

Morphometric alterations in juvenile female black iguana (*Ctenosaura pectinata*) due to protein and energy intake variation

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Abstract

As an ectothermic animal, black iguana (*Ctenosaura pectinata*) eats diverse foods and its growth is not constant; therefore, its weight gain and longitudinal growth are low. In this research, the morphometric changes of the black iguana ambient temperature were studied. Different servings of crude protein and metabolizable energy were tested. A total of 30 juvenile females with an average weight of 124.4 ± 61.1 g were used. Each female was kept in an individual cage with a semi-automatic feeder and waterer. Diet consisted of a combination of crude protein (29.4 and 33.4 %) and three variants of metabolizable energy: 2.49, 2.55 and 2.7 Mcal/kg. The variables evaluated were live weight (mg), perimeter, diameter and body length (mm). The variables associated with feed consumption were: dry matter (mg), crude protein (CP) and metabolizable energy (ME). A randomized complete block design with a 2x3 factorial arrangement was used, where the blocking criterion was the weight of the iguanas. To observe the differences between treatments, the Tukey test was applied. There were differences ($P < 0.0500$) in the width of the head and the base diameter of the tail due to the effect of the energy factor. The treatments of 29.4 CP and 2.55 ME, and 33.4 CP and 2.55 ME led to greater ($P < 0.0500$) consumption of dry matter, protein and energy. Due to the type of feeding, an increase in some morphometric variables was also recorded. Juvenile females grew more with the nutritional combination of: 33.4 and 2.55 (CP-ME).

Keywords: Environment; Measurements; Nutrition; Reptiles; Thermoregulation.

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Additional information and declarations
can be found on page 13

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Study contribution

Metabolizable energy and crude protein consumption in juvenile black iguana females modifies some morphometric parameters. The purpose of this work was to analyze the morphometric changes of the black iguana, when they were fed different amounts of crude protein and metabolizable energy while kept at room temperature, in a warm subhumid climate. This study suggests that if an individual loses weight it is because energy reserves accumulated in the first third of their tail during the day, are used when they are at rest for growth or to maintain their metabolism. When these animals rest at room temperature they can consume their energy by exchanging heat with the environment. The results show that the accumulated and used energy levels are variable. Therefore, it is recommended to feed the black iguana with a ratio of 33.40 % CP and 2.55 Mcal of ME.

Introduction

In some places of Mexico, black iguana (*Ctenosaura pectinata*) is hunted for food.⁽¹⁾ It can be produced in captive breeding systems.⁽²⁾ However, to date, there is insufficient information on nutrition of the species to provide solid basis for the management of *C. pectinata* in captivity in its different stages of growth and development.^(3–10) Ecologically, it is important to know about both, the nutrition and management of these animals. This way, it is possible to gain understanding of the survival and productivity of each population, as well as to estimate the nutritional carrying capacity.^(1, 8–11)

In the wild, the black iguana consumes different foods according to its physiological stage and ontogeny. For example, as a hatchling, i.e. from birth to its first year, it eats mainly insects; in the juvenile stage, it feeds on plant tissues; and finally, as an adult, it will consume vegetables.⁽⁴⁾ Nevertheless, iguanas are considered to be omnivores so feeding depends mostly on food availability, whether they are under human care or in the wild.⁽⁵⁾ The above indicates that crude protein (CP) and metabolizable energy (ME) intake change with age: offspring consume foods high in CP and ME, and it decreases when they are adults.^(5, 6) Food consumption of adult iguanas in the wild should provide 14.50–25.50 % of CP, and 2.193–2.703 Mcal/kg of ME.^(1, 3, 4)

Studies have been carried out on hatchlings using food with a high crude protein content: 12.80 % and 50.1 %, thus, it is known that iguanas grow better when fed with a high crude protein content.^(4, 6–9) Lysine consumption was also evaluated. The analysis showed positive results in weight and length as well as in feed consumption: digestibility and feed conversion decreased,⁽¹⁰⁾ which indicates that the needs of protein and amino acids are higher than those of concentrates for chickens and rabbits.⁽⁷⁾ However, contradictory results have been recorded with respect to the growth of morphometric variables in *C. pectinata*,^(6, 12) they suggest that temperature plays an important role in the metabolism of ectotherms such as the iguana.⁽⁴⁾ It has been shown how temperature influences growth, since from 35.4 °C onwards the iguanas grew more than when the environmental temperature was lower.⁽⁸⁾

From 36 to 39 °C, food-degrading microorganisms of various animal species have efficient metabolic activity, which benefits both.⁽¹³⁾ For food-degrading micro-

organisms to have adequate activity, the body temperature should be similar to that of other species⁽¹³⁾ or even higher, 30 °C during activity.⁽¹⁴⁾ Under human care, *C. pectinata* has a more adequate growth between 35–40 °C.^(8, 14) At an ambient temperature of 28 °C, the rectal temperature of the iguanas is 28.7 °C, that is, the rectal temperature is slightly higher than the ambient temperature.⁽¹⁵⁾ At this temperature (28 °C), the metabolic processes of the iguanas are inefficient, therefore, iguanas require sunbathing.

So different concentrations of CP and ME in the food of *Ctenosaura pectinata* are not sufficient to maintain continuous growth because the average ambient temperature range of the subhumid tropics is 28–30 °C and the metabolic process of the iguana at that temperature is less efficient, which mean intermittent weight loss or gains during the study period. The objective of this research was to consider whether the morphometry of juvenile females of black iguana (*Ctenosaura pectinata*) was modified in the subhumid tropics of the coastal region, when fed with different concentrations of CP and ME.

Materials and methods

Ethical statement

The present work was approved by the Graduate Center and did not require the approval of the Institutional Committee of the Universidad del Mar. The practices carried out on the iguanas during the study such as feeding, weighing the animals and, their handling are routine actions. The facilities of the Centro de Conservación y Reproducción de Iguanas of the Universidad del Mar have a permit with code: INE/CITES/DGVS-CR-IN-0668-OAX./00 and Environmental Registration Number: CCRSY2006711.

Study site

The study was carried out at the facilities of the Iguana Conservation and Reproduction Center of the Universidad del Mar (CECOREI-UMAR), located at kilometer 128.1 on Federal Highway 200, Pinotepa Nacional-Puerto Escondido. This place is located at 15° 55' 23.1" N y 97° 09' 05" W, with an elevation of 12 meters above sea level,⁽¹⁶⁾ with climate A(w), which corresponds to warm subhumid with rains in summer. Rainfall there varies from 731.90 to 2 054 mm, with an annual temperature range between 28 and 30 °C.⁽¹⁷⁾

Subjects

Thirty two-and-a-half-year-old juvenile females *Ctenosaura pectinata* were included in the study. In order to carry out a selection of individuals that would enter the reproductive stage, it was necessary to record their behavior during growth and storage of energy reserves. The females were kept in conditions of captivity, with an average live weight of 124.35 ± 61.14 g, and an average snout-vent length of 16.29 ± 2.10 cm. No mutilations or injuries were visible and the animals appeared to be in good health.

Cages and duration of the experiment

Individual cages of 45×45×45 cm were used, lined with sieve cloth with a 0.5 cm mesh opening. The roof of the cages was mixed, divided into two sections: one provided shade and the other allowed the passage of solar radiation.⁽⁹⁾ Inside the cages, semi-automatic PVC pipes, 13.97 cm wide and 20 cm long waterers and feeders were installed.⁽¹²⁾ Plastic mats were used on the floor of the cage to prevent food loss and to ensure that the iguanas were not injured. The experiment consisted of two stages: 1) 15-day period of cage and diet adaptation,⁽¹⁰⁾ 2) Due to environmental issues, an 87-day data collection period.

Feeding and environment

The iguanas were kept in individual cages, outdoors under environmental conditions pertaining to the area of research. During the day, the females could sun themselves or be in the shade *ad libitum*, thus increasing or decreasing their body temperature according to their needs. At night and on cloudy days, they were subject to the variation in ambient temperature. They were provided with food and water every day at 8:00 h. Each individual was fed according to the treatment assigned to it. A thorough cleaning and disinfection of cages, feeders and drinkers was carried out every seven days.

Treatments

Six diets were selected based on previous studies (Table 1).^(1, 3, 5–7) Two concentrations of CP (29.4 and 33.4 %) were combined with three concentrations of ME (2.49, 2.55 and 2.70 Mcal/kg of food). Raising iguanas with concentrate feeds of corn, soy, wheat bran or alfalfa hay has given positive results.^(7–11) The diets were formulated with the “Solver” supplement from the Exel® package.⁽¹⁸⁾ The values of CP were obtained through the methodology of the Association of Official Analytical Chemists,⁽¹⁹⁾ the gross energy (GE) was obtained using the bomb calorimeter (Parr 6100 CALORIMETER), the metabolizable energy (ME) was calculated using the formula:

$$ME = \frac{(\% ME \times GE)}{100}$$

and the percentage of diet metabolized (% ME), was obtained with the equation: $ME (\%) = -13.199 + 1.055 (\% \text{ digestibility})$.⁽¹³⁾

Variables evaluated

The change in weight of the iguanas (final weight–initial weight) was determined with a grain scale (Noval, model MB-2610 with an approximation of 0.1 g); in addition, with the support of food analyses, daily dry matter intake, CP (mg/animal/day) and ME intake (cal/animal) were evaluated. A digital vernier (CALIPER 0–150 mm ± 0.10 mm) and a tape measure (DAVEY brand ± 0.10 mm) were used to take measurements (µm/animal/day) of the snout-vent length (from the tip of the mouth to the cloaca), total length (from the tip of the mouth to the tip of the tail), leg length, pelvis length, head length and head width, as well as

Table 1. Composition of the diet with different levels of CP and ME in juvenile females of *Ctenosaura pectinata* raised under ambient temperature

| Diet (PC–EM) | Inclusion of raw materials in the diet (%) | | | | | |
|-----------------|--|-------|---------|------------|-------------|------|
| | Soybean meal | Corn | Sorghum | Wheat bran | Alfalfa hay | Oil |
| 29.4–2.49 | 56.45 | 5.00 | 18.13 | 15.00 | 0.00 | 0.00 |
| 29.4–2.55 | 59.01 | 23.70 | 5.00 | 6.74 | 0.00 | 0.00 |
| 29.4–2.70 | 61.07 | 14.03 | 5.00 | 7.00 | 0.00 | 7.37 |
| 33.4–2.49 | 61.79 | 0.50 | 0.50 | 17.67 | 15.00 | 0.12 |
| 33.4–2.55 | 69.57 | 14.37 | 5.00 | 5.88 | 0.00 | 0.00 |
| 33.4–2.70 | 72.57 | 13.44 | 2.00 | 1.00 | 0.00 | 5.72 |

100 % of the diets were supplemented with phosphorus, calcium, methionine, lysine and vitamins according to the formula.
CP (Crude Protein) = (%)
ME (Metabolizable Energy) = (Mcal/kg)

the perimeter of the thorax and abdomen, and the diameter of the base of the tail, hip and leg.^(10, 12, 20)

We also calculated the average body condition (BC) of black iguana females with the formula:

$$BC = \frac{\text{weight of the iguanas (g)}}{\text{volume of the iguanas (mL)}}$$

we calculated the latter by displacement of water in a graduated PVC tube.⁽²¹⁾ We calculated the energy and protein balance point according to food consumption, weight gain and loss. Using a digital thermometer-hygrometer (model HTC-1) placed in the middle of the cage, we took readings of ambient temperature and relative humidity every hour, every day, day and night, for a month.

Experimental model

We used a completely randomized block design with a 2×3 factorial arrangement, where one factor was the CP level and the other was the ME level. We repeated each treatment five times. The blocking criterion was given by the live weight of the iguanas. Subsequently, we used the Tukey test to observe differences between treatments. The covariate was the initial weight of the iguanas when it was suspected that they affected the results, thus reducing the experimental error. To obtain the amount of CP and ME that iguanas must consume in order not to lose or gain weight and to know the percentage of variability in weight gain or loss to explain consumption, we analyzed the linear regression between the change in live weight and the consumption of CP and EM through the SAS procedure.⁽²²⁾ It was not of our interest to obtain a prediction equation that would explain weight gain as a function of consumption.

Results

There is no interaction ($P > 0.0500$) ME×CP, or effect of CP and ME levels on the response variables (Table 2), except in two variables due to the effect of ME: 1) the width of the head was greater ($P = 0.0235$, $F = 2.67$) at 2.7 Mcal in relation to the

Table 2. Probability of ME, CP and ME×CP in diets with different levels of CP and ME in juvenile *Ctenosaura pectinata* females raised at ambient temperature.

| Variables | Factors | | | |
|----------------------------------|---------|--------|--------|----------------|
| | ME | CP | ME×CP | F ¹ |
| Dry matter consumption | 0.2710 | 0.6774 | 0.3115 | 1.08 |
| Protein consumption | 0.2161 | 0.6665 | 0.2247 | 1.03 |
| Metabolizable energy consumption | 0.2089 | 0.6238 | 0.2902 | 1.24 |
| Weight | 0.3202 | 0.4730 | 0.2547 | 1.16 |
| Head length | 0.0687 | 0.9110 | 0.0798 | 2.33 |
| Head width | 0.0235 | 0.9415 | 0.1254 | 2.67 |
| Cloaca-snout length | 0.4527 | 0.5715 | 0.0716 | 1.57 |
| Total length | 0.8044 | 0.9800 | 0.0577 | 1.38 |
| Chest perimeter | 0.4873 | 0.9229 | 0.4719 | 0.61 |
| Abdominal perimeter | 0.2675 | 0.5534 | 0.7271 | 0.76 |
| Tail base diameter | 0.0474 | 0.2934 | 0.1720 | 2.38 |
| Hip diameter | 0.8614 | 0.7720 | 0.3074 | 0.57 |
| Leg diameter | 0.3545 | 0.3407 | 0.3239 | 1.09 |
| Leg length | 0.0860 | 0.5693 | 0.4666 | 1.47 |
| Pelvic length | 0.1383 | 0.8795 | 0.6399 | 1.05 |
| Body condition | 0.4249 | 0.8961 | 0.4929 | 0.65 |

¹ Calculated F values.

CP (Crude Protein) = (%)

ME (Metabolizable Energy) = (Mcal/kg)

levels 2.49 and 2.55 Mcal, with values of 12.84, 6.09 and 6.61 µm /animal/day respectively, and 2) the diameter of the base of the tail was greater ($P = 0.0474$, $F = 2.38$) with 2.55 and 2.70 energy in relation to level 2.49, with values of 12.02, 11.09 and -3.31 µm/animal/day.

There were differences ($P < 0.0500$) in the variables related to the daily consumption of DM, PC and EM. The best protein-energy combinations were 29.4–2.55 and 33.4–2.55, providing 27.11 % CP and 3120.7 cal/g of feed consumed. However, the body condition was similar ($P > 0.0500$) with an average value of 0.841 g/mL (Table 3).

The external characteristics of the black iguana were similar ($P > 0.0500$) in terms of weight, thorax and abdomen perimeter, hip and leg diameter, as well as leg and pelvis length. This demonstrates high variability in growth with both negative and positive values. The combined treatment 29.4–2.55 (CP and ME) provided greater gain ($P < 0.0500$) in snout-vent lengths and total length although the combination of 33.4–2.55 (CP and ME) also showed greater ($P < 0.0500$) gain in head length and width: 3.6 and 3.3 times respectively in relation to other combinations. The 33.4–2.70 diet was similar ($P > 0.0500$) to the 33.4:2.55 diet (CP and ME), referred to head width. The base diameter of the tail was smaller ($P < 0.0500$) and negative in the CP-ME combination of 29.4–2.49 in relation to the average of the treatments 33.4–2.49 and 33.4–2.55 with a value of 16.4 (µm/animal/ day) (Tables 4 and 5).

The temperature of the study area was 27.8 ± 3.5 °C (with a minimum value of 23.3 °C and maximum of 33.5 °C) and 61.1 ± 3.8 % relative humidity (with a minimum value of 52 % and maximum 64 %), respectively. (Figure 1).

Table 3. Growth in juvenile *Ctenosaura pectinata* females fed with different amounts of CP and ME, and raised at room temperature

| Diet (CP–ME) | Daily consumption | | | Body condition (g/mL) |
|------------------|----------------------|----------------------|-----------------------|-----------------------|
| | MS (mg) | CP (mg) | ME (lime) | |
| 29.4–2.49 | 782.2 ^{ab} | 226.3 ^b | 2 480.8 ^{ab} | 0.853 |
| 29.4–2.55 | 1 086.3 ^a | 319.96 ^a | 3 347.9 ^a | 0.856 |
| 29.4–2.70 | 546.4 ^b | 162.52 ^b | 1 730.5 ^b | 0.813 |
| 33.4–2.49 | 723.9 ^{ab} | 234.96 ^{ab} | 2 227.1 ^{ab} | 0.840 |
| 33.4–2.55 | 1 035.9 ^a | 255.53 ^a | 3 274.9 ^a | 0.853 |
| 33.4–2.70 | 756.6 ^{ab} | 253.7 ^{ab} | 2 421.7 ^{ab} | 0.830 |
| Average | 821.86 | 258.83 | 2 580.5 | 0.841 |
| Probability | <0.0500 | <0.0500 | <0.0500 | 0.492 |
| EEM ¹ | 80.58 | 25.24 | 346 | 0.008 |

¹SEM: Standard error of the mean. (n = 30).^{a,b}: Subscripts in the same column indicate statistical difference (P < 0.0500).

CP (Crude Protein) = (%)

ME (Metabolizable Energy) = (Mcal/kg)

Table 4. Morphometry of juvenile females of *Ctenosaura pectinata* fed with different amounts of CP and ME, and maintained in intensive production

| Diet (CP–ME) | Weight (mg/ animal/day) | Loss or gain (µm/animal/day) | | | | |
|------------------|-------------------------|------------------------------|-------------------|-------------------|---------------------|------------------|
| | | Head length | Head width | Snout-vent length | Total length | Thorax perimeter |
| 29.4–2.49 | -191 | 3.6 ^b | 4.2 ^b | 0.0 ^b | -37.9 ^{ab} | -1.6 |
| 29.4–2.55 | 132.2 | 18.9 ^{ab} | 8.0 ^{ab} | 8.5 ^a | 20.3 ^a | 1.8 |
| 29.4–2.70 | 86.2 | 15.1 ^{ab} | 9.6 ^{ab} | 3.2 ^{ab} | 15.9 ^{ab} | 1.6 |
| 33.4–2.49 | 61.1 | 13.3 ^b | 3.6 ^b | 0.0 ^b | -54.3 ^b | 5.5 |
| 33.4–2.55 | 202.3 | 30.8 ^a | 11.5 ^a | 5.5 ^{ab} | -7.6 ^{ab} | 11.5 |
| 33.4–2.70 | 130.6 | 18.8 ^{ab} | 14.2 ^a | 3.9 ^{ab} | 2.8 ^{ab} | 2.8 |
| Average | 70.2 | 16.7 | 8.5 | 3.5 | -10.1 | 3.6 |
| Probability | 0.3056 | <0.0500 | <0.0500 | <0.0500 | <0.0500 | 0.6542 |
| SEM ¹ | 52.5 | 2.6 | 1.2 | 1.1 | 10.8 | 2.3 |

¹SEM: Standard error of the mean. (n = 30).^{a,b}: Subscripts in the same column indicate statistical difference (P < 0.0500).

CP (Crude Protein) = (%)

ME (Metabolizable Energy) = (Mcal/kg)

Table 5. Changes in the morphometry of juvenile females of *C. pectinata* fed with different amounts of CP and ME in intensive production at room temperature

| Diet (CP–ME) | Loss or gain (µm/animal/day) | | | | | |
|------------------|------------------------------|---------------------|--------------|--------------|------------|---------------|
| | Abdomen perimeter | Tail base diameter | Hip diameter | Leg diameter | Leg length | Pelvis length |
| 29.4–2.49 | -1.61 | -10.92 ^b | -8.41 | -242.1 | 1.61 | -11.4 |
| 29.4–2.55 | 1.38 | 4.3 ^{ab} | 5.2 | 2.7 | 17.26 | -1.22 |
| 29.4–2.70 | -5.98 | 6.69 ^{ab} | 4.97 | 5.7 | 24.76 | 2.34 |
| 33.4–2.49 | 0.69 | 17.35 ^a | 3.33 | -8.7 | 31.31 | 0.16 |
| 33.4–2.55 | 6.9 | 15.44 ^a | 11.4 | 6.6 | 28.33 | 24.02 |
| 33.4–2.70 | 5.06 | 6.74 ^{ab} | -8.14 | 3.2 | 27.63 | 11.56 |
| Average | 1.07 | 6.6 | 1.39 | -38.77 | 20.13 | 4.25 |
| Probability | 0.6441 | <0.0500 | 0.6666 | 0.4007 | 0.3002 | 0.3926 |
| SEM ¹ | 2.27 | 32.96 | 4.14 | 39.24 | 3.49 | 4.87 |

¹SEM: Standard error of the mean. (n = 30).^{a,b}: Subscripts in the same column indicate statistical difference (P < 0.0500).

CP (Crude Protein) = (%)

ME (Metabolizable Energy) = (Mcal/kg)

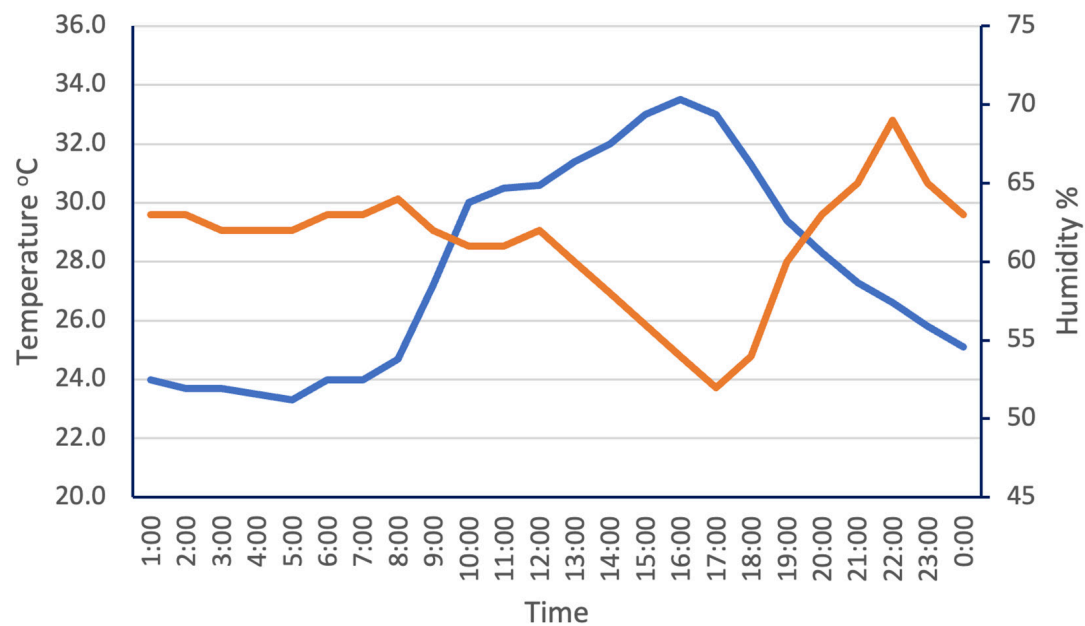


Figure 1. Average daily variation of temperature (blue line) and relative humidity (orange line) in subhumid tropical climate.

Two prediction equations were obtained for weight gain as a function of energy consumption ($P = 0.0826$, $F = 3.24$) and crude protein ($P = 0.0566$, $F = 3.96$). Each of them explains the reason for 10 and 12 % of weight gain or loss respectively. Since the regressions are not significant, it means that they are not suitable for making predictions. However, they indicate the energy and protein balance points. When the iguanas ingest 1 533.65 cal of ME or 162.84 mg of CP per day, they do not lose or gain weight. The higher the food consumption, the more excess energy or protein to be stored and used to grow or gain weight; while on the other hand, lower consumption will cause the iguanas to stop growing or gaining weight (Figure 2).

Discussion

The metabolizable energy level of the diet with 2.7 Mcal/kg of food stimulates the iguanas to maintain continuous growth in head width, while at lower ME concentrations no growth and no loss of head diameter are recorded. Therefore, head width is suggested as an appropriate measure of continued growth. On the other hand, energy levels of 2.7 and 3.1 Mcal/kg are appropriate because they allow them to store energy in the form of fat at the base of the tail, as indicated by Cupul-Magaña et al.⁽²³⁾ and Martín,⁽²⁴⁾ which indicates that, with these energy levels, the nutritional needs for maintenance and growth are covered.

However, 2 Mcal/kg do not cover the maintenance needs of the iguanas, which results in fat loss when measuring the diameter of the tail base. The metabolizable energy required in juvenile female iguanas agrees with the ME requirement of adult iguanas, since the latter need less ME: 2.193–2.703 Mcal/kg of food,^(1, 3)

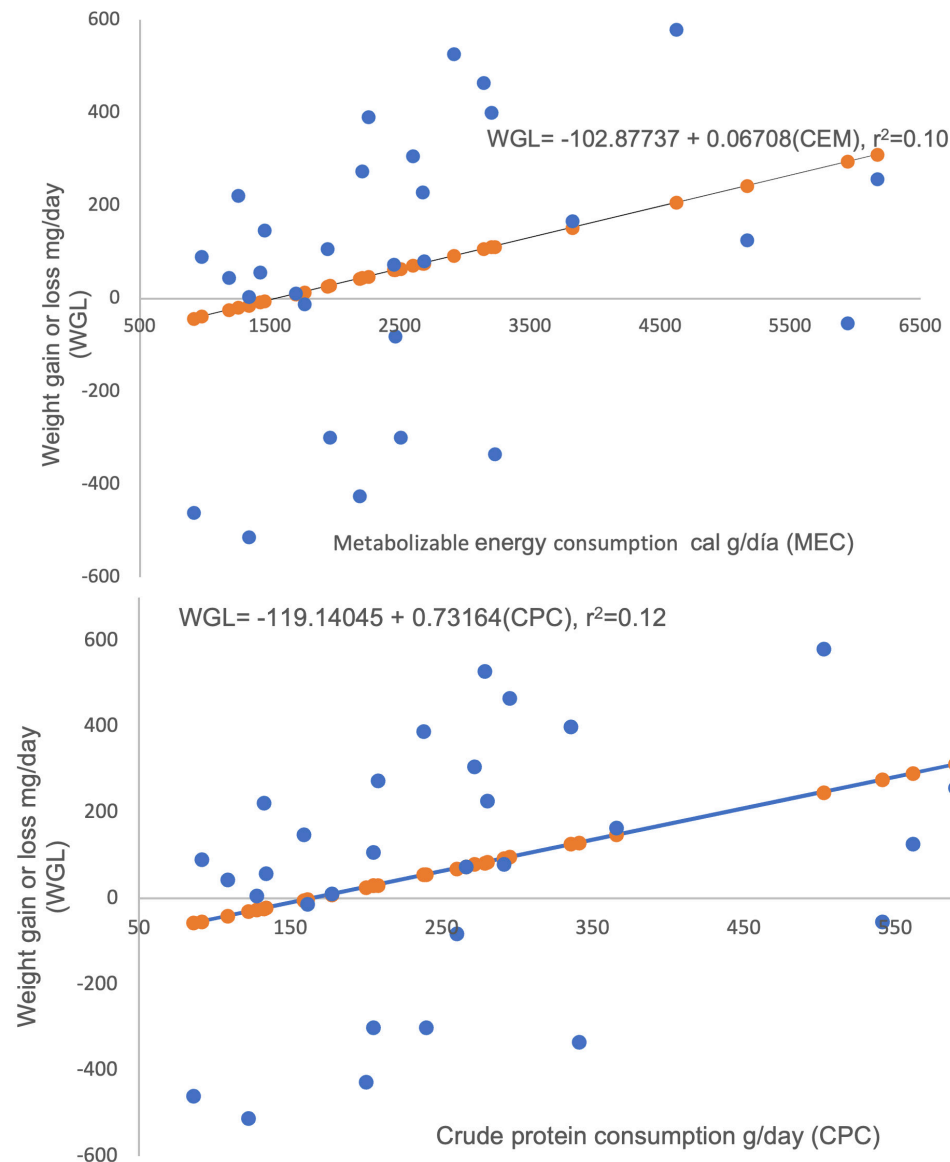


Figure 2. Weight change of *Ctenosaura pectinata* in relation to metabolizable energy consumption and crude protein consumption, when raised at ambient temperature.

because they no longer grow. To achieve an adequate level of growth in iguanas, ME is not enough; protein and physical activity are also required.

Proteins are essential constituents involved in growth performance, muscle quality, and animal health.⁽²⁵⁾ However, muscle and bone development during growth are influenced by gravity and physical activity, since inactivity or immobilization results in reduced muscle development and weakening of bones.⁽²⁶⁾ For iguanas to have physical activity and bone strength in addition to consuming energy and protein, it is necessary that the environmental temperature is adequate so that they can carry out their daily activities.⁽¹³⁾

The different diet protein levels affected the variables evaluated; therefore, the relationship between ME and CP contained in a food is important, since it determines the amount growth of the individual.⁽²⁷⁾ This relationship must be adjusted according to factors such as sex, age and environmental conditions.⁽²⁸⁾ Protein

consumption in adult iguanas is 20 % of their daily intake.^(1, 3) In the juveniles of the present experiment it was 27.1 % and, in several months of age individuals, it was higher. Apparently they prefer to consume insects.⁽⁴⁾ Therefore, the smaller the iguana, the more CP it requires. This requirement decreases as it approaches adulthood.⁽²⁹⁾ Despite this, little is known about the nutritional needs of the iguana under human care, both for adequate growth and good health.^(5–11, 30)

Nutrient consumption is related to body condition (BC). Unlike other species in which it has been evaluated in more detail, this condition has not been studied in depth in *C. pectinata*.⁽³¹⁾ Still there are records of BC in reproductive adult females,⁽²¹⁾ where four categories are mentioned: extremely thin, thin, excellent and excessively corpulent. In accordance with the above, the juvenile females evaluated in the present study show an extremely thin BC. This suggests that, for each physiological stage, an index must be calculated and a greater number of measurements than those currently recorded is required for an adequate assessment.

Morphometric characterization of individuals is important for the conservation of the species and to improve its growth. The change in the morphometric characteristics of an animal depends on genetic bases and environmental factors such as diet, health status, and climatological effects.^(20, 32) The management of the iguana under human care or in the wild implies that measurements of length may vary because the iguana frequently loses part of its tail as a survival mechanism due to poor handling or against predators.⁽⁵⁾

The morphometric changes of the iguana occur at different growth rates until reaching the size determined by genetics and nutrition. Thus, bone tissue takes second place in reaching its maximum growth rate.^(33–35) Therefore, it would be appropriate to use the width of the head as a measure of growth, since it will produce almost imperceptible changes, positive and never negative. In contrast, the storage of muscle and fat in the juvenile female over time can be positive or negative, and this results in an inadequate measurement over time.

Bone growth requires anabolic activity based on protein synthesis,⁽³⁶⁾ it is also influenced by vitamin D, which stimulates the absorption of calcium and phosphorus, and for which exposure to ultraviolet radiation is essential.^(37, 38) Bone is a dynamic tissue whose growth varies in response to internal (genetic, molecular, cellular, hormonal) and external (nutritional, pathological and physical activity) factors.⁽³³⁾ In the black iguana individuals of the present study, the head length and width, snout-vent length and leg length increased continuously; which means that the amount of solar radiation was adequate since there was no evidence of bone malformations.

The amount of fat accumulated in an organism is another factor that generates changes in morphometric measurements. Fat serves many functions; undoubtedly, the most important is to serve as a reserve store of energy so that the iguana can survive a possible period of food shortage.⁽³⁹⁾ In saurians, about 60 % of the energy obtained by consuming food is stored in the form of fat, mainly in the tail, in the mesenteric organs of the abdomen and along the back.^(23, 24) The perimeters of the thorax and abdomen have not been evaluated in the black iguana as in other species, where the objective has been to measure maximum growth.^(40, 41) This is possibly due to the fact that the iguana can increase the volume of the thorax and abdomen at will. In addition, it can reduce its accumulated fat.⁽⁴²⁾

In the iguana, greater emphasis has been placed on tail morphometry. The thickness decreases when the iguana uses the fat to grow in length⁽⁴²⁾ or to main-

tain body temperature. García-Alix et al.⁽⁴³⁾ indicate that the width and length of the head are determined by genetics, environment and anatomy, such as the thickness of the skin, tissue and bone. The genetic factors of the present study were adequately controlled, because the selection was carried out randomly. From an anatomical point of view, the bone structures do not grow at the same rate, which causes differential growth.⁽⁴⁴⁾ This indicates that during the juvenile stage, *C. pectinata* can take advantage of nutrients to increase the width and length of the head in preference over other bones.⁽⁶⁾

Growth of the head is a secondary sexual characteristic; in females it is smaller than in males. In addition, the head is hard because it serves as a defense mechanism against predators. Females are known to be less territorial than males and are unlikely to compete with other females for territory, food, or reproduction.⁽⁴⁵⁾

In general, the results analyzed in this study suggest that heat exchange between the surface area of the iguanas and the environment strongly influenced food consumption, weight gain and weight loss. This is based on the fact that the consumption of ME and CP explains on average 11 % of the variation in weight gain or loss. In addition, the management was similar throughout the experimental process. Animals satisfy their nutritional requirements through voluntary consumption, a factor that determines adequate growth.⁽⁴⁶⁾ Therefore, it is necessary to ascertain the factor that has such a high impact on the feeding of *C. pectinata*.

A key factor to consider was the environmental temperature.⁽⁸⁾ Therefore an experiment was carried out with the same environmental range as the present study, but always at a specific temperature. As a result, it was concluded that an environmental temperature greater than 34.5 °C induced a food intake of 0.51 % in relation to the live weight (LW) of the iguana; while in the present study it was 0.66 % of the LW. This indicates that at higher environmental temperatures, food consumption is altered positively or negatively, depending on the stress of the iguana.

However, while we were developing the experiment, Hurricane "Agatha" hit the region, which decreased the time and intensity of solar radiation. On sunny days, the iguanas basked in it intermittently, moved more, and consumed more food than on cloudy days, where the iguanas remained immobilized. The iguana decreases its activity, consumption and digestion when the environmental temperature is low, modifying its metabolism.^(47, 48) As an ectotherm individual, the protein and energy balance of the as well as the energy balance with the environment must be considered as well as the energy balance with the environment, since correct physiological development depends on them. Energy balance of the iguana is achieved when the energy consumed equals the energy released in the form of excrement and the heat released by radiation, convection or conduction.⁽⁴⁹⁾

When taking into account the balance point; if the energy released by the iguana into the environment is greater than the energy consumed, then it will cool down and use the metabolic energy for its vital maintenance processes (basal metabolism) and possibly lose fat and weight, similar to what occurred in the evaluated treatments with the exception of 33.4-2.55 (CP-ME). Consequently, the energy reserves must be used for metabolic maintenance functions to resist low environmental temperatures.⁽⁵⁰⁾ On the other hand, if the energy released into the environment is less than that consumed, the iguana will remain warm.

Therefore, once it reaches an energy balance thanks to an adequate CP-ME nutritional ratio (33.4-2.55), it can use the excess metabolizable energy to gain

muscle mass, and length, to reproduce and as a reserve in the form of fat. Now, for the iguana to have energy gain,⁽⁵¹⁾ it will have to be comfortable and it needs to maintain a body temperature between 35 and 40 °C.^(7, 50) Thus, to maintain body temperature in climates with wide temperature fluctuations (26 to 38 °C), the iguana will have to sunbathe for intermittent periods, as indicated by the behavior of the species.⁽⁴⁾

However, at night and on cloudy days, environmental temperature drops and it is not possible for this species to regulate its body temperature, which is why it uses a burrow,⁽⁵⁾ to provide itself with an appropriate nocturnal microclimate. The limited capacity of ectotherms to regulate their body temperature makes them especially vulnerable to environmental temperature changes,⁽⁵²⁾ which is why it is necessary to provide them with sufficient protein and energy in the food, to withstand such changes without losing weight.

Although iguanas have a broad thermal tolerance threshold which enables them to reach the optimal body temperature for their activity or function,⁽⁵³⁾ greater care must be taken in the critical thermal range, where they are affected by physiological stress with sublethal effects or even death.⁽⁵⁴⁾ In oscillating environments of heat and cold, the species has various adaptive strategies, both ethological (position and mobility) and physiological (hormonal, enzymatic and metabolic) to reduce the rate of heat exchange and acclimatize to certain temperature levels.⁽⁵²⁾ This is achieved through solar radiation, which is possibly the most important factor in the synchronization of the circadian clock, which gives way to different activities in animals, controlling processes such as gene expression, patterns of behavior and mainly the metabolism of food, since it is responsible for producing nutrients and energy for the physiological processes of iguanas.^(55, 56)

Conclusion

Under the environmental conditions in which the experiment was carried out, the juvenile female black iguana (*Ctenosaura pectinata*) requires a high amount of metabolizable energy of 2.7 Mcal/kg of food for optimal functioning. However, the combination of 33.4 % crude protein and 2.55 Mcal of ME/kg of food generates greater increase of the diameter of the base of the tail and the length and width of the head. The head width and length are two characteristics that help determine the growth of this species without reflecting negative changes. The juvenile iguana with a live weight between 55.5 and 355.6 g needs to consume 163 mg of crude protein and 1 534 cal of metabolizable energy daily to avoid losing or gaining weight in the subhumid tropics.

Data availability

The data set associated with this research is available in the SciELO Data repository.

Conflicts of interest

We declare that we have no conflict of interest.

Author contributions

Conceptualization, data management and data analysis: C. Sánchez, J Arcos.

Writing, review, editing and approval of the final version of the manuscript: C. Sánchez, R López, H. Santiago, J. Martínez, G Mendoza, J Arcos.

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