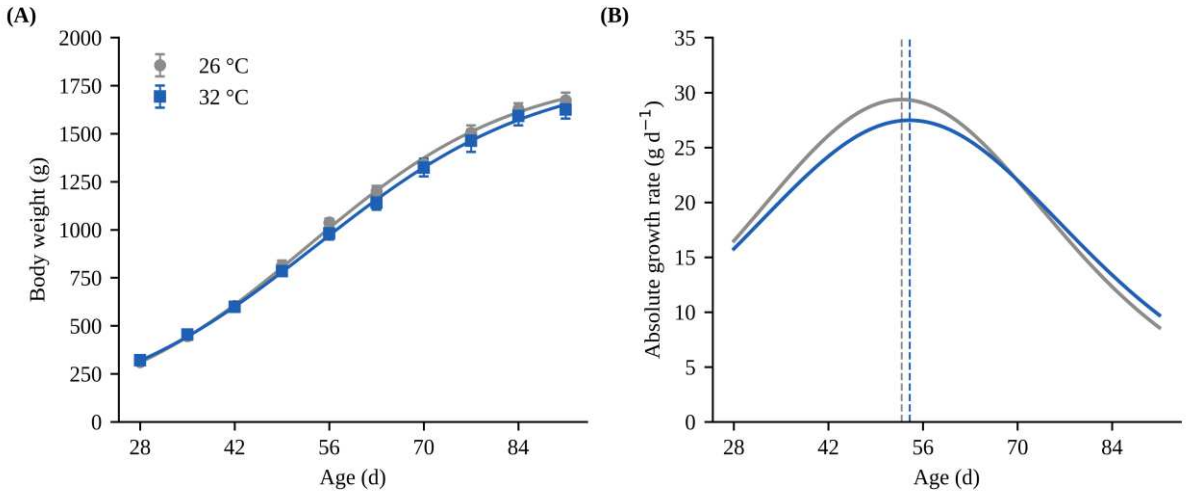


Fig. 1. Growth of guinea fowl reared at 26 °C (grey) or 32 °C (blue) from 28 to 91 days of age. (A) Body weight: symbols are box means ± SE (n = 4 boxes of 12 birds) and lines are logistic fits. (B) Absolute growth rate derived from the logistic model; dashed lines mark the age at inflection. The two curves nearly overlap, showing that chronic heat did not change the growth trajectory.

3.3. Flock uniformity

Within-box CV of body weight fell with age at both temperatures (Fig. 2). Mean CV (16.3 vs 18.4%; P = 0.54), final CV (12.9 vs 15.8%; P = 0.40) and the weekly decline in CV (−1.2 vs −1.4 percentage points; P = 0.72) did not differ between 26 and 32 °C. At 91 days, 56% and 50% of birds were within ±10% of the box mean (P = 0.61).

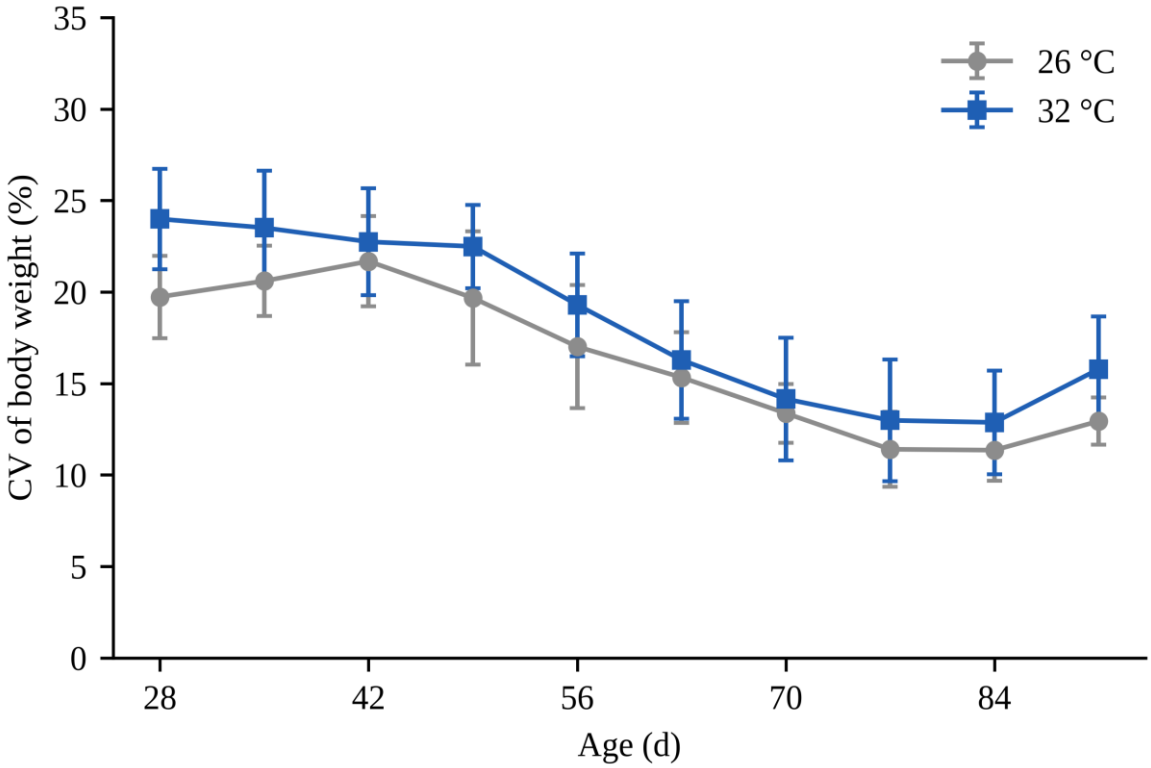


Fig. 2. Within-box coefficient of variation (CV) of body weight of guinea fowl reared at 26 °C (grey) or 32 °C (blue). Values are means ± SE of four boxes of 12 birds. Flocks became more uniform with age, and heat did not affect uniformity ($P \geq 0.27$).

3.4. Water-to-feed ratio

The water-to-feed ratio was 19% higher at 32 °C than at 26 °C over the whole period (2.29 vs 1.93 mL g^{-1}; $P = 0.021$; Fig. 3). The difference was largest at 35 days (3.09 vs 1.65 mL g^{-1}; Holm-adjusted $P = 0.027$). At 77 days, the difference (2.57 vs 2.00 mL g^{-1}) was significant before adjustment ($P = 0.020$) but not after ($P = 0.16$). It was greater from 28 to 49 days (+28%; $P = 0.043$) than from 56 to 91 days (+11%; $P = 0.025$).

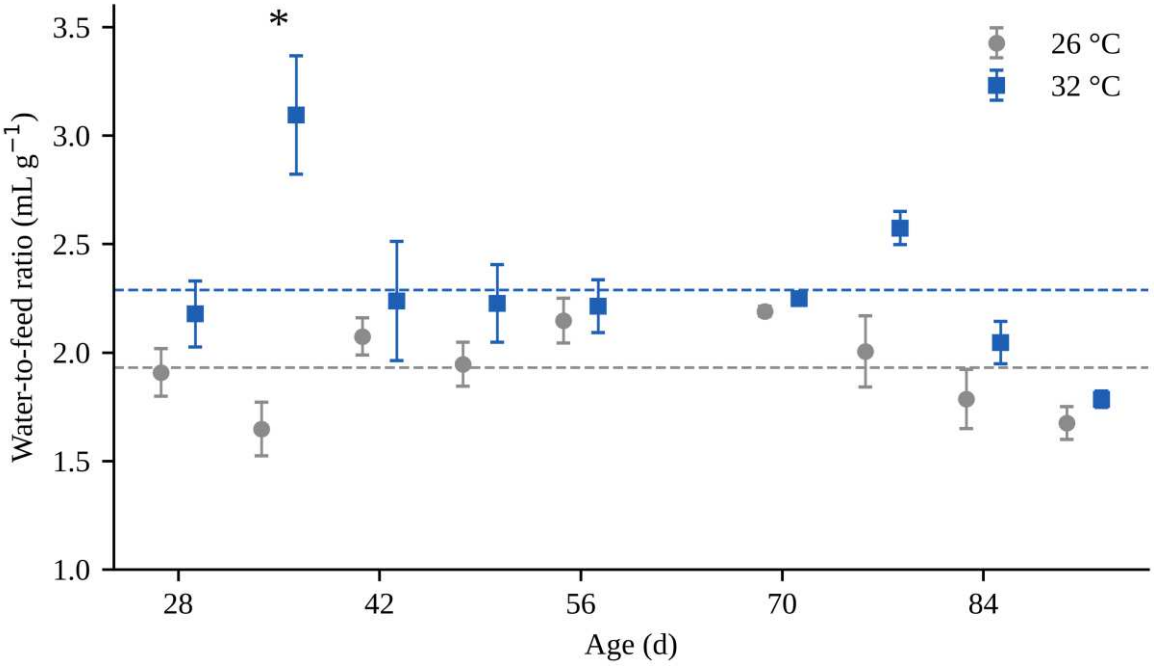


Fig. 3. Weekly water-to-feed ratio of guinea fowl reared at 26 °C (grey) or 32 °C (blue) (mean ± SE, n = 4 boxes). Dashed lines show the mean over the whole period. Data for 63 days were excluded (duplicated record). * Holm-adjusted $P < 0.05$ between temperatures at the same age. Heat raised water use per gram of feed, most strongly at 35 days.

3.5. Body weight and thermoregulatory responses

Within the same age, heavier birds at 32 °C had warmer body surfaces (+0.16 °C per 100 g; $P = 0.011$), mainly on the back and wing (Table 3). At 26 °C, heavier birds had lower respiratory rates (−1.6 breaths min^{-1} per 100 g; $P = 0.001$). No slope differed significantly between temperatures at box level ($P \geq 0.12$).

Table 3. Within-age slopes of respiratory rate and surface temperatures on body weight (per 100 g) in guinea fowl reared at 26 or 32 °C, from 28 to 70 days of age (n = 220 records).

Variable	Slope, 26 °C	P	Slope, 32 °C	P	P (26 vs 32 °C)
Respiratory rate (breaths min^{-1})	−1.60	0.001	−0.42	0.19	0.18

Variable	Slope, 26 °C	P	Slope, 32 °C	P	P (26 vs 32 °C)
Mean surface temperature (°C)	+0.07	0.63	+0.16	0.011	0.47
Wing temperature (°C)	+0.01	0.96	+0.23	0.025	0.12
Shank temperature (°C)	+0.45	0.001	+0.28	0.038	0.86
Head temperature (°C)	+0.10	0.48	+0.09	0.40	0.27
Back temperature (°C)	+0.06	0.78	+0.17	0.037	0.43

Slopes were estimated on deviations from box-week means, which removes the effect of age. The last column compares box-level slopes between temperatures (t test, n = 4 boxes).

3.6. Economic slaughter age

Feed intake rose linearly with age (26 °C: FI = 30.0 + 1.06 × age, $r^2 = 0.79$; 32 °C: FI = 33.5 + 0.89 × age, $r^2 = 0.83$). Marginal feed conversion rose steeply after 70 days and reached 14.7 (26 °C) and 11.8 g g^{-1} (32 °C) at 91 days. The economic slaughter age ranged from 65 to 88 days across price ratios of 4 to 10 (Table 4). It was 2–3 days later at 32 °C, but the difference was not significant.

Table 4. Economic slaughter age and live weight at that age for guinea fowl reared at 26 or 32 °C, at four live-weight/feed price ratios (mean ± SE, n = 4 boxes).

Price ratio (Pw/Pf)	Age, 26 °C (d)	Age, 32 °C (d)	P	Live weight (g)
4	65.3 ± 0.8	67.0 ± 1.3	0.30	1260
6	75.0 ± 1.1	77.5 ± 1.5	0.22	1473
8	80.6 ± 1.3	83.6 ± 1.8	0.23	1565
10	84.5 ± 1.5	87.9 ± 2.0	0.24	1617

The economic slaughter age is the age at which marginal feed conversion equals the price ratio; it considers feed cost only. Live weight is the mean of both temperatures, which did not differ.

4. Discussion

4.1. Growth model

The logistic model fitted best in all eight boxes, whereas the Gompertz model described pearl gray and French guinea fowl best in earlier studies (Nahashon et al., 2006a, 2006b). The difference is likely due to the age range. Those studies modelled growth from hatch, where the models differ most and where the logistic model overestimated hatching weight (Nahashon et al., 2006b). Our data started at 28 days and covered the middle and late phases, where the symmetric logistic curve fits well. Aggrey (2002) likewise found that the best function depends on the data set and the age range covered. Our estimates fall between those of the two strains. Asymptotic weight was 1.83 kg, against 1.57 kg (logistic, pearl gray) and about 2.0 kg (Gompertz, French). Maximum growth occurred at 53–54 days, against 57 days for the logistic fit of pearl gray birds (Nahashon et al., 2006a). These parameters can serve as reference values for guinea fowl reared in confinement in hot regions, within the age range studied.

4.2. Growth under chronic heat

We expected chronic heat to slow maturation and delay the age of maximum growth, but the data did not support this hypothesis. All parameters were similar at 26 and 32 °C, and the 95% confidence intervals rule out large effects: asymptotic weight within ±12% and inflection within −3 to +5 days. In heat-stressed broilers, growth losses come mainly from reduced feed intake (Lara and Rostagno, 2013), and their size depends on the strain (Roushdy et al., 2018). In our birds, feed intake did not differ between temperatures (Marques et al., 2023). It rose slightly more slowly with age at 32 °C (0.89 vs 1.06 g d^{-1} per day of age), but this did not alter the curve.

The guinea fowl kept growing at 32 °C because its thermoregulatory responses removed the extra heat. At 32 °C, birds shifted from sensible to evaporative heat loss, raised their respiratory rate and lost part of their feathers (Marques et al., 2023), which reduces plumage insulation and eases heat transfer from the skin (Wolf and Walsberg, 2000). These responses kept cloacal temperature within a narrow range (41.1 vs 41.6 °C) without diverting enough energy to reduce growth. Such homeostasis depends on the combined effect of air temperature, humidity and air velocity (Tao and Xin, 2003), which were controlled in this study. The heat tolerance shown earlier by final weight and carcass yield therefore also holds for the whole growth trajectory. This agrees with the view that slow-growing, locally adapted genotypes cope better with hot climates than fast-growing ones (Settar et al., 1999; Renaudeau et al., 2012).

4.3. Water as the cost of heat

The clearest effect of heat was on water use. The water-to-feed ratio was 19% higher at 32 °C, whereas total water intake had risen only 5.6% (Marques et al., 2023). Expressing water per gram of feed removes the effect of body size and feed intake, so the ratio isolates the thermoregulatory demand. This agrees with the link between water intake and evaporative cooling in broilers (Belay and Teeter, 1993). Panting and gular flutter dissipate heat by respiratory evaporation (Hutchinson, 1954; Sverdlova et al., 2012), and the water lost this way must be replaced by drinking.

The timing also matches heat exchange. The gap peaked at 35 days, in the phase when evaporative heat loss at 32 °C was highest: 66.6 W m^{-2} at 4–6 weeks of age, against 49.5 W m^{-2} at 11–13 weeks (Marques et al., 2023, based on the models of McArthur, 1987, and Turnpenny et al., 2000, with body surface estimated after Mitchell, 1930). Total heat loss per unit of body surface was also highest at this age (122.8 W m^{-2}; Marques et al., 2023), so the

thermoregulatory demand for water peaked early in rearing. For producers, the ratio offers a cheap way to detect heat load from water meters and feed records already kept on farms. It also shows that water supply in hot regions must be sized for the extra demand in the first weeks of confinement. Water quality also deserves attention, as water salinity has been studied as a factor in the performance of alternative poultry (Arruda et al., 2021).

4.4. Body size and thermoregulation

At 32 °C, heavier birds of the same age had warmer surfaces, mainly on the back and wing; this was not seen at 26 °C. At 26 °C, heavier birds breathed more slowly. A possible explanation is that larger birds lose heat passively with ease at thermoneutrality, whereas at 32 °C they must raise surface temperature to keep a gradient with the air. Changes in skin temperature are a main way by which chickens regulate sensible heat loss (Richards, 1971). Slopes did not differ significantly between temperatures at box level, so this remains a hypothesis to be tested in a study designed for it.

4.5. Flock uniformity

Within-box CV fell from about 22% to 13% between 28 and 84 days in both environments, and heat did not increase the spread of weights. This matters in practice, because uneven flocks complicate feeding and slaughter planning. It also adds evidence that 32 °C was within the range the species tolerates.

4.6. Economic slaughter age

Feed spent per gram of gain rose steeply after about 70 days, as expected once birds pass the inflection point and growth slows (Santos et al., 2005). Marginal feed conversion reached 14.7 (26 °C) and 11.8 g g^{-1} (32 °C) at 91 days, against a cumulative value of about 5

for the whole period (Marques et al., 2023). For price ratios of 4 to 10, the economic slaughter age was 65–88 days. This supports the earlier suggestion to slaughter at the start of the final phase (Marques et al., 2023) and gives it a number linked to market prices. At 32 °C the optimum was 2–3 days later, a non-significant shift consistent with the slightly lower slope of feed intake. The criterion covers feed cost only. Labour, housing and the market's preferred carcass size would move the optimum, and producers can apply the same method with their own costs.

5. Conclusions

The logistic model best describes the growth of guinea fowl from 28 to 91 days of age, with an asymptotic weight of about 1.83 kg and maximum growth (about 28 g d^{-1}) at 53–54 days. Chronic exposure to 32 °C did not change the growth trajectory or flock uniformity, which confirms the heat tolerance of the species at the level of the whole growth curve. The cost of heat appeared in water use: birds at 32 °C drank 19% more water per gram of feed, most of all in the fourth and fifth weeks of life. The water-to-feed ratio is a simple, low-cost indicator of heat load on guinea fowl farms, and water supply should be planned for this extra demand. For live-weight/feed price ratios of 4 to 10, slaughter at 65–88 days is more economical than rearing to 13 weeks in both thermal environments.

Author Contributions

Patrício Gomes Leite: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft and Writing – review & editing; **Jordânio Inácio Marques:** Data curation, Formal analysis, Methodology, Software, Supervision, Validation, Writing – original draft and Writing – review & editing; **Dermeval**

Araújo Furtado: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – original draft and Writing – review & editing; **Airton Gonçalves de Oliveira:** Conceptualization, Data curation, Investigation, Visualization, Writing – original draft and Writing – review & editing; **Washington da Silva Sousa:** Investigation, Methodology, Visualization, Writing – original draft and Writing – review & editing; **Marcos Vinícius da Silva:** Formal analysis, Software, Supervision, Validation, Visualization, Writing – original draft and Writing – review & editing.

Statement of Animal Rights

All procedures were approved by the Research Ethics Committee of the Federal University of Campina Grande (protocol CEP nº 020/2019).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Claude (Anthropic) to support data analysis and language editing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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