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Kleiber ratios and growth curves of African Black and Red Neck ostrich breeds and their crossbreeds

Razão Kleiber e curva de crescimento para raças de avestruzes African Black e Red Neck e seus cruzamentos

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Highlights

An animal's genetic potential for growth can be described for its growth curve.
Kleiber ratio is an alternative for ostrich's selection regarding feed efficiency.
It is possible to obtain animals with precocity for growth and high Kleiber ratio.
African Black ostrich has a greater precocity.
This study embraces two factors for the cost-benefit ratio of rearing these animals.

Abstract

The selection of animals with lower production costs can be achieved by using feed efficiency and growth curve information. Kleiber ratio (KR) is an alternative option for discriminating against the animals that have the greatest weight gain about their final weight. Alternative feed efficiency and growth curves for ostriches of the African Black (AB) and Red Neck (RN) breeds and their crossbreeds (CB) were investigated using KR and Gompertz equation. Univariate and multivariate analyses were used. The highest adult weight was

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identified in the RN and CB. AB was more precocious than the RN and CB individuals. Only AB animals reached 75% of their mature weight at one year of age. At 180 days, AB showed better KR. AB was different from the others, mainly for KR at 90 days and 180 days. Considering multivariate analysis, AB animals were different from the others, regardless of sex, mainly for KR at 90 days and KR at 180 days. Other subgroups separated the animals by sex. In a market preferring animals of minor structure (smaller cuts) and greater precocity, it would be suitable to opt for AB. When animals with greater body structure (larger cuts) are desired, males RN and CR is the best option, however, it will be slaughtered with greater age and lower value for KR (may generate a bigger production cost). It is possible to obtain animals with precocity and high KR, being well represented by the AB breed.
Key words: Grau de maturidade. Eficiência alimentar. Análise multivariada. Modelo não linear. *Struthio camelus.*

Resumo

A seleção de animais com custos de produção mais baixos pode ser alcançada usando a eficiência alimentar e informações da curva de crescimento. A razão de Kleiber (KR) é uma alternativa para discriminar os animais que apresentam maior ganho de peso em relação ao peso final. Eficiência alimentar alternativa e curvas de crescimento para avestruzes das raças African Black (AB) e Red Neck (RN) e seus cruzamentos (CB) foram investigadas usando a equação de KR e Gompertz. Análises univariadas e multivariadas foram utilizadas. O maior peso adulto foi observado no RN e no CB. AB foi mais precoce do que os indivíduos RN e CB. Apenas animais AB atingiram 75% de seu peso adulto até um ano de idade. Aos 180 dias, AB tem maior KR. AB foi diferente dos demais, principalmente para KR aos 90 dias e 180 dias. Considerando a análise multivariada, os animais AB diferiram dos demais, independente do sexo, principalmente pelos seguintes parâmetros: KR aos 90 dias, KR aos 180 dias. Outros subgrupos separaram os animais por sexo. Em um mercado que prefere animais de menor estrutura corporal (cortes menores) e maior precocidade, seria adequado optar pela AB. Para animais com maior estrutura corporal (cortes maiores), os machos RN e CR são a melhor opção, porém, serão abatidos com maior idade e menor valor para KR (pode gerar um maior custo de produção). É possível obter animais com precocidade e alto KR, sendo bem representados pelo AB.
Palavras-chave: Grau de maturidade. Eficiência alimentar. Análise multivariada. Modelo não linear. *Struthio camelus.*

Introduction

Ostriches are highly useful animals, providing meat, feathers, eggs, and leather. There is growing interest in rearing ostriches in many countries (Miah, Abdulle, Rahman, & Salma, 2020; Umar, Qureshi, Shahid, & Deeba, 2021). In this scenario, Brazil has the second-largest ostrich herd globally, and is ranked fifth worldwide in the industrialization of ostrich by-products, with a total of approximately 14,300 animals being slaughtered annually (Minari, Arruda, & Mativi, 2021). Obtaining a functional biotype and viable production mechanism for ostriches to be competitive with other livestock species could pave the way for opening new markets for ostrich farming in Brazil.

A bird's genetic potential for growth can be described in terms of its growth curve (Michalczuk, Damaziak, & Goryl, 2016). Moreover, the same growth curve can be used to define the ideal age of slaughter (Rezende et al., 2020), identify the animals with the best potential for high weight gain, and help define specific nutritional management (Figueiredo et al., 2019; Cyril, Josef, & Widya, 2021). Non-optimal nutrition, for example, has a significant impact on the chick's development and survival (Prabakar, Pavulraj, Shanmuganathan, Kirubakaran, & Mohana, 2016). Feeding costs are the largest expense in an ostrich production system, reaching 70–80% of the costs, as stated by Brand, Nell, and Van Schalkwyk (2000), and protein is one of the most expensive components of the diet (Carstens, Sharifi, Brand, & Hoffman, 2014; Nikravesh-Masouleh, Seidavi, Kawka, & Dadashbeiki, 2018). Thus, growth curves are useful tools for the management of agricultural ventures as they facilitate checking whether the weight gain of the animals is within acceptable limits.

The use of the Kleiber ratio (KR) (Kleiber, 1936) is an alternative option for ostrich's selection regarding feed efficiency since it is good for discriminating against the animals that have the greatest weight gain in relation to their final weight. The main advantage of this index is its calculation does not require the precise evaluation of individual feed intake, making it accessible to breeders. There are many studies on other livestock species using the KR (Figueiredo et al., 2019; Bangar, Magotra, & Yadav, 2020; Tesema et al., 2020; Yousefi, Gholizadeh, & Hafezian, 2020); however, to our knowledge, there are no studies thus far regarding ostriches or domestic birds in general. This study provides information needed for considering the adoption of this index in ostrich production and other species of domestic birds in the future.

From an economic perspective, it is essential to produce animals with a high weight gain capacity in a short time and with good feed efficiency. In the first situation, we have a short and optimized production cycle; while in the second situation, we can reduce costs with nutritional management. This study analyzes these factors for the cost-benefit ratio of rearing these animals. Further, it has been indicated that the environmental impact of ostrich production systems is minor in relation to the chicken (Ramedani, Alimohammadian, Kheialipour, Delpisheh, & Abbasi, 2019). Thus, the objective of the present study was to evaluate the KRs and growth curves of African Black and Red Neck breeds of *Struthio camelus* ostriches and their crossbreeds in Brazil.

Materials and Methods

Data

Ethics committee approval was not required because the data were obtained from the Brazilian Ostrich Breeding Program database. The data consisted of 901 animals grouped by breed and sex as follows: African Black (AB) female (n = 53) and male (n = 61), red neck (RN) female (n = 39), male (n = 62), and crossbreeds (CB) female (n = 355) and male (n = 331).

The weight of the ostriches was assessed at 30-day intervals to estimate the growth curve parameters (A and k) using the non-linear Gompertz model (Equation 1) and the NLIN procedure of the SAS software (Statistical Analysis System Institute [SAS Institute], 2021).

$$yt = A/[1 + b \exp(-kt)] \quad (1)$$

where y is the weight in kg, t is the age in days, A is the asymptotic or adult weight, b is an integration constant, and k is the maturity rate.

The degree of maturity of the ostriches slaughtered at 90 (90D), 180 (180D), and 400 days was evaluated using the following equation:

$$Ut = Yt/A \quad (2)$$

where Ut is the maturity degree (%), Yt is the weight (kg) of the ostrich at 90, 180, and 400 days, and A is the asymptotic weight. The Gompertz function was chosen because of its economy of parameters and ability to describe relative growth rate as a simple function of size (Ramos et al., 2013); it has been used in other studies to evaluate ostrich growth (Niemann, Brand, & Hoffman, 2018). In addition, the function offers the possibility of describing continuous growth, sigmoid forms, asymptotes, inflection points, and parameters with biological interpretations.

KR, defined as the average daily gain divided by metabolic body weight, was calculated by dividing 90D and 180D mean daily weight gain (DWG) by the metabolic live weight (Kleiber, 1936). Thus, the DWG of the ostriches was calculated as follows:

$$DWG = (FW – IW)/N \quad (3)$$

where FW is the final weight, IW is the initial weight, and N is the number of days in the period. Metabolic weight is the live weight to the 0.75 power.

Statistical analysis

Analysis of variance was performed to verify the hypothesis of equality between the ostrich groups for KR, A, and k parameters using the Tukey test at 5% significance, implemented by the GLM procedure of SAS software (SAS Institute, 2021). Pearson's correlation analysis between the KR at 90D and 180D was also performed using the CORR procedure in SAS software (SAS Institute, 2021). In addition, a principal components analysis was performed considering the A and k parameters, degree of maturity at 90D, degree of maturity at 180D, and KR at 90D and 180D.

The number of extracted principal components was defined according to the variance criterion (i.e., the inflection point in the graph of the eigenvalues curve was used as a determinant of the number of principal components to be considered; data not shown). The meanings of these components were established according to the coefficients of the variables in each component. The diversity among the ostriches under study and their relationship with the measured variables was evaluated using a heatmap graph constructed with the aid of the BIBLIO part of the R software (R Development Core Team [R], 2018), representing the mean Euclidean distances and grouping through complete linkage. An approximately unbiased (AU) test was performed using multiscale bootstrap resampling to obtain the confidence set of trees. Clusters (edges) with high AU values (e.g., 95%) were strongly supported by the data.

Results and Discussion

Upon calculating the values of the parameters for the different ostrich groups, we found that the A parameter of the growth curve (equation (1)) was negatively related to parameter k. This indicates that larger animals tend to have slower growth rates. The highest value of A was identified in RN and CB, whose estimated values were significantly different (p > 0.05) from those of AB (Table 1). Specifically, the estimated values were smaller in AB than RN and CB (independent of sex). Conversely, the k estimates were significantly higher (p < 0.05) in AB than in an RN and CB individuals (again, regardless of sex).

Table 1
Parameter estimates (A, k and b) obtained by Gompertz function

Breed	Parameters			Inflexion Time (days)	Inflexion Weight (kg)
	A	k	B		
Female					
African Black	115.4 b	0.0088 a	4.15	161.72	42.45
Red Neck	129.5 a	0.0071 b	4.09	198.38	47.64
Crossbreed	128.3 a	0.0075 b	4.10	188.13	47.19
Male					
African Black	137.3 b	0.0076 a	3.95	180.75	50.51
Red Neck	145.2 a	0.0066 b	3.96	208.52	53.40
Crossbreed	143.4 a	0.0067 b	4.01	207.28	52.75

A - asymptotic weight, b - integration constant, k - maturity rate. Means inside sex with different letters are significantly different, at 5% probability by the Tukey test.

Whereas the k values are reflected in the inflection time [(ln3B)/k], AB is more precocious than the others. In general, AB (females and males) reached the inflection point at 161.7 days and 180.7 days, respectively. RN and CB males reached the inflection point (age and weight) at the same time. Therefore, the weight gain between the groups was similar, indicating that it is possible to use either of the two groups on the farm, providing an equal productive response. The females of RN presented an inflection point with 10 days of difference compared to CB but with a similar weight inflection (kg).

The inflection point of the growth curve is at approximately 40% to 50% relative to the final growth. Additionally, the data indicate that the predicted growth inflection point may correspond to changes in the animal's physiological state, possibly due to the onset of sexual maturity. We observed that the KR tended to follow the k parameter of the curve in all ostriches.

The degree of maturity (equation (2)) for ostriches at different ages (Table 2) showed similar results as the inflection point, with RN and CB showing a lower degree of maturity than AB. The females of RN and CB reached 50% of the mature weight (A50%) at 251 days (8.4 months) and 236 days (7.9 months), respectively. The mature weight of 75% (A75%) was reached by RN and CB females at 373 days (12.4 months) and 352 days of age (11.7 months), respectively.

Table 2
Degree of maturity (%) at different ages by sex for model

Age (days)	Female			Male		
	AB	RN	CB	AB	RN	CB
90	15.31	11.50	12.49	13.59	11.19	11.06
180	42.86	31.90	34.84	36.55	29.88	29.93
400	88.58	78.67	81.87	82.8	75.41	75.78
Maturity						
A50% (days)	203	251	236	229	264	261
A75% (days)	302	373	352	345	393	394

AB - African Black, RN - Red Neck, CB - crossbreeds.

All females, independent of origin, either pure or crossbred, reached 75% of their mature weight at around one year of age. The RN and CB males reached 50% of the mature weight (A50%) at 264 days (8.8 months) and 261 days (8.7 months), respectively. Only AB ostrich males reached 75% (A75%) of their mature weight before the first year of age (345 days, i.e., 11.5 months).

RN females are less precocious than AB and CB females (Figure 1A); CB females have an intermediate growth, while AB females are the most precocious, reaching the mature weight of the other two breeds at approximately 175 days (5.8 months) of age. The growth curves of RN and CB males were very similar (Figure 1B), possibly due to the small differences in the A and k parameters (Table 1). AB growth was faster, reaching the mature weight of the other two breeds at approximately 187.5 days (6.3 months) of age.

It should be noted that the absolute growth rates (AGRs) of RN and CB males from the second semester of life were superior to all others (Figure 2). The AB group had the highest gain among all groups up to 6 months of age, and males maintained their superiority up to 8 months of age. The maximum AGRs were 0.352, 0.384, and 0.352 g for the crossbreed, AB, and RN males, respectively. In females, the maximum AGRs were 0.356, 0.375, and 0.337 g for the crossbreed, AB, and RN, respectively. In general, the sex factor is important for obtaining accurate estimates of the growth-curve parameters. This result has also been observed by Cyril et al. (2021).

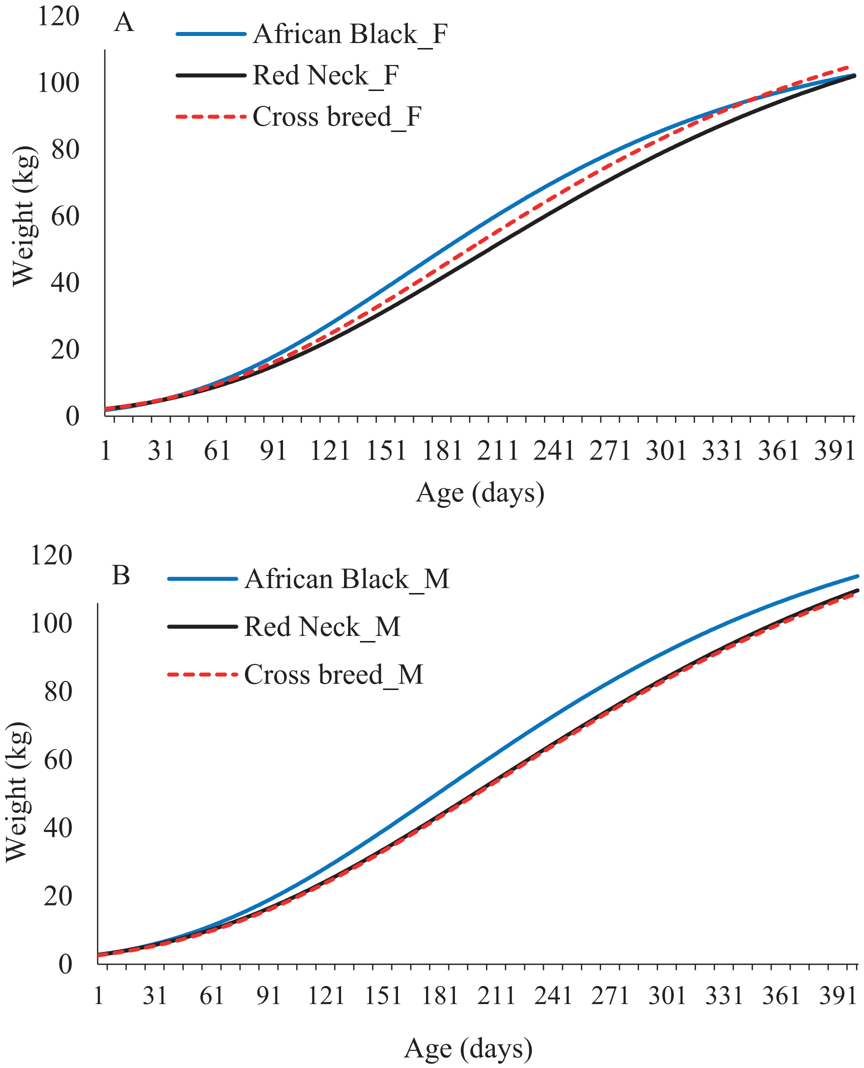

Figure 1. Growth curve for females (A) and males (B) of the African Black, Red Neck and Cross breed breeds using Gompertz functions.

In general, it may be recommended to slaughter ostriches at approximately 390 days in all groups. It should be considered that the slaughter age of ostriches is a determining factor for the viability of the production system. It is also important to note that nervous and bone tissues develop first. As the animal matures, the need for muscle increases, and the growth of this tissue will become a priority. In this process, the slowest maturing tissue is fat, and its growth rate increases at a later stage in the growth cycle. Thus, delayed slaughtering is not desirable because of the maintenance production costs of the animal; when passing the optimum age, fat deposition starts, and significant non-gain in muscle tissues begins; this greatly impacts the overall economy of the ostrich production process (Silva, Nogueira, Brandalise, Beserra, & Peres, 2016). Another factor is that the fat in ostriches is mostly stored in the abdominal cavity and under the skin (Sales, Horbanczuk, Dingle, Coleman, & Sensik, 1999; it is uneconomical to slaughter obese ostriches as most of the fat is removed before determining the carcass weight in the commercial abattoirs, although ostrich fat has a more advantageous composition of fatty acids compared to beef, sheep, and chicken fat (Basuny, Arafat, & Nasef, 2011). According to Belichovska, Hajrulai-Musliu, Uzunov, Belichovska and Arapcheska (2015), unlike other animal fats, ostrich fat is characterized by a high content of unsaturated fatty acids and can therefore be considered a healthy food for the human diet.

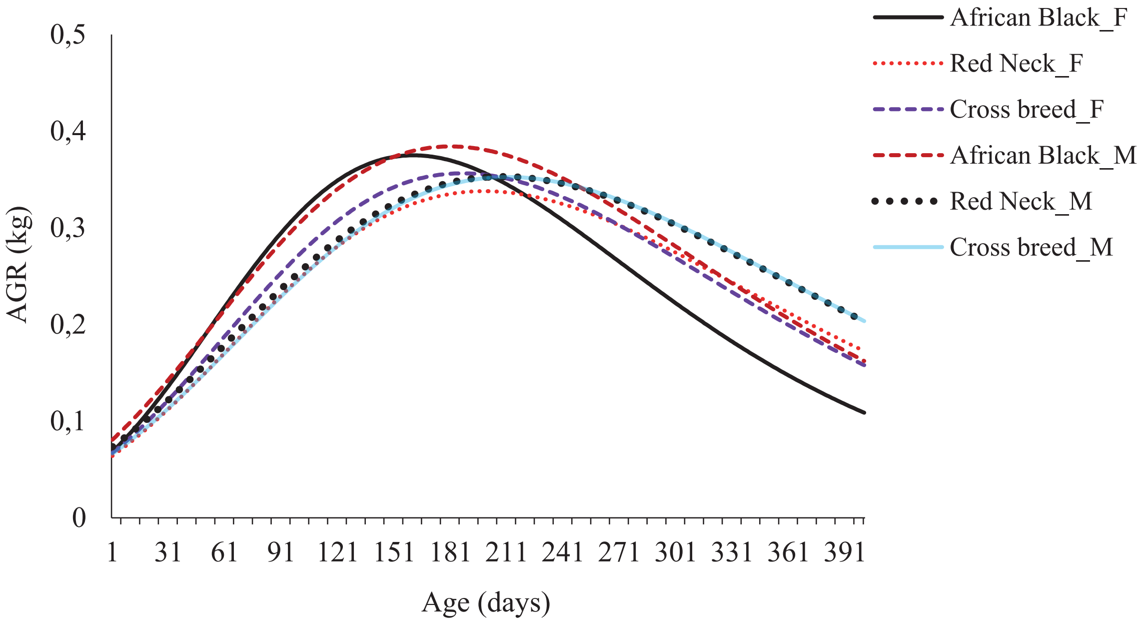

Figure 2. The Absolute Growth Rate (AGR) for Males (M) and Females (F) of the African Black, Red Neck and Cross breed breeds using Gompertz functions.

The Kleiber ratio (equation (3)) decreased ($p < 0.05$) with the increasing age of the animals. However, there was a correlation of 0.98, meaning that more efficient animals at 90D tend to be the same at 180D. At 90D, the KR of the animals was not significantly different ($p > 0.05$). At 180 days of age, both AB females and males showed higher feed efficiency (180D) relative to the other groups (Table 3). This result confirms the appropriateness of the KR as an indicator to identify animals with higher body growth rates without increasing the cost of maintaining energy, as reported by Gomes et al. (2012). The decrease in dietary efficiency with the advancement of age is related to the physiological behavior of the animal; adult animals have already undergone high increases in body weight and tend to stabilize, as already seen with the aid of the growth curve. Another important aspect is the influence of asymptotic weight, as the RN obtained a lower value of KR compared to AB.

AB is more precocious than RN because it has a smaller adult size and a greater KR value.

The first two principal components accounted for 98.5% of the variation between the ostriches. The first principal component explained 83.14% of the variation, as follows: −0.35*A + 0.43*k + 0.44*degree of maturity 90D + 0.44*degree of maturity 180D + 0.37*Kleiber ratio 90D + 0.38*Kleiber ratio 180D. The second principal component explained 15.35% of the variation and was described as: 0.61*A − 0.24*k − 0.03*degree of maturity 90D − 0.14*degree of maturity 180D + 0.55*Kleiber ratio 90D + 0.49*Kleiber ratio 180D.

Table 3
Kleiber ratio of the African Black, Red Neck and Cross breed breeds

	Kleiber ratio 90D		Kleiber ratio 180D	
	Mean	Standard error.	Mean	Standard error.
		Female		
African Black female	2.24 Aa	0.21	1.54 Ba	0.53
Red Neck female	2.15 Ab	0.19	1.32 Bb	0.49
Crossbreed female	2.16 Ab	0.20	1.30 Bb	0.48
		Male		
African Black male	2.26 Aa	0.17	1.61 Ba	0.42
Red Neck male	2.14 Ab	0.21	1.25 Bb	0.44
Crossbreed male	2.18 Aab	0.19	1.31 Bb	0.43

Means inside sex with different letters minuscule are significantly different, at 5% probability by the Tukey test.
Means between columns with different capital letters are significantly different, at 5% probability by the Tukey test.

The AU index derived from the heatmap developed by calculating the Euclidian distance (Figure 3) shows that only two subgroups (> 0.95) are strongly supported by the analysis despite all the other differences being supported by the high bootstrap values (> 75). The AB subgroup was different from the others regardless of sex mainly due to the effect of the similarity of the KR 90D and KR 180D parameters. However, in general, this subgroup also had the highest value for all parameters except parameter a of the growth curve in AB females.

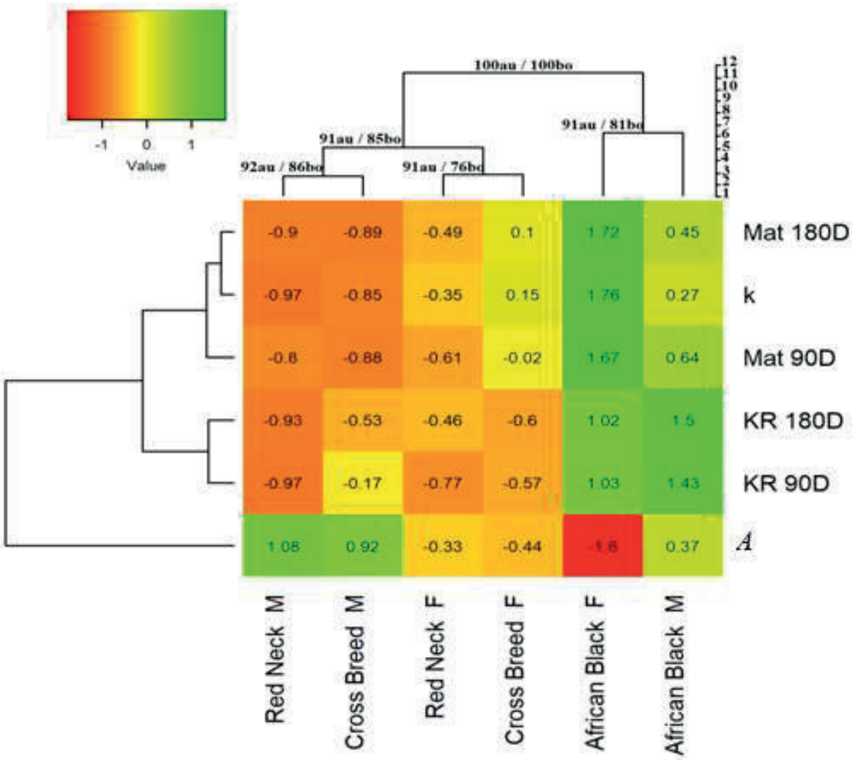

Figure 3. *Heatmap* and cluster of the African Black, Red Neck and Cross breed breeds.
A - asymptotic weight, *k* - maturity rate, Mat - degree of maturity, KR - Kleiber ratio, M - Males, F - Females.

Animals in subgroups RN and CB were separated by sex. The males were in the first group and females in the second group. The dendrogram of the traits also presented two distinct groups. The parameter A (asymptotic weight) of the growth curve was isolated from the other traits. This corroborates the interpretation of the principal component analyses.

Ostrich products are not restricted to meat. Thus, it is important to report that when examining the growth of birds, it is necessary to separate the growth of feathers from the growth of the rest of the body (Niemann et al., 2018). Feather proteins differ from body proteins, and the maturation rate is different for feathers and total body protein weight (Emmans & Fisher, 1986). This is significant because feathers are not allometrically related to total body protein, and predictions for feather growth cannot be made from body protein growth. Some studies have shown a strong relationship between the area and size of the skin, mainly with nutritional management (Brand et al., 2004). Thus, predicting the growth of ostriches is necessary for the development of a precise and economical feeding strategy (Brand & Gous, 2006) to include the use of skin along with meat and feathers.

In the context of considering the meat market, the AB ostrich is more precocious, with lower adult weight and higher feed efficiency, and is of interest to production systems or farms serving a consumer market seeking to reduce beef consumption by using meat from smaller animals; an advantage these animals offer besides optimizing the production cycle is also their contribution to the reduction of nutritional management expenses. Based on estimates of the A parameter among crossbreed and pure breed animals, heterosis was small. Crossbred animals showed less development than paternal lines (RN). This may have occurred because the origin of the breed was very close. The absolute growth rate for AB_F (AB females) showed a large explosion starting at 31 days and 170 days; however, AB_M (AB males) showed superiority to all this (at 31 and 239 days). The curve for RN_M (RN males) and CB_M (CB males) indicates that these animals are more robust than the other groups (this is clearly visible from the curve).

In general, research to improve the efficiency of production and the quality of products originating from ostrich is important for industrial-scale ostrich farming. The industry is likely to get a boost as the consumer market becomes more selective and attentive to health benefits with the nutritional quality of foods (Hoffman, Joubert, Brand, & Manley, 2005). Additionally, ostrich farming may be an alternative for farmers with limited space for large animals, such as cattle in the Northeast of Brazil, for example, because of their rusticity. The results of the growth curve and simultaneous KR can be employed as the first step towards the prediction of nutrient requirements and growth under limiting conditions.

Conclusion

In a market preferring smaller animals, it would be suitable to opt for the AB breed; moreover, these ostriches have a greater precocity, being able to be slaughtered at a younger age compared to the others. If there is a preference for animals with larger sizes (larger cuts), RN and CR males are the best option. However, these will need to be slaughtered at a relatively advanced age and have a lower value for KR that may generate higher production costs. An important option is to use ostriches offering precocity and high KR: the AB breed would then be a good choice.

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