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GROWTH CURVE AND FEED EFFICIENCY OF *BOA CONSTRICTOR* SUBSPECIES KEPT IN CAPTIVITY

(*Curva de crescimento e eficiência alimentar de subspécies de Boa constrictor mantidas em cativeiro*)

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ABSTRACT - The growth curve is an important parameter for estimating the development of an animal and assisting breeding programs and assessing welfare. However, little data is available on the growth curves of snakes, including native species such as Boa constrictors. Therefore, the objective of the present study was to determine the growth curve of three subspecies of Boa constrictor juveniles (*B. constrictor constrictor* - Bcc, *B. constrictor amarali* - Bca and *B. constrictor occidentalis* - Bco) using data from a commercial breeder located in Brazil. Thirty-seven newborn snakes were placed in individual plastic boxes and kept in a temperature-controlled room (30±2°C and 70-80% humidity) until they reached commercial size (58 days). The snakes' weight and food intake were recorded weekly. These data were used to calculate total food intake, relative weight gain, feed efficiency and growth curves for snakes, comparing animals within subspecies and sexes. There was no difference in growth between genders for Bcc (p = 0.9844) and Bco (p = 0.9845), while for Bca females presented a greater growth (p = 0.0052). There were no statistical differences in relative weight gain and feed efficiency among subspecies. The parameters and growth curves determined in this study can be used as an initial reference guide to monitor the growth of Boa constrictor newborns and contribute to the establishment of an adequate food management for snakes kept in captivity, being a possible parameter for quantifying to determine welfare during the development of newborn snakes.

Key words: exotic pets wildlife; pet market; reptile; snake.

RESUMO - A curva de crescimento é um parâmetro importante para estimar o desenvolvimento de um animal e auxiliar em programas de reprodução e avaliação do bem-estar. No entanto, poucos dados estão disponíveis sobre as curvas de crescimento de serpentes, inclusive espécies nativas como as jiboias. Portanto, o objetivo do presente trabalho foi determinar a curva de crescimento de três subespécies de *Boa constrictor* juvenis (*B. constrictor constrictor* - Bcc, *B. constrictor amarali* - Bca e *B. constrictor occidentalis* - Bco) usando os dados de um criador comercial localizado no Brasil. Trinta e sete cobras recém-nascidas foram alocadas em caixas plásticas individuais e mantidas em uma sala com temperatura controlada (30±2°C e 70-80% umidade) até atingir o tamanho comercial (58 dias). O peso e a ingestão alimentar das cobras foram registrados semanalmente. Esses dados foram usados para calcular a ingestão total dos alimentos, o ganho de peso relativo, a eficiência alimentar e as curvas de crescimento das serpentes e comparados entre as subespécies e entre sexos. Não houve diferença no crescimento entre os sexos para Bcc (p=0,9844) e Bco (p=0,9845), enquanto para Bca as fêmeas apresentaram maior crescimento (p=0,0052). Não foi observada diferença estatística quanto ao ganho de peso relativo e a eficiência alimentar entre as subespécies. Os parâmetros e as curvas de crescimento determinados neste estudo

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podem ser usados como referência para acompanhamento do crescimento de filhotes de *Boa constrictor* e contribuir para o estabelecimento de um manejo alimentar adequado para serpentes mantidas em cativeiro, sendo um possível parâmetro para quantificação do bem-estar durante o desenvolvimento de serpentes recém-nascidas.

Palavras-chave - animais silvestres e exóticos; mercado pet; réptil; serpente.

INTRODUCTION

The exotic pet market is worth billions of dollars worldwide considering live animals, pet food and supplies and animal origin products (ABINPET, 2019). The pet reptile population in the United Kingdom was estimated over 700 thousand animals in 2019 (PFMA, 2020), while in the United States of America, it is estimated over 9 million animals in more than 4.5 million residences (AVMA, 2018).

The popularity of reptiles as pets began in the 90s driven by many factors: the easy maintenance, adaptability to different environments, the variety of species, forms, colors and the reduced requirement for physical space. Snakes are even more advantageous because their feeding schedules are sparse with extensive fasting periods. Additionally, they have a low demand for cleaning, physical activity and affection. These factors allow people with diverse and unstable routines to keep snakes as pets without compromising the animals' welfare. These attributes have increased the popularity of snakes as pets, for example, the pet snake population in the USA increased in 96% between 2007 and 2012, while other reptiles such as turtles and lizards only increased 15% and 4%, respectively (AVMA, 2009; AVMA, 2012).

Boas are snakes from the Boidae family being medium to large-sized, rarely reaching more than 5 meters long and 15 kg, not venomous, with aglypha dentition, crepuscular and nocturnal habits and very docile when frequently handled. Their color patterns are exuberant from yellowish to red with different grayscale backgrounds. Lateral and dorsal patches, called ocelli, are present from the neck to the tail making each animal unique and justifying the Boas high commercial value and popularity as pets. Because the species are illegally traded for meat, skin and pets, most Boas subspecies are listed in CITES as Appendix II (04/02/1977), being the Argentine boa (*Boa constrictor occidentalis*) listed in Appendix I (22/10/1987).

Many authors have been using growth curves to understand and predict the growth behavior of animals (Lee et al., 2020; Yunqing & Yaoyuan, 1992). This is important not only in a commercial perspective, but also to monitor wild populations. Although there is some literature determining the growth curves of reptiles with emphasis to snakes, no studies with Boas are available in the literature. Most studies in the Boidae family focus on diseases and reproductive biology.

Although Boas are widely reproduced in captivity around the world, growth performance traits are scarce in the literature. If we take into account that growth traits are an indication of adequate welfare of an animal, knowing the behavior of the growth curve and efficiency of using food resources in captivity can be a useful tool to maintain these snakes in good welfare accurately. Additionally, limited studies are available on Boas growth rate even in their natural habitat. Therefore, we gathered a dataset from a commercial breeder to assess the growth curve of juvenile Boas of three different subspecies kept in a controlled captive environment.

MATERIALS & METHODS

Data collection and animal care

Feeding and growth data of newborn Boa offspring were recorded every week. The subspecies used in the experiment were: *Boa constrictor constrictor* (Bcc), *Boa constrictor occidentalis* (Bco) and *Boa constrictor amarali* (Bca) available in the company stock. The newborns used in the experiment were derived from commercially bred snakes from Jiboias Brasil Ltda and data were acquired according to the routine protocols of the company.

Newborns were allocated into individual plastic cages (26.2 x 17.7 x 8.5 cm) in a thermostatically-controlled room (30±2°C and 70-80% humidity). Cleaning was performed once a week; however, the cages were checked daily and cleaned as needed. To facilitate the breeder routine, the first feeding was performed after all the animals from the batch had undergone the first ecdysis, what occurred in the 14th, 22nd and 16th day for Bcc, Bco and Bca, respectively. Feeding was performed in a specific day of the week, therefore, first feeding occurred in the 16th, 25th and 18th day after birth for Bcc, Bco and Bca, respectively.

Mice (*Mus musculus*) newborns were weighed and offered as the only food source in a weekly basis. To determine the size of the prey, before every feeding, relative prey mass (RPM) was determined for each animal dividing the prey weight by the snake weight and expressed in percentage. RPM for each species was determined according to the previous experiences of the breeder (table 1), always that possible a single prey was used to achieve this volume, however, when not possible, two preys with similar weight were used to achieve the determined RPM. Freshwater was available ad libitum. The snakes were weighed every week until being ready to be commercialized (at 60-day-old). No animals were submitted any handling for research purposes and only data was gathered, therefore this research project did not require approval of the committee of ethics on using animals.

Experimental design and statistical analysis

Growth and feed utilization efficiency were recorded from 37 snakes from birth to 67-day-old. Fourteen Bcc (nine males and five females), 16 Bco (four males and 12 females) and seven Bca (three males and four females) from the same batch per subspecies were followed up during this period. All animals were individually weighed before feeding to adjust the size of the prey, according to Table 1. All cages were checked after each feeding to ensure that all the preys were ingested. Weight gain was calculated by subtracting the weight of the animals on the first feeding from the final weight at the end of the experimental period. Feed efficiency was calculated by dividing the weight gain by the food intake in the period and multiplying the result by 100.

Table 1 - Feeding rate used by the company and day of first feeding of the three *B. constrictor* subspecies.

Subspecie[1]	1st feeding D0	RPM[2] D7	RPM D14	RPM D21	RPM D28	RPM D35	RPM D42	Final Weight
Bcc	16 days-old	10%	10%	10%	20%	20%	30%	58 days-old
Bco	25 days-old	10%	10%	10%	20%	20%	20%	67 days-old
Bca	18 days-old	15%	15%	15%	15%	15%	15%	60 days-old

[1]Bcc: *Boa constrictor constrictor*, Bco: *Boa constrictor occidentalis*; Bca: *Boa constrictor amarali*
[2]RPM: Relative prey mass (newborn weight*100/snake weight)

All data were tested for normality and homoscedasticity before analysis. Exponential growth equations were fitted for each species. Growth curves for each dataset were compared using Akaike's Informative Criteria (AICc) to check differences in growth curves between species or sexes. The best model was selected based on R^2, the least sum of squares of residuals and AICc. Data on growth performance was submitted to ANOVA, and when significant differences were observed, the Tukey's multiple range test was used to compare subspecies. All analysis and graphs were performed using the software Graphpad Prism (version 8.1).

RESULTS

All animals used in this follow-up study promptly consumed the preys every week. Growth curves of *B. constrictor* were different for each subspecies ($p<0.0001$). Although the same model (exponential growth) fitted for all the subspecies, there were significant differences among the equations for each species. Except for Bca, all other subspecies evaluated in this study showed no differences between sexes ($p=0.9844$ for Bcc; $p=0.9845$ for Bco). Therefore, data from both sexes were used to construct the growth curves for Bcc and Bco.

The best equation which depicted the growth behavior of Bcc was $Y=85.1e^{0.013x}$ (Fig. 1a). For Bco the growth curve was slower than Bcc ($P<0.0001$) and was best described by $Y=62.82e^{0.014x}$ (Fig. 1b). Bca showed differences between sexes during the growth period ($p=0.0052$). The curves which best describes the growth of Bca were $Y=31.64e^{0.016x}$ and $Y=35.96e^{0.017x}$ for males and females, respectively (Fig. 1c).

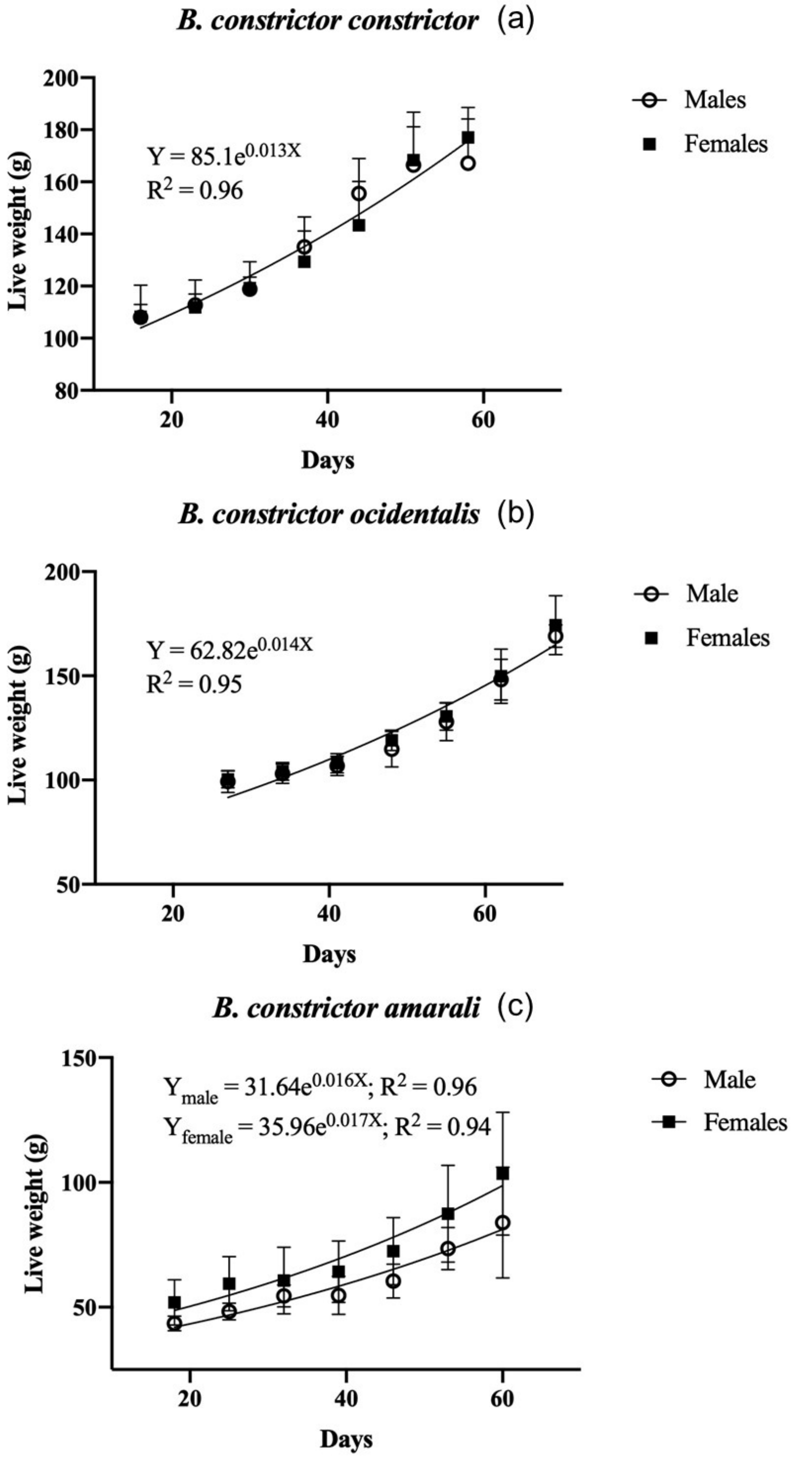

Figure 1 – Growth curves of (a) *Boa constrictor constrictor*, (b) *Boa constrictor ocidentalis* and (c) *Boa constrictor amarali*.

The Boidae snakes evaluated in this study showed similar efficiency of using food for growth purposes (P>0.05). Although Bco showed the highest efficiency of using feed (84.67%) compared to BCA (68.99%) and BCC (66.76%), this was not statistically significant. Surprisingly, sex did not affect any growth parameter evaluated in any subspecies (P>0.05). Bca showed the highest relative weight gain (90±32%) among the snakes, while Bco showed the lowest relative weight gain (73±8%) and Bcc showed intermediate values (89±25%), once more no statistical differences were noted (Fig 2).

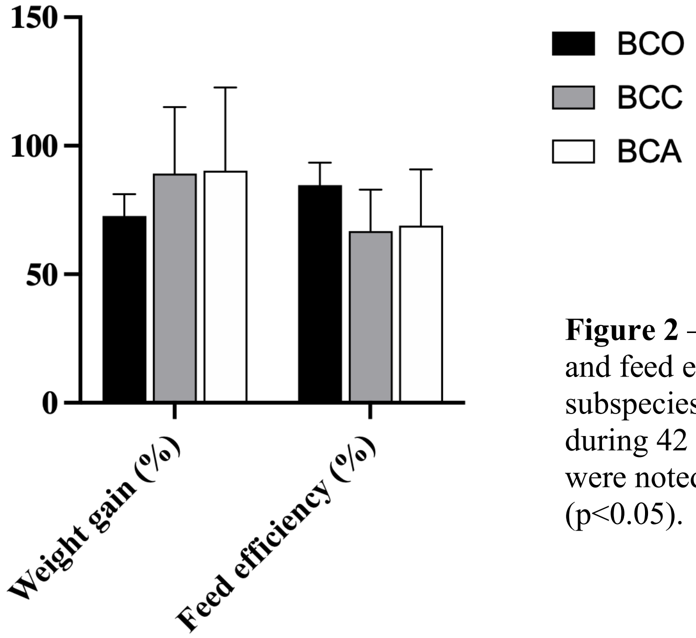

Figure 2 – Relative weight gain and feed efficiency in three subspecies of Boidae snakes during 42 days. No differences were noted among subspecies (p<0.05).

DISCUSSION

The scientific literature regarding breeding and growth of snakes is still scarce, especially considering captivity and specific species as Boas (de Cássia Lamonica et al., 2007; Dmi'el, 1967; Volsøe, 1944). In the present study, the growth curve of juvenile Boas was determined in a captive environment of a commercial breeder from birth to two months of age. Moreover, differences between sexes and three subspecies were determined.

Reptiles are well known for growing throughout their lives. Some reptiles present persistent cartilaginous growing plates which allow them to grow throughout their lives even after reaching maturity (Avery, 1994; Frýdlová et al, 2019). Snout vent length (SVL) has been commonly used to assess growth in snakes. In this study, SVL was considered to be used in addition to body weight; however, annotations of length were remarkably inconsistent in the facility. Luiselli (2005) demonstrated in field studies that shrinkage in snake species, including Boas, is probably justified by measurement errors related to animals' difficulty to be handled due to animals' size and aggressiveness. Besides, increments in length and weight occur alternately in snakes, being the increase in weight before the increase in length (Dmi'el, 1967). Therefore, considering the data quality and life stage of the animals in the present study, the SVL of snakes was not considered as a growth parameter in this study.

Reptile growth is dependent on some variables, including prey type, frequency of feeding, size and environmental temperature. Captive snakes can grow up to twice as fast as wild snakes (Dmi'el, 1967) due to higher feeding frequency and optimal environmental conditions. Sit-and-wait-predators, such as Boas, are well adapted to long periods of fasting in nature. Physiological changes are triggered when they eat to allow proper digestion and nutrition, i.e. increase in the mass of visceral organs such as stomach, liver, kidneys, lungs, heart and pancreas and of intestinal microvilli, increase in heart rate, stroke volume and oxygen uptake (Hasegawa & Mori, 2008; Secor & Diamond, 2000; Toledo et al., 2003). These changes are very energy-demanding for the individuals. On the other hand, Boas kept in captivity are fed high quality preys in a high feeding frequency and kept in optimal environmental conditions; therefore, sparing energy for growing purposes. To the best of our knowledge, no growth curve for *Boa constrictor*, in captivity or wild, is published, and this is the first study to report the growth curve of *Boa constrictor* subspecies. The present study explored the database of the commercial breeder with their routine feeding protocol, considering that, it is not possible to assume some inferences in comparison of subspecies since the feeding protocol differed based on the breeder experience.

Differences in growth rates between sexes were noted for Bca. This might be an effect of the small sample size (n=7) in this subspecies. Additionally, it is possible that, since Bca is the smallest of the three subspecies, and female adult Boas are expected to be larger than males, this subspecies showed differences in growth rates earlier than the other subspecies. However, further studies with an extended period of evaluation and a larger sample size are needed to confirm this hypothesis.

The rate and frequency of feeding used in this study were based on the breeder's experience. In the wild, infrequent feeders such as Boas can ingest large prey items in sporadic feeding opportunities (Branch et al., 2002; Greene, 2000; Shine et al., 1998). However, satiation in snakes is dependent both on prey size and feeding frequency (Nielsen et al., 2011). In the wild, prey size is correlated to snakes size due to predator's ability to hunt, prey-size selection or from different encounter rates (Shine, 1991). Not all these natural regulatory factors are present in captivity, and the snake will eat any prey they can physically handle since it is offered. In pythons and anacondas, species closely related to Boas, satiety seems to be associated with the size of the prey and hormonal responses to pregastric and gastric receptors, occurring in 6-12 hours post-feeding (Nielsen et al., 2011). While satiety over time seems to differ between species, anacondas remained satiated after 24 hours of ingesting a prey of 20% RPM, but pythons were not satiated (Secor & Diamond, 2000). Unfortunately, there are no available studies in Boas and feeding frequency and prey size of this study cannot be deeply discussed. Prey sizes up to 40% RPM were demonstrated to be efficiently digested by Bca in optimal environmental temperatures (25-30ºC), however feeding frequency was not considered for a long-term sustainable feeding protocol (Toledo et al., 2003). The feeding protocols used in this study were based on decades of experience of captive management of Boas in Brazil. Although good results are achieved, no scientific evidence was previously reported, and further research is warranted for building a solid knowledge of Boas growth in captivity.

Food efficiency is punctually described for different species of snakes. A python fed on 4-11% RPM with birds and mammals had a food efficiency of 13%, while for anacondas it was 16% (Dmi'el, 1967). Both these reports are for adult animals. Pope (1957) reported a young *Python molurus* to have a food efficiency of 57%, which is closer to our results. It is expected for snakes, as in other vertebrates, that animals before sexual maturity present higher food efficiency and growth rates than adults (Dmi'el, 1967). All these reports are vague, with no detailed description of feeding protocol or environmental control as the present study. Dmi'el (1967) reported differences in males and females' food efficiency for adult *Spalerosophis cliffordi*. However, we have not observed an effect of sex on growth parameters (relative weight gain or feed efficiency) for any Boa subspecies in this study.

Although differences were noted in food ingestion and weight gain for the subspecies during the analyzed period, relative values and food efficiency was similar among Boas subspecies. Hasegawa & Mori (2008) discussed gigantism occurrence in snake species and concluded that variation in size among species reflect a plastic phenotypic variation rather than an adaptively fixed trait. Variations depend on environmental factors such as lack of predators, interspecific competition and differences in prey availability. All these factors are easily manipulated in captivity and pet animals may present different growth patterns than wild snakes. However, in Hasegawa & Mori (2008) long-term analysis, these differences occur due to continuous growth throughout adulthood, which would not be detectable in our analysis of the initial phase of development. Long-term studies in pet Boas may indicate if captive animals will present differences from wild populations and if differences in growth and food efficiency occur in adulthood between subspecies.

There are limitations in this study, especially for being retrospective. Feeding protocols varied between subspecies and during the analyzed period, the sample size was small, and animals of each subspecies were from a single offspring. A controlled prospective research with more animals of each subspecies is suggested to affirm the hypothesis presented in this study. It is well established that snakes maintained under optimal environmental and feeding conditions can grow twice as fast as free-living animals, and the highest growth rate is observed in the initial phase (Dmi'el, 1967). Still, no previous study determined growth indices for captive Boas, such as weight gain and feed efficiency. The present study determined the growth curve for three subspecies of *Boa constrictor* maintained in captivity for breeding purposes and will assist reproductive programs in assessing their young animals' performance and being a start point for future studies.

CONCLUSIONS

The growth curves determined in this study could be used as an initial reference guide for the growth of Boa subspecies. These results will contribute to the establishment of proper feeding management for snakes kept in captivity and could be used as a welfare indication for newborn snakes. Additionally, by improving the maintenance conditions of snakes kept in legalized commercial breeders, this will assist in reducing the pressure on wild animals, helping to maintain diversity in natural habitats.

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