

MORPHOMETRIC ANALYSIS AND CARCASS YIELD OF KINOSTERNON SCORPIOIDES (LINNAEUS, 1776) REARED IN CAPTIVITY ON MARAJÓ ISLAND, PARÁ, BRAZIL

ANÁLISE MORFOMÉTRICA E RENDIMENTO DE CARÇAÇA DE KINOSTERNON SCORPIOIDES (LINNAEUS, 1776) CRIADOS EM CATIVEIRO NA ILHA DE MARAJÓ-PA

ANÁLISIS MORFOMÉTRICO Y RENDIMIENTO DE CANAL DE KINOSTERNON SCORPIOIDES (LINNAEUS, 1776) CRIADOS EN CAUTIVERIO EN LA ISLA DE MARAJÓ, PARÁ, BRASIL

 <https://doi.org/10.56238/sevened2025.039-010>

David Augusto Cavalcante de Oliveira¹, Pedro Henrique Lira Pereira², Fernando Elias Rodrigues da Silva³, Rosa Maria Souza Santa Rosa⁴, Lilian de Nazaré Santos Dias⁵, Suenny Quemel Mesquita⁶, Palmira Francisca Gonçalves⁷, José Ribamar Felipe Marques⁸, Lucas Carvalho Ferreira Lins⁹, Geovana de Souza Nunes¹⁰, Hélen Clarice Chaves Costa¹¹, Ana Caroline Pereira da Silva¹²

ABSTRACT

Muçuã (*Kinosternon scorpioides*) has economic and social importance in the Amazon region, being widely consumed by the local population. This study aimed to evaluate the morphometry and carcass yield of muçuãs raised in captivity on Marajó Island, Pará, Brazil. A total of 26 (twenty-six) adult female specimens, four years old, from an authorized breeding facility were used. Morphometric analyses included measurements of the carapace and plastron. For yield evaluation, live weight and the yields of meat, viscera, and carcass were determined. The muçuãs showed a mean carapace length of 15.1 ± 0.7 cm and a mean meat weight of 54.5 ± 10.8 g. The mean carcass yield was $19.1 \pm 2.8\%$, which is lower than values reported in the literature. The observed differences were attributed to methodological and biological factors, such as age, genetics, and rearing conditions. It is concluded that muçuãs

¹ Graduated in Veterinary Medicine. Universidade Federal Rural da Amazônia. E-mail: medvetdavid2019@gmail.com

² Graduated in Veterinary Medicine. Universidade Federal Rural da Amazônia. E-mail: pedrohenriquelirapereira@gmail.com

³ Dr. in Veterinary Medicine. Universidade Federal Fluminense. E-mail: fernando.silva@ufra.edu.br

⁴ Dr. in Veterinary Medicine. Universidade Federal Fluminense. E-mail: rosa.rosa@ufra.edu.br

⁵ Dr. in Animal Sciences. Universidade Federal do Pará. E-mail: lilian.dias@ufra.edu.br

⁶ Graduated in Veterinary Medicine. Universidade Federal Rural da Amazônia. E-mail: suequemel@gmail.com

⁷ Dr. in Animal Health and Production in the Amazon. Universidade Federal Rural da Amazônia. E-mail: laracoel@gmail.com

⁸ Dr. in Genetics. Universidade Estadual Paulista. E-mail: ribamar.marques@embrapa.br

⁹ Graduated in Veterinary Medicine. Universidade Federal Rural da Amazônia. E-mail: carvalholucas1701@gmail.com

¹⁰ Graduated in Animal Science. Universidade Federal Rural da Amazônia. E-mail: geovanadesouzanunes9@gmail.com

¹¹ Graduated in Veterinary Medicine. Universidade Estadual do Maranhão. E-mail: helencosta633@gmail.com

¹² Undergraduate student in Agronomy. Universidade Federal Rural da Amazônia. E-mail: ana.carollyne@discente.ufra.edu.br

present a morphometric profile consistent with the literature and a carcass yield that is relevant for sustainable production systems in the Amazon.

Keywords: Chelonians. Meat Yield. Chelonian Size.

RESUMO

O muçua (Kinosternon scorpioides) possui importância econômica e social na Amazônia, sendo amplamente consumido pela população local. Este estudo objetivou avaliar a morfometria e o rendimento de carcaça de muçuas criados em cativeiro na Ilha de Marajó, Pará. Foram utilizados 26 (vinte e seis) exemplares de fêmeas adultas, com quatro anos de idade, provenientes de criação autorizada. As análises morfométricas incluíram medidas da carapaça e do plastrão. Para o rendimento, os animais tiveram o peso vivo e os rendimentos de carne, vísceras e carcaça determinados. Os muçuas apresentaram comprimento médio de carapaça de $15,1 \pm 0,7$ cm e peso médio de carne de $54,5 \pm 10,8$ g. O rendimento médio de carcaça foi de $19,1 \pm 2,8\%$, valor inferior ao relatado na literatura. As diferenças observadas foram atribuídas a fatores metodológicos e biológicos, como idade, genética e condições de criação. Conclui-se que os muçuas apresentam perfil morfométrico compatível com a literatura e rendimento de carcaça relevante para sistemas produtivos sustentáveis na Amazônia.

Palavras-chave: Quelônios. Quantidade de Carne. Tamanho de Quelônio.

RESUMEN

El muçua (Kinosternon scorpioides) posee importancia económica y social en la Amazonía, siendo ampliamente consumido por la población local. Este estudio tuvo como objetivo evaluar la morfometría y el rendimiento de canal de muçuas criados en cautiverio en la Isla de Marajó, Pará, Brasil. Se utilizaron 26 (veintiséis) ejemplares de hembras adultas, de cuatro años de edad, provenientes de una cría autorizada. Los análisis morfométricos incluyeron mediciones del caparazón y del plastrón. Para la evaluación del rendimiento, se determinaron el peso vivo y los rendimientos de carne, vísceras y canal. Los muçuas presentaron una longitud media del caparazón de $15,1 \pm 0,7$ cm y un peso medio de carne de $54,5 \pm 10,8$ g. El rendimiento medio de canal fue de $19,1 \pm 2,8\%$, valor inferior al reportado en la literatura. Las diferencias observadas se atribuyeron a factores metodológicos y biológicos, como la edad, la genética y las condiciones de cría. Se concluye que los muçuas presentan un perfil morfométrico compatible con la literatura y un rendimiento de canal relevante para sistemas productivos sostenibles en la Amazonía.

Palabras clave: Quelonios. Rendimiento de Carne. Tamaño del Quelonio.

1 INTRODUCTION

The muçuã (*Kinosternon scorpioides* Linnaeus, 1776) is a freshwater, semi-aquatic animal, commonly known as the mud turtle or musk turtle, and this is due to the habit of living in areas with high water density, and also to the strong odor they propagate when handled (MURPHY, 1997; CROTHER, 1999; BERRY and YVERSON, 2011). Its geographical distribution covers a vast area, being recorded and described in different countries in Central and South America (BERRY and YVERSON, 2011).

These animals live in flooded fields that dry up in the summer, which favors the illegal capture of the species, since it is appreciated in the local cuisine and makes up the dish called "casquinho de muçuã" (CASTRO, 2006). They are found with great ease in the region known as the Amazon Delta, where the island of Marajó/PA is located (BRITO *et al.*, 2016). The shell and eggs of the muçuãs have medicinal uses, and as the only representative of the Kinosternidae family in the Brazilian Amazon, they are a genetic resource to be preserved (MOLINA, 1989).

Brazilian legislation (BRASIL, 2017/2020) classifies muçuã as fish, however, the gap left by the absence of complementary rules specifically for the species is noticeable; This fact makes well-established operations for other species a complete challenge, both for production and to determine the carcass yield of the species.

Carcass yield refers to the proportion of carcass mass in relation to the live weight of the animal, and is an important indicator of production efficiency (CASTRO, 2006). The evaluation of carcass yield allows estimating the production potential of meat and other by-products of muçuã (FERREIRA *et al.*, 2017), as well as optimizing management and slaughter practices for sustainable and economical production.

This study aimed to evaluate the morphometry and carcass yield of muçuãs raised in captivity on the island of Marajó/PA, knowing the economic and social importance of the species for the Amazon Region.

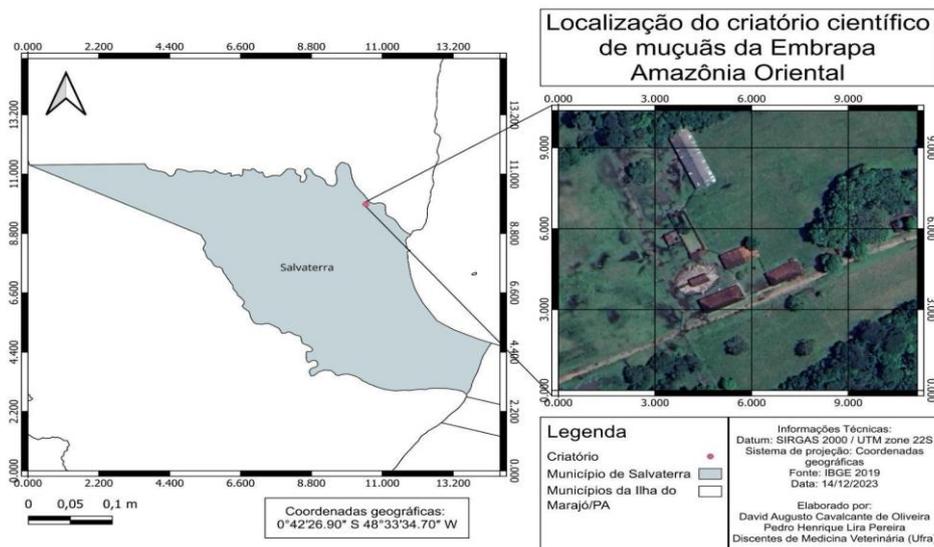
2 METHODOLOGY

The research was authorized by the Animal Ethics Committee of Embrapa Eastern Amazon, under protocol n0 001/2016, and the animals registered in process n.^{the} 0000032636, Operating License No.º 7310. The analyses were carried out at the Laboratory of Analysis of Products of Animal Origin of the Institute of Animal Health and Production (Lapoa/Ispa), of the Federal Rural University of the Amazon (Ufra/Campus Belém-PA).

A total of 26 (twenty-six) adult females aged four years, from the captive breeding of Embrapa/Eastern Amazon, were used, referring to the project "In situ conservation studies of muçuã populations on the island of Marajó", Figure 1.

Figure 1

Visual representation and location of the captive breeding of muçuãs from the Animal Germplasm Bank of the Eastern Amazon/Bagam (geographic coordinates: 0°42'26.90"S and 48°33'34.70"W), Salvaterra-Marajó Island/PA. Map prepared in the Quantum Geographic Information System (Qgis)



Source: The authors (2024).

The animals were euthanized by administration of ketamine 20 mg/kg/IM, followed by a lethal dosage of propofol 30 mg/kg/IV, by adjustment of three times the non-lethal dosage of the protocol defined by Santos *et al.* (2011) for *Podocnemis expansa*. This method aimed to ensure unconsciousness before any physical and mental suffering, according to the guidelines contained in the Guidelines for the Practice of Euthanasia of the National Council for the Control of Animal Experimentation (Concea).

After death, fifteen animals were eviscerated (G2), while the remaining eleven were not eviscerated (G1) — this division as to the occurrence or not of evisceration was made due to the fact that the present study was carried out together with the analysis of the influence of evisceration on the centesimal composition of these same individuals in another study. Then, all animals were frozen in a domestic freezer at -18 °C.

The PI (Weight of the whole animal) of G2 (n=15) is unknown because they were eviscerated before freezing in a previous study, without having recorded their initial weight prior to evisceration. Therefore, G2 was not used to obtain yield, but only for morphometry, since the calculation of yield depends on the PI.

For statistical analysis, Pearson's correlation analyses were performed and the construction of a graph of the importance of yield values as a function of morphometric variables were performed.

2.1 BIOMETRIC PARAMETERS

2.1.1 Morphometry

The morphometric proportions of plastron length (CP) and carapace (CC); plastron width (LP) and carapace width (LC); and dorsal carapace height (AC) of 26 specimens of *K. scorpioides* were analyzed (Figure 2).

Figure 2

Detailing of the morphometry methodology, highlighting the measurement of length, width and height of carapace and plastron. CC = Carapace length; LC = Carapace width; AC = Dorsal carapace height; CP = Plastron length; LP = Plastron width



Source: The authors (2024).

2.1.2 Income

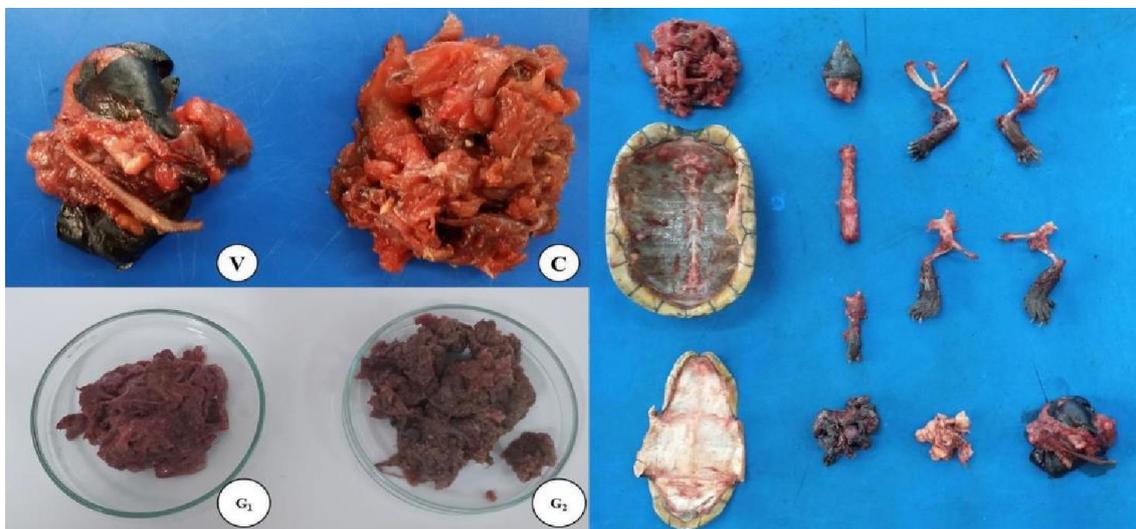
The weight of the whole animal (PI) was obtained only for G1, because G2 had already been eviscerated before freezing, without recording its yield, and therefore its initial weight was unknown. It was still possible to obtain the meat weight (BW) of G2, although it was not

possible to use this value to calculate the meat yield (CR), because this calculation depends on the knowledge of its IP.

Meat (CR) and viscera (RV) yields, obtained only for G1, were determined directly by weighing on an electronic scale, after removing the head, plastron, carapace, fat and bones (Figure 3), as well as a toilet to remove skin and dark muscle residues.

Figure 3

Visual representation of meat (C) and offal (V); comparison between meat obtained from G1 and G2, and visualization of hoof, meat, viscera, bones and fat obtained after complete desiccation of *K. Scorpioides*



Source: The authors (2024).

The carcass weight comprised the sum of the weights of meat, bones and fat, according to Article 277, Chapter VIII, of RIISPOA (BRASIL, 2017/2020). The following equations were used:

$$\text{Meat Yield (RC)} = \frac{\text{Meat Weight (BW)} \times 100\%}{\text{Whole weight (PI)}}$$

$$\text{Viscera Yield (RV)} = \frac{\text{Viscera Weight (PV)} \times 100\%}{\text{Whole weight (PI)}}$$

$$\text{Carcass Yield (RC\text{C})} = \frac{\text{Carcass Weight (PCC)} \times 100\%}{\text{Whole weight (PI)}}$$

For the G2 group, there was no OR, LR or RCÇ because the calculations depended on the knowledge of their initial weight.

3 RESULTS AND DISCUSSION

3.1 MORPHOMETRY

The results of the morphometric determination of the muçuãs are presented in Table 1.

Table 1

Morphometry (cm) of the carapace and plastron. SD = standard deviation; Min = minimum; Max = maximum; CC = Carapace length; LC = Carapace width; AC = Carapace height; CP = Plastron length; LP = Plastron width

Measur e	General (n=26)			G1 (n=11)			G2 (n=15)		
	Average± DP	Min	Max	Average± DP	Min	Max	Average±D P	Min	Max
CC	15.1±0.7	12,5	15,8	15.2±0.3	14,6	15,5	15.0±0.8	12,5	15,8
LC	10.4±0.5	9,6	11,7	10.1±0.2	9,6	10,3	10.7±0.6	9,8	11,7
AC	5.7±0.3	5,0	6,5	5.7±0.2	5,4	5,9	5.7±0.4	5,0	6,5
CP	14.0±0.5	13,0	15,3	13.8±0.5	13,0	14,5	14.1±0.5	13,2	15,3
LP	8.4±1.0	6,2	10,1	8.6±0.7	7,5	10,1	8.3±1.1	6,2	9,6

Source: The authors (2024).

The muçuãs had an average of 15.1cm (± 0.7) carapace length, which is within the measurements already reported for the species, when considering the sex and age of 4 years (CASTRO, 2006). Neto (2018) observed, in a group of 165 individuals, a length of 14.81cm (± 0.09), similar to Ferreira *et al.* (2017), which, analyzing 15 specimens, obtained a value of 14.7cm (± 0.6). However, measurements lower than these were found by Ferreira (2023), who, studying 262 animals, obtained a measurement of 11.06 cm (± 1.08). These differences, as well as that of the other morphometric measurements, can be attributed to the animal populations studied, rearing conditions, measurement methods or especially to age differences.

No major differences were observed between groups G1 and G2 in terms of morphometric results.

3.2 YIELD

The results of the carcass yield of the muçuãs are presented in Table 2.

Table 2

Weighing (g) of meat, offal and whole animal; and yield (%) of meat, offal and carcass for groups G1, G2 and General. SD = standard deviation; Min = minimum; Max = maximum; CP = Weight of the meat; PV = Viscera weight; PI = Weight of the whole animal; RC = Meat yield; RV = Viscera yield; RCÇ = Carcass yield

Measure	General (n=26)			G1 (n=11)			G2 (n=15)		
	Average±DP	Min	Max	Average±DP	Min	Max	Average±DP	Min	Max
PC	54.5±10.8	36,9	82,0	56.8±12.2	38,3	82,0	52.8±9.6	36,9	70,0
PV	–	–	–	50.1±10.1	39,5	69,8	–	–	–
IP	–	–	–	510.0±32.6	470,0	560,0	–	–	–
RC	–	–	–	11.1±2.2	7,6	15,0	–	–	–
VR	–	–	–	9.8±1.9	7,1	12,8	–	–	–
RCÇ	–	–	–	19.1±2.8	14,6	24,2	–	–	–

Source: The authors (2024).

In total (n=26), BW was 54.5g (±10.8) and for G1 (n=11) LW was 50.1g (±10.1). Similarly, Ferreira *et al.* (2017), using 15 specimens over 2 years of age, obtained similar results, with minimum and maximum BW of 43.8g to 85.0 g, respectively. These results demonstrate the efficiency in the use of resources and profitability for the muçuã producer, as they represent service to the local consumer market, ensuring adequate supply of meat (BRAZIL *et al.*, 2025).

Regarding yields, RCÇ and RV have greater commercial importance in the Amazon (BRAZIL *et al.*, 2025), as *K. scorpioides* is consumed as a "muçuã shell", a typical dish of regional cuisine in which meat and viscera are used. In this study, it was only possible to determine the PI for the animals in the G1 group (n=11), so OR, RV and RCÇ were only calculated for this group, although it was still possible to obtain the WC of G2. The OR obtained with deboning was 11.1% (±2.2), a result lower than the 15.0% (±1.7) obtained by Ferreira *et al.* (2017).

The animals in the present study showed 19.1% (±2.8) carcass yield, which differs from what has been reported for the species. Neto (2018) observed an RCÇ of 29.28%, while

Ferreira *et al.* (2017) obtained a value of 27.5% - obtained by the algebraic sum between 15.0% (± 1.7) of the OR and 12.49% (± 3.65) of the bone yield. Differences in results between experiments can be attributed to differences in methodology, including slaughter protocols, nutrition, genetics, and environmental conditions. Variations in the sample, such as age, race, and sex, also play a significant role in the results (YOUNG *et al.*, 2001).

3.3 MORPHOMETRY-YIELD CORRELATION

Table 3 shows the relationship between the morphometric parameters and the yields obtained for *K. scorpioides*.

Table 3

Pearson's correlogram for morphometric variables and yield. Plastron Length (CP), Plastron Width (LP), Carapace Width (LC), Carapace Length (CC), Carapace Width (LC), Carapace Height (AC), Whole Animal Weight (PI), Meat Yield (RC), Viscera Yield (RV) and Carcass Yield (RCC) of G1 (n=11)

	CP	LP	CC	LC	AC	IP	RC	VR	RCC
CP	1,00	0,4981 (0.119)	0,248 (0.462)	0,377 (0.252)	-0,838 (0.806)	0,624 (0.0399*)	0,919 (0.788)	-1,076 (0.753)	0.148 (0.664)
LP		1,00	0,194 (0.566)	0,288 (0.389)	-0,5790 (0.062)	-0,355 (0.284)	-4,251 (0.192)	-1,709 (0.615)	-0.187 (0.581)
CC			1,00	0,2310 (0.494)	-0,354 (0.285)	0,606 (0.048*)	-0,241 (0.944)	-1,742 (0.601)	0.0366 (0.915)
LC				1,00	-0,417 (0.202)	0,363 (0.272)	-2,671 (0.427)	0,588 (0.864)	-0.132 (0.699)
AC					1,00	-0,184 (0.587)	4,916 (0.125)	-1,485 (0.663)	0.215 (0.525)
IP						1,00	1,596 (0.639)	-1,593 (0.640)	0.133 (0.697)
RC							1,00	1,797 (0.597)	0.899 (0,0001**)
VR								1,00	0.628 (0.165)
RCC									1,00

The P-value is recorded in parentheses below the corresponding Pearson's coefficient (R) and is interpreted as statistically significant evidence when ≤ 0.05 (*) and highly significant when ≤ 0.01 (**)

Source: The authors (2024).

Considering only the correlations with $p\text{-value} < 0.05$, there was a positive correlation ($R > 0$) between PI and NC (0.0399*), as well as PI and WC (0.048*), as already observed by

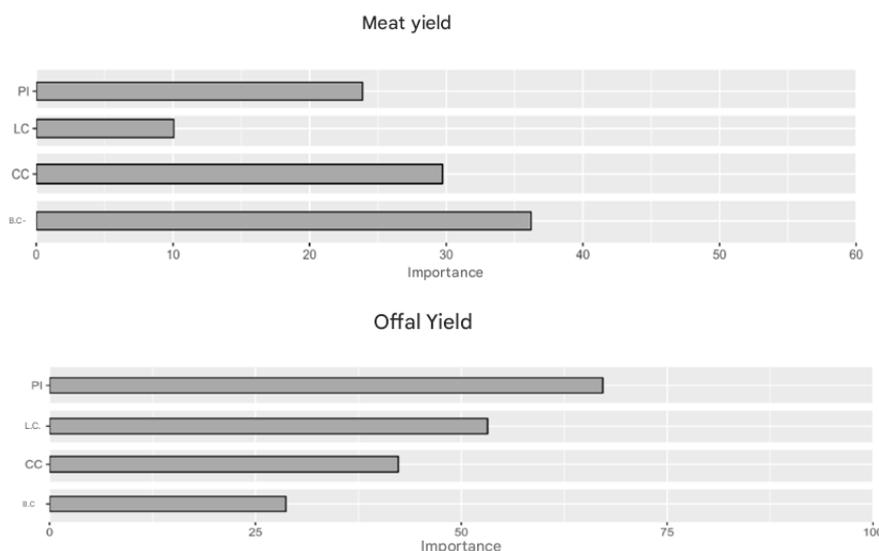
Castro (2006). The CR showed a positive correlation ($p\text{-value} < 0.01^{**}$) with the RCÇ, which was already expected due to the fact that the carcass weight is made up of the weight of meat, bones and fat (BRASIL, 2017, 2020).

No correlation was observed between morphometric measurements and yields ($p\text{-value} > 0.05$). This fact can be attributed, in part, to the possible influence of the animal's age, according to Castro (2006), who observed that the p -value of Pearson's correlations between various morphometric parameters and weight varied according to the animal's age. Therefore, in the same way, the present study may not have identified a relationship between these variables due to the reproductive age in which these muçuã females were, so that animals of larger sizes and weights have these high values in attribution to the development of the reproductive system and egg production, but not to carcass and viscera yield, because factors such as biological maturity have an impact on the morphometric-yield correlation (Castro, 2006).

Figure 5 illustrates the comparison between the importance of morphometric variables for CR and LR. This type of graph represents the contribution of an independent variable (such as LC, WC, and PI) to a parameter defined as a dependent variable (CR and RV) (JAMES *et al.*, 2013).

Figure 5

Graph of importance (%) of morphometric variables in relation to CR and RV Meat yield. LC = Carapace width; CC = Carapace length; LC = Carapace width; AC = Carapace height (AC); PI = Weight of the whole animal



Source: The authors (2024).

For the CR, greater importance was observed for the variables CA, WC and PI, which means that these characteristics determine most of what the CR is (JAMES *et al.*, 2013). Biologically, these characteristics are related to the health and nutrition of the muçuã, as well as to the age group and sexual maturity, since healthy and sexually mature animals tend to have different physical characteristics that can influence meat yield (CASTRO, 2006). Similarly, for the RV, the PI, LC and CC are of greater importance, probably because they are associated with anatomical development and the proportion of internal organs in relation to the total size of the animal's body.

4 CONCLUSION

The muçuãs raised in captivity on the island of Marajó presented a morphometric profile according to the data found in the literature, considering age and sex, and which may be associated with considerable meat and viscera yield.

REFERENCES

- Andrade, P. C. M., et al. (2021). Panorama da quelonicultura no Brasil: Uma estratégia para conservação das espécies e geração de renda. *Aquaculture Brasil*, 22, 32.
- Berry, J. F., & Iverson, J. B. (2011). *Kinosternon scorpioides* (Linnaeus, 1766) – Scorpion mud turtle. In A. G. J. Rhodin et al. (Eds.), *Conservation biology of freshwater turtles and tortoises* (pp. 063.1–063.15). Chelonian Research Foundation.
- Brasil. Decreto nº 9.013, de 29 de março de 2017. Regulamenta a Lei nº 1.283, de 18 de dezembro de 1950, e a Lei nº 7.889, de 23 de novembro de 1989, que dispõem sobre a inspeção industrial e sanitária de produtos de origem animal, *Diário Oficial da União*, 30 mar. 2017. Atualizado pelo Decreto nº 10.468, de 18 de agosto de 2020.
- Brasil. Portaria SDA/MAPA nº 864, de 31 de julho de 2023. Aprova o regulamento técnico de manejo pré-abate e abate humanitário e os métodos de insensibilização autorizados, *Diário Oficial da União*, 1 ago. 2023.
- Brito, T. P., et al. (2016). Avaliação do consumo de quelônios no município de Castanhal, Pará, Brasil. *Revista Ouricuri*, 6(1), 71–103.
- Castro, A. B. D. (2006). *Biologia reprodutiva e crescimento do muçuã (Kinosternon scorpioides Linnaeus, 1776) em cativeiro [Dissertação de mestrado, Universidade Federal do Pará]*.
- Crother, B. I. (1999). Evolutionary relationships. In B. I. Crother (Ed.), *Caribbean amphibians and reptiles* (pp. 269–334). Academic Press.
- Dantas-Filho, J. V., et al. (2020). Cultivo de quelônios promove conservação e desenvolvimento social e econômico da Amazônia. *Revista Ciência e Saúde Animal*, 2, 9. <https://doi.org/10.6084/m9.figshare.12058596.v1>

- Ferreira, L. K. S., et al. (2017). Análise do manejo produtivo e composição físico-química da carne de jurará (*Kinosternon scorpioides* Linnaeus, 1766) [Dissertação de mestrado, Universidade Estadual do Maranhão].
- Ferreira, P. F. G. (2023). Criação de *Kinosternon scorpioides* (Linnaeus, 1766): Base zootécnica, ambiental e molecular para a conservação da espécie na Amazônia [Tese de doutorado, Universidade Federal Rural da Amazônia].
- James, G., et al. (2013). An introduction to statistical learning. Springer.
- Maia, C. F. G. (2020). Legislação sanitária de abate em Testudines: Complicações enfrentadas pelo Estado brasileiro para fins comerciais de exportação. *Revista Ibero-Americana de Humanidades, Ciências e Educação*, 6(12), 2675–3375. <https://doi.org/10.29327/217514.6.12-11>
- Molina, F. B. (1989). Observações sobre a biologia e o comportamento de *Phrynops geoffroanus* (Schweigger, 1812) em cativeiro [Dissertação de mestrado, Universidade de São Paulo].
- Murphy, J. C. (1997). *Amphibians and reptiles of Trinidad and Tobago*. Krieger Publishing Company.
- Neto, D. L. F. (2018). Manejo da postura em muçua (*Kinosternon scorpioides* Linnaeus, 1766) submetidos a diferentes níveis de cálcio na dieta [Trabalho acadêmico]. [Instituição não informada].
- Santos, A. L. Q., et al. (2011). Anestesia de tartaruga-da-amazônia (*Podocnemis expansa*) com associação de cetamina e propofol. *Pubvet*, 5, 1118–1123.
- Young, L. L., et al. (2001). Effects of age, sex and duration of postmortem aging on percentage yield of parts from broiler chicken carcasses. *Poultry Science*, 80(3), 376–379. <https://doi.org/10.1093/ps/80.3.376>
- Brazil, M. V. S., et al. (2025). The potential and limitations of turtle farming to contribute to conservation in the Brazilian Amazon. *Biological Conservation*, 304, Article 111055. <https://doi.org/10.1016/j.biocon.2025.111055>