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Applying machine learning to understand the relationship between body weight and beak and nail dimensions in broiler chickens

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ABSTRACT

The aim of this research was to determine whether body weight could be used as a reliable indicator of beak and claw length in broiler chickens during the production cycle. Sixty broiler chickens were evaluated individually and evaluated weekly (1, 7, 14, 21, 28, 35 and 42 days) throughout the production cycle. The following variables were measured: body weight, length of nails and beaks (maxillary mandible and beak area considering the presence of the nostril). The evaluation of body weight was performed using a digital scale. Nail lengths (U1, U2 and U3) were obtained using a digital calliper. The biomechanical analysis of the length of the beaks of the birds was carried out through photographs, using a digital camera and the analysis of the images carried out through the ImageJ software. It is concluded that the correlations between body weight x maxila, body weight x area of the beak with nostril and body weight x nails (U1, U2 and U3), can be a reliable indicator of dependence between the variables if we consider the complete breeding cycle of broiler chickens. However, when the correlations are evaluated weekly separately, they are not a reliable indicator. The first two main components revealed 94.7% of the data variation, with all morphological variables being important, as the communalities were greater than 0.93. The factorial analysis biplot revealed that nail characteristics, especially Nail1 and Nail 3, are strongly associated with the body weight of birds considering the complete cycle (42 days), i.e. nail characteristics are the main phenotypic predictors of body weight. The morphological traits of the nail and beak are predictors of body weight when evaluating the complete cycle (42 days), especially nail 1 and nail 3.

HIGHLIGHTS

- It was determined whether body weight could be used as a reliable indicator of beak and nails length in chickens.
- There is a low positive correlation in the biomechanics of the nostrils and peak with body weight in the rearing weeks evaluated individually.
- Correlations between body weight x mandible, bodyweight x beak area with nostril and body weight x nails can be a reliable indicator of dependence between variables if we consider the complete reproductive cycle of broiler chickens

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Introduction

In industrial poultry production, the highest production cost is attributed to the ingredients which make up diet formulation, corresponding to up to 70% of expenses (Carioca Júnior et al. 2015). Another important factor is the feed particle size, which is directly related to production cost, as the smaller the particle size of the feed material, the longer the grinding and sieving time, consuming a greater amount of energy during the manufacturing process, thus increasing the cost. Therefore, it is important to reduce losses during broiler feeding and feed milling to further reduce costs.

The ration is influenced by the size, shape and structure of the grain (Serrano et al. 2013; Classen 2017; Abdollahi et al. 2018). Birds are able to differentiate the size of feed particles by mecarreceptors located in the beak (Gentle 1979; Abdanan

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Mehdizadeh et al. 2015). Young broilers (4 days old) can distinguish small differences in the particle size of feeds (Nir et al. 1990; Abdanan Mehdizadeh et al. 2015; Abdollahi et al. 2018). Therefore, birds select the feed particles according to the size of the beak and oral cavity, so with the ageing of these, the oral biomechanical dimensions increase and the diet preference is for larger granulometries (Moran 1982).

For a better understanding of the importance of granulometry and food apprehension by broilers, it is necessary to understand the biomechanics of the feeding process and its influence on beak growth. The mechanical process of bird feeding is divided into stages, starting with the identification of the food particle and ending with its ingestion (Abdanan Mehdizadeh et al. 2015). The relationship between body weight and beak dimension of day-old chicks (Hy-Line W-36) was studied by Fahey et al (2007) who found a significant correlation. In view of this study, it is important to verify the association between beak length and body weight during the production cycle, aiming at a better dimensioning of precision feeders, with lower losses in feed intake.

Regarding nail length and body weight, no research was found correlating these variables. However, it is known that there are numerous losses in rearing, catching and transport due to lesions on the broiler carcase, due to the length of the nails, which can also affect the natural scratching behaviour of the birds. Therefore, it is necessary to develop management techniques that manage to minimise these damages; however, a previous study to determine nail lengths through body weight could facilitate the creation of this management technique.

Faced with this problem, the objective of this research was to determine whether body weight could be used as a reliable indicator of beak and claw length in broilers during the production cycle.

Material and methods

Sixty Cobb broiler chickens (male and female) were evaluated during the production cycle (42 days), which were reared in a climatic chamber under conditions of controlled air temperature and relative humidity, following the thermal requirements of the birds according to age and the Cobb manual. Birds had *ad libitum* access to water, feed, and unrestricted use of beds made of rice straw. The experimental diets were formulated according to the breed's manual recommendations. The bromatological composition of the feed formulation ingredients followed recommendations by Rostagno et al. (2011).

Birds were identified using numbers on plastic clamps. The following variables were measured: body weight, length of nails and beaks of 60 birds individually at each rearing week (1, 7, 14, 21, 28, 35 and 42 days).

The measurement of body weight was performed using a BAT1 digital scale (Veit Electronics). The claw lengths were obtained using a Starrett digital calliper, model 727 6/150 mm, measuring the lengths of the three nails (U1, U2 and U3) on the right feet of each bird (Figure 1).

The biomechanical analysis of beak length in broilers was based on the methodology described by Fahey et al (2007) who measured this variable in one-day-old White Leghorn chicks (Hy-Line W-36) using photographs. In this research, the lengths of broiler beaks during the production cycle (1, 7, 14, 21, 27, 28, 35 and 42 days) were verified through individual photographs of each bird following their ageing (Figure 2). Birds were positioned sideways in front of a dark surface to promote contrast, along with a graduated ruler positioned below the beak in order to provide a calibration scale. Images were obtained using a Sony high-resolution digital camera (Cyber-Shot model).

Image analysis was performed using the ImageJ software developed by Rasband (1997), the variables measured were: linear length of the maxilla and mandible, and beak areas considering the presence of the nostril (Figure 3).

In this study, the correlations evaluated were: U1 x body weight, U2 x body weight, U3 x body weight, maxilla x body weight, mandible x body weight and area of the beak with nostril x body weight. Exploratory statistics of the variables under study are presented in Table 1.

For the statistical analysis of the data, Pearson and Spearman correlations ($p < 0.05$) were used, which

Figure 1. Image of the disposition of the nails (U1, U2 and U3) on the feet of broiler chickens.

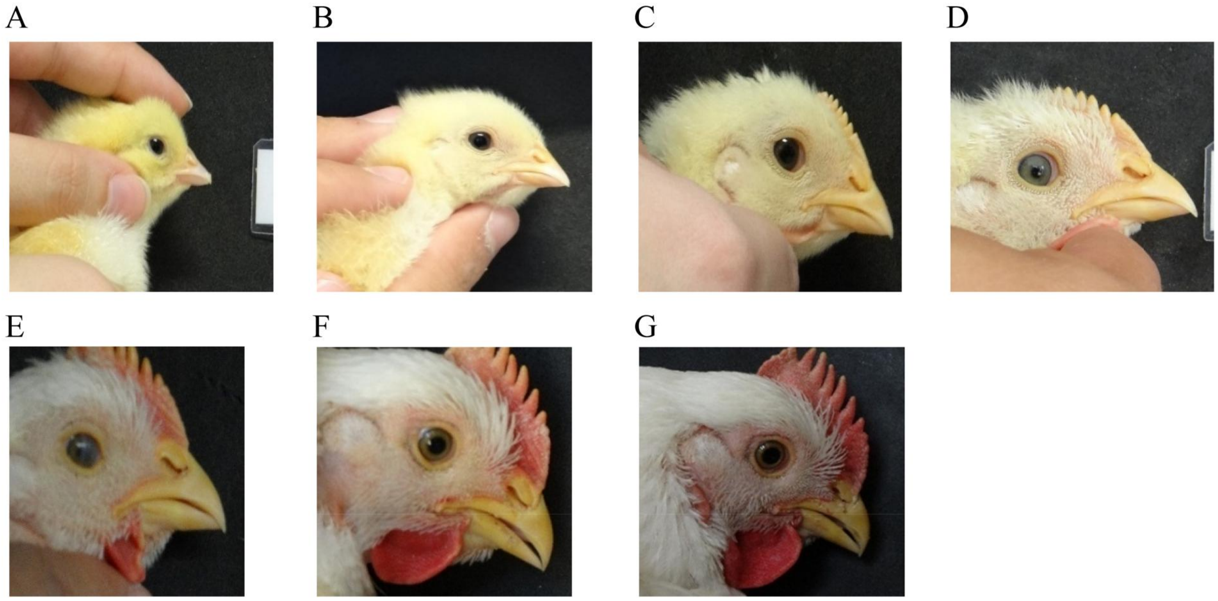

Figure 2. Images of broiler beak growth during the production cycle (*a* = 1 day; *B* = 7 days; *C* = 14 days; *D* = 21 days; *E* = 28 days; *F* = 35 days; *G* = 42 days).

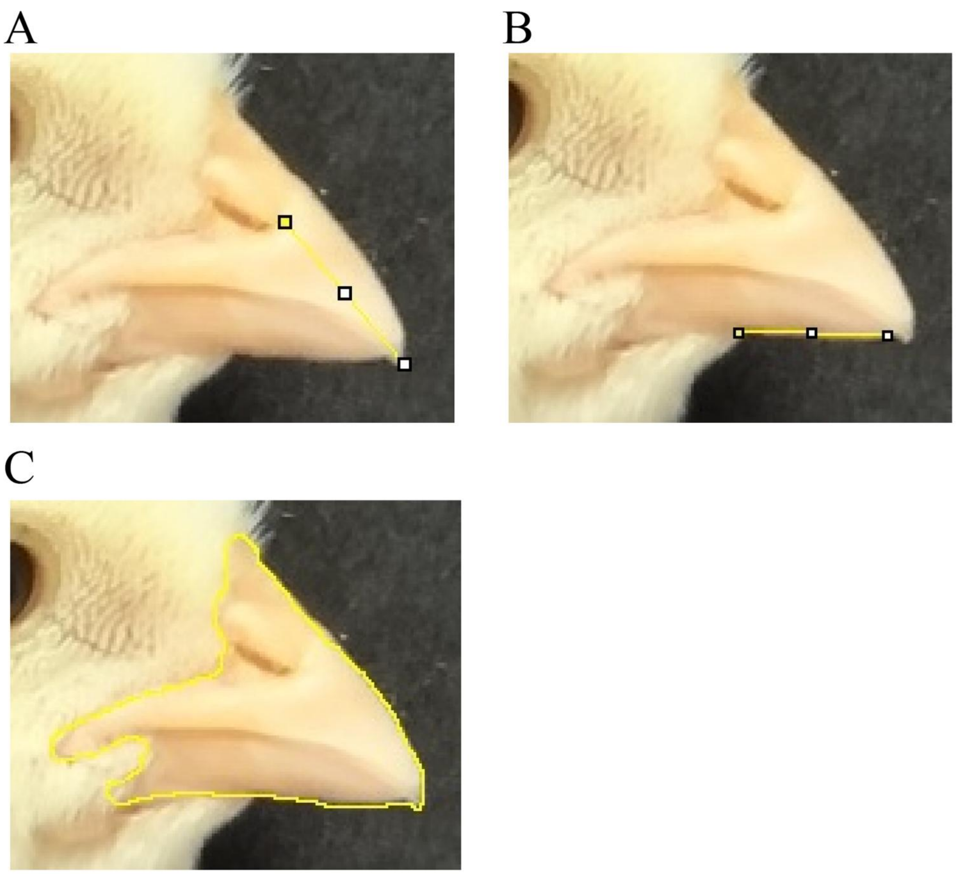

Figure 3. Images of obtaining values for the linear length of the maxila (A) and linear length of the maxila (B) and beak areas considering the nostril (C) of broiler chickens aged 7 days old.

were calculated for non-transformed data. The index obtained by this analysis is a measure of bivariate association between two factors, and this correlation may or may not imply causality. This association is represented by a dimensionless numeric value that varies between −1 and 1. Where 1 indicates a perfect positive correlation (complete dependence of one variable on another), 0 indicates absence of any kind of

Table 1. Exploratory statistics of the variables under study.

	N	Minimum	Maximum	Mean	Standard error
Nail 1 (cm)	407	0.10	1.41	0.74	0.29
Nail 2 (cm)	407	0.16	1.48	0.86	0.30
Nail 3 (cm)	407	0.30	1.24	0.72	0.22
Area of the beak with nostril	407	0.35	3.74	1.60	0.74
Maxila (cm)	407	0.49	1.92	1.13	0.36
Mandible (cm)	407	0.43	1.86	0.97	0.30
Body weight (kg)	407	0.04	3.72	1.22	1.07

correlation and −1 indicates a perfect negative correlation (Forlay-Frick et al. 2005).

Exploratory factor analysis was performed in order to understand the relationship between variables, more precisely which morphological characteristics of the beak and nail are related to body weight. The factor analysis model is expressed by Equation (1):

$$\begin{aligned} X_1 &= a_{11} \times F_1 + a_{12} \times F_2 + \cdots + a_{1m} \times F_m + e_p \\ X_2 &= a_{21} \times F_2 + a_{21} \times F_2 + \cdots + a_{2m} \times F_m + e_p \\ &\vdots \\ X_p &= a_{p1} \times F_1 + a_{p1} \times F_2 + \cdots + a_{pm} \times F_m + e_p \end{aligned} \quad [1]$$

where X_p is the pth score of the standardised variable ($p = 1, 2, \ldots, m$), F_m is the extracted factor, a_{pm} is the factor loading, and e_p is the error.

Factor scores for each group were estimated by multiplying standardised variables by the coefficient of the corresponding factor score, as follows Equation (2)

$$\begin{aligned} F_1 &= d_{11} \times X_1 + d_{12} \times X_2 + \cdots + d_{1j} \times X_{jp} \\ F_2 &= d_{21} \times X_2 + d_{21} \times X_2 + \cdots + d_{2j} \times X_{jp} \\ &\vdots \\ F_j &= d_{p1} \times X_1 + a_{j1} \times X_2 \ + \cdots + d_{jp} \times X_{jp} \end{aligned} \quad [2]$$

Where: F_j is the j-th factor extracted, d_{pj} is the factor score coefficient, and p is the number of variables (Hair et al. 2009).

Canonical discriminant analysis (CDA) was performed to evaluate the classification dynamics of birds according to weeks based on the morphological characteristics of the beak and nail. The general model of the CDA is described in the equation:

$$Z_n = \propto + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \quad (3)$$

Where: Z_n is the dependent variable (breed/sex), $\propto$ is the intercept, X_i are the explanatory variables, and β_i are the discriminant coefficients for each explanatory variable.

CDA was performed by the stepwise method. The significance of variables was determined by Wilk's Lambda statistic ($p < 0.05$). The relative importance of the variables within the canonical discriminatory functions was given by the value of the standardised canonical coefficients of the discriminant functions. The first two functions were plotted in a two-dimensional graph to evaluate the animals' classification according to their group of origin.

Results and discussion

Through the average values of beak length x body weight (A), nail length x body weight (B) and beak areas x body weight (C) of broiler chickens at different rearing ages, it was possible to verify that there is a simultaneous average increase in all variables analysed according to the ageing of the birds (Figure 4).

Based on these average values, it can be stated that there is a correlation between the increase in beak length x body weight, increase in the area of the beak with nostril x body weight and increase in nail length (U1, U2 and U3) x body weight of the birds. This correlation was confirmed through the correlation values (Pearson and Spearman) and the respective significance ($p < 0.05$) mentioned in Table 2.

All Pearson and Spearman correlations were significant ($p < 0.05$) for the variables: body weight x maxilla, body weight x mandible, body weight x beak area without nostril and body weight x beak area with nostril. However, these showed a strong and positive correlation coefficient (BW x MA = +0.950 and +1.000; BW x MN = +0.966 and +1.000; BW x AB = +0.941 and + 1.000; BW x U1 = +0.984 and +1.000; BW x U2 = +0.975 and +1.000; BW x U3 = +0.978 and +1.000). According to Forlay-Frick et al. (2005) and Santos (2007) a correlation coefficient of $p \geq 0.80$ indicates that these variables were dependent on each other, that is, there was a simultaneous increase in both variables in broiler chickens.

These results differ from those obtained by Fahey et al. (2007) who obtained significant correlations ($p < 0.05$) between body weight and beak dimensions of one-day-old White Leghorn chicks (Hy-Line W-36), though these correlations were low ($p < 0.23$). However, Laiolo and Rolando (2003) did not obtain significant correlations between body weight and beak dimensions in 28 crow species. In contrast to previous authors, Palacios and Tubaro (2000) found positive correlations between body weight and beak length in woodpeckers. Similarly, Clegg & Owens (2002) found that there is a great tendency among free-living birds to have larger beaks according to their weight gain. The disagreements reported in this work in relation to the research by Fahey et al. (2007) are due to the fact that the author carried out his research with day-old chicks, and in our research, we

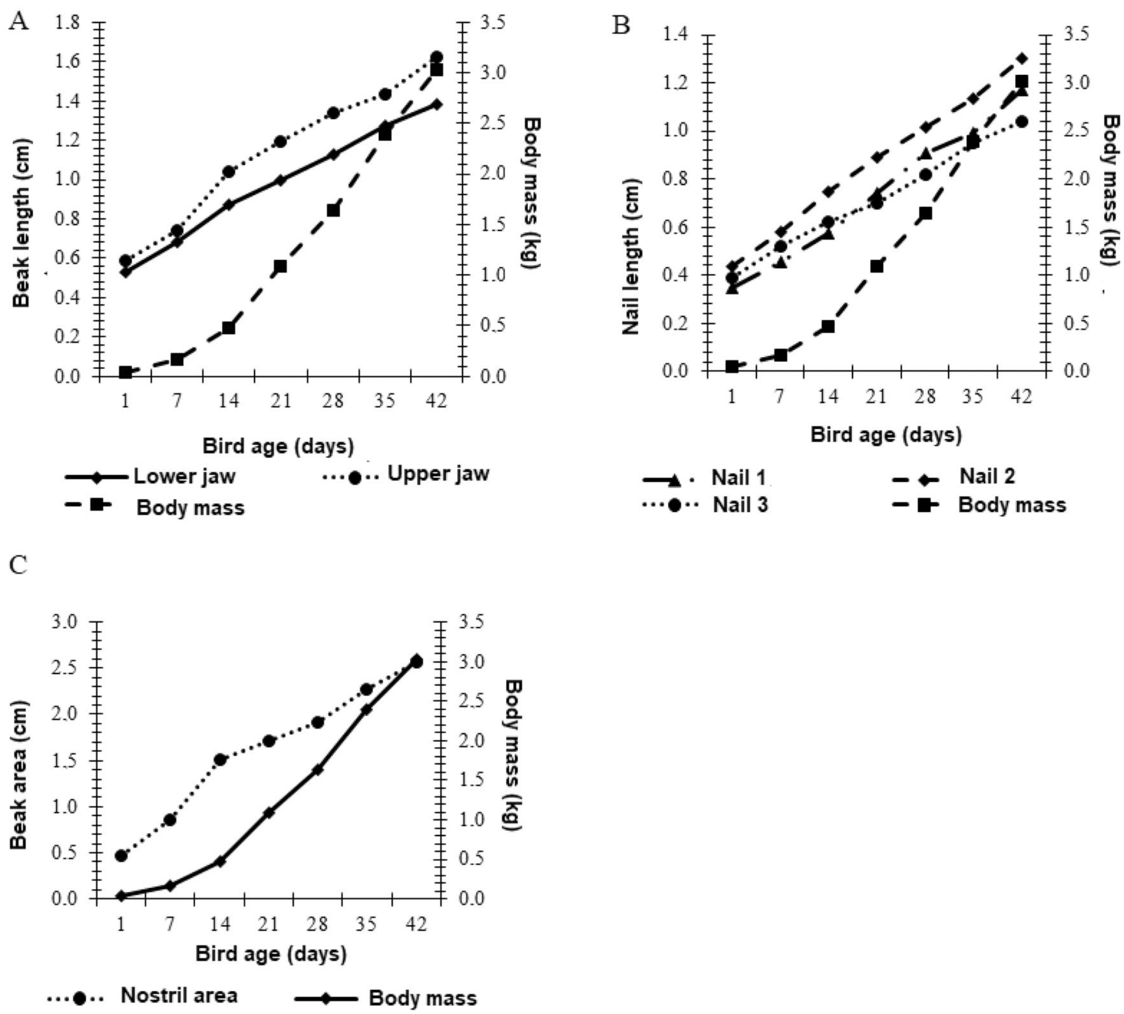

Figure 4. Average values of beak length x body weight (a), nail length x body weight (B) and areas of beak with nostril x body weight (C) of broilers at different rearing ages.

Table 2. Correlations and significance ($p < 0.05$) between body weight and beak length (maxila, mandible, nostril area) of broilers during the production cycle.

Correlation Type	BW x MA	BW x MN	BW x AB	BW x N1	BW x N2	BW x N3
Pearson	+0.950	+0.966	+0.941	+0.984	+0.975	+0.978
$p < 0.05$	<0.0010*	<0.0004*	<0.0016*	<0.0001*	<0.0002*	<0.0001*
Spearman	+1.000	+1.000	+1.000	+1.000	+1.000	+1.000
$p < 0.05$	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*

BW: Body weight; MA: maxila; MN: mandible and AB: area of the beak with nostril =. NS: not significant ($p > 0.05$), * – Significant ($p < 0.05$); N1: Nail 1; N2: Nail 2; N3: Nail 3.

evaluated throughout the production cycle, that is, throughout the animal's growth.

Knowledge of the oral biomechanics of broilers is directly related to feed granulometry, so understanding these properties will facilitate the design of new feeders which minimise feed losses. As already mentioned, broilers are able to differentiate the size of feed particles and, as they grow, they prefer food with larger granules (Moran 1982; Serrano et al. 2013; Abdollahi et al. 2018). This fact justifies the importance of information for the development of intelligent feeders and granulometric variation of food.

Regarding the length of nails and body weight of broilers, it can be said that this correlation will help in the development of a technique which promotes the reduction of losses due to injuries in the carcase. According to Benincasa (2017) the amounts of scratches during the rearing of broilers was 89.3 and in the pre-slaughter period 22% was reported. However, Gouveia et al. (2009) and Allain et al. (2009)

Table 3. Pearson correlations and significance ($p < 0.05$) for different correlated variables during the rearing cycle (bird age).

Bird age (days)	Correlated variables	Pearson's correlation (r)	p value ($p < 0.05$)
1	Nail 1 x Body weight	0.2291	0.0782NS
	Nail 2 x Body weight	0.2174	0.0953NS
	Nail 3 x Body weight	0.2077	0.1113NS
	Maxila x Body weight	0.028	0.8320NS
	Maxila x body weight	−0.023	0.8614NS
	Beak area x Body weight	−0.1554	0.2357NS
7	Nail 1 x Body weight	0.2135	0.1045NS
	Nail 2 x Body weight	0.2905	0.0256*
	Nail 3 x Body weight	0.2762	0.0342*
	Maxila x Body weight	0.279	0.0324*
	Maxila x body weight	−0.0154	0.9076NS
	Beak area x Body weight	0.1937	0.1415NS
14	Nail 1 x Body weight	0.1211	0.3652NS
	Nail 2 x Body weight	−0.0139	0.9173NS
	Nail 3 x Body weight	0.0699	0.6021NS
	Maxila x Body weight	0.4974	<.0001*
	Maxila x body weight	0.3817	0.0031*
	Beak area x Body weight	0.4717	0.0002*
21	Nail 1 x Body weight	−0.1575	0.2335NS
	Nail 2 x Body weight	0.294	0.0238*
	Nail 3 x Body weight	−0.1841	0.1629NS
	Maxila x Body weight	0.205	0.1194NS
	Maxila x body weight	0.1091	0.4107NS
	Beak area x Body weight	0.2679	0.0402*
28	Nail 1 x Body weight	0.0602	0.6504NS
	Nail 2 x Body weight	0.1134	0.3926NS
	Nail 3 x Body weight	0.0392	0.7679NS
	Maxila x Body weight	0.3472	0.0071*
	Maxila x body weight	0.1201	0.3649NS
	Beak area x Body weight	0.3502	0.0065*
35	Nail 1 x Body weight	0.0743	0.5793NS
	Nail 2 x Body weight	0.2897	0.0274*
	Nail 3 x Body weight	0.0523	0.6969NS
	Maxila x Body weight	0.1709	0.1996NS
	Maxila x body weight	−0.0348	0.7952NS
	Beak area x Body weight	0.0367	0.7843NS
42	Nail 1 x Body weight	−0.0809	0.5609NS
	Nail 2 x Body weight	0.0876	0.5290NS
	Nail 3 x Body weight	0.3095	0.0227*
	Maxila x Body weight	0.495	0.0001*
	Maxila x body weight	0.0549	0.6935NS
	Beak area x Body weight	0.1088	0.4335NS

NS: not significant ($p > 0.05$), *: Significant ($p < 0.05$).

found 22 and 79.7% of injuries attributed to scratches during poultry rearing. In addition, the natural scratching behaviour of broilers can be affected by nail length.

Partial correlations between the variables under study (weekly) were verified and presented in Table 3. It is noted that in these weekly assessments, the correlations were weak and positive ($0.1 \leq r < 0.5$). It can be stated that there is a low dependence on the significant correlations in the rearing weeks evaluated individually.

The results obtained for the different rearing ages were similar to those found by Fahey et al. (2007) who evaluated one-day-old White Leghorn chicks (Hy-Line W-36) and obtained a low and positive correlation between body weight and beak size. However, Laiolo and Rolando (2003) did not obtain significant correlations between body weight and beak size in 28 crow species.

The relationship between the morphological variables of the nail and beak is presented in Figure 5. The first two main components revealed 94.7% of the data variation, with all morphological variables being important, as the communalities were greater than 0.93. The factorial analysis biplot revealed that nail characteristics, especially Nail1 and Nail 3, are strongly associated with the body weight of birds considering the complete cycle (42 days), i.e. nail characteristics are the main phenotypic predictors of body weight, being justified because the characteristics of the nail can be related to support and assistance for locomotion, especially in industrial poultry farming which has a short cycle and fast-growing animals. The other morphological variables also showed moderate correlation, as shown in Figure 5.

The weekly classificatory dynamics of the birds according to the morphological variables of the nail

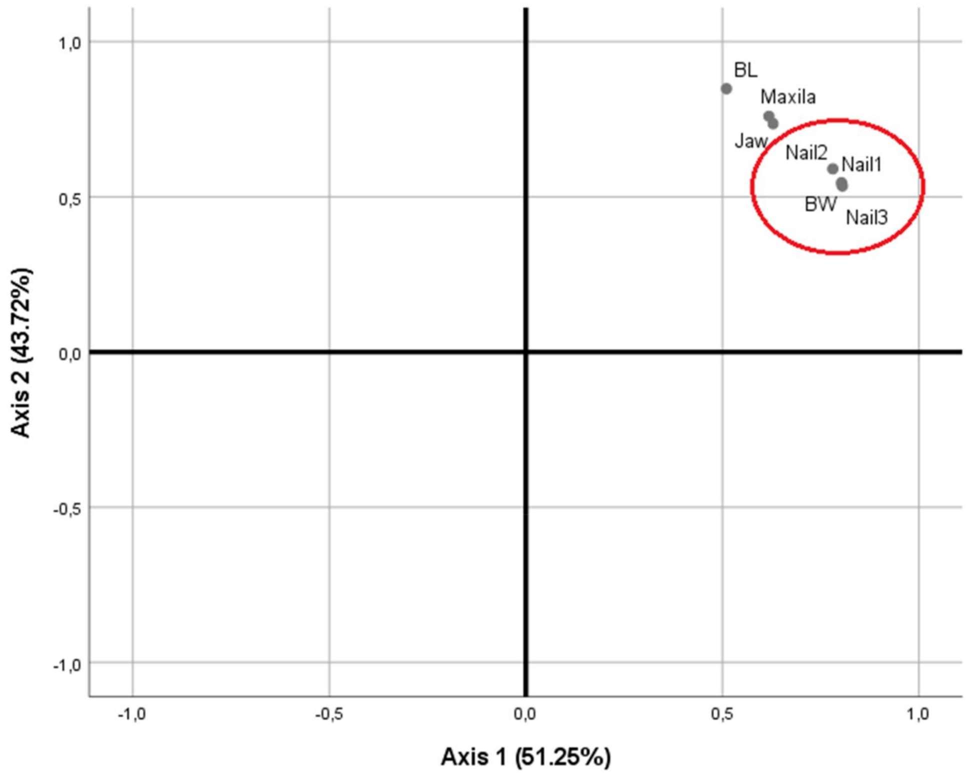

Figure 5. Biplot of the exploratory factor analysis for the characteristics of the beak and nails of broiler chickens considering the complete production cycle (42 days).

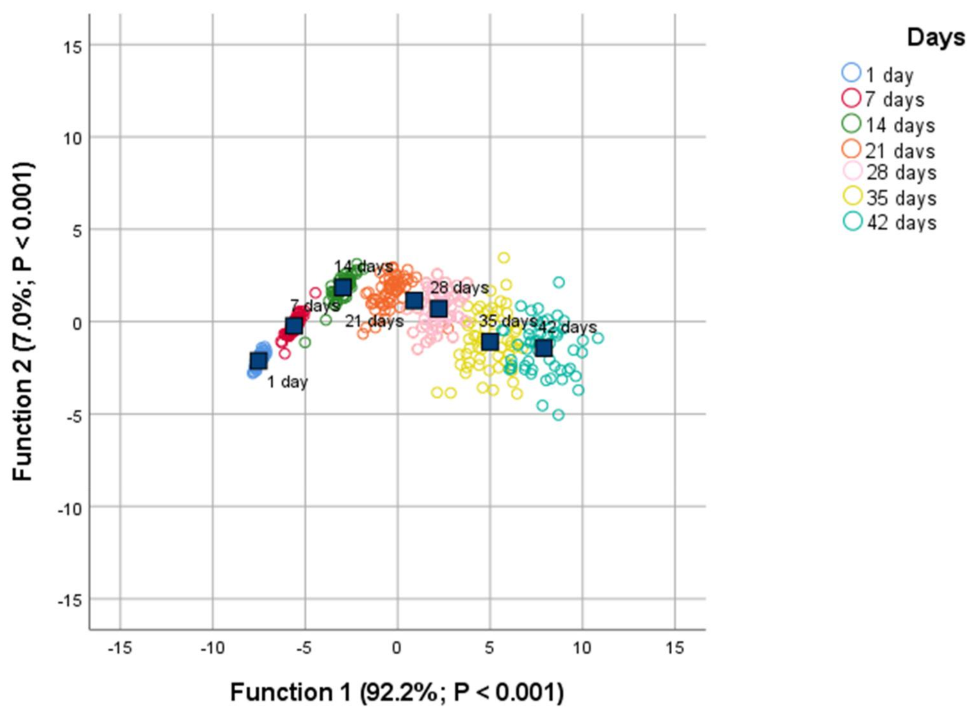

Figure 6. Biplot of the canonical discriminate analysis for the characteristics of the beak and nails of broiler chickens.

and beak is presented in Figure 6. It was observed that 98.2% of the variation was discriminated in the first two canonical functions, these being significant ($p < 0.005$). The main phenotypic biomarker which differentiates birds based on weeks is body weight, justifying the selection of productive traits in the genetic improvement of birds combined with animal nutrition systems.

Conclusions

The morphological traits of the nail and beak are not a reliable indicator of body weight when we only consider weekly data, but it is a reliable indicator when considering the complete cycle (42 days), with Nail 1 and Nail 3 being the two most common predictors associated with body weight as demonstrated by machine learning. Body weight is the phenotypic biomarker of the weekly classification dynamics of birds considering the morphological and performance variables which were evaluated in this study.

Authors' contribution

Aérica Cirqueira Nazareno (Supervision, Project administration, Methodology; Writing - original draft and Funding acquisition); Robson Mateus Freitas Silveira (Writing - original draft and final review).

Ethical Approval

This study was approved by the Animal Ethics Committee (CEUA) of ESALQ/USP under protocol no. 2016/10.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Data will be made available on request.

Code availability

Not applicable.

References

Abdollahi M, Zaefarian F, Ravindran V. 2018. Feed intake response of broilers: impact of feed processing. Anim. Feed Sci. Technol. 237:154–165. doi: 10.1016/j.anifeedsci.2018.01.013.

Abdanan Mehdizadeh S, Neves DP, Tscharke M, Nääs IA, Banhazi TM. 2015. Image analysis method to evaluate beak and head motion of broiler chickens during feeding. Comput. Electron. Agric. 114:88–95. doi: 10.1016/j.compag.2015.03.017.

Allain V, Mirabito L, Arnould C, Colas M, Le Bouquin S, Lupo C, Michel V. 2009. Skin lesions in broiler chickens measured at the slaughterhouse: relationships between lesions and between their prevalence and rearing factors. Br Poult Sci. 50(4):407–417. doi: 10.1080/00071660903110901.

Benincasa NC. 2017. Caracterização do sistema de criação de frangos de corte em galpões de pressão negativa, das operações pré-abate e da qualidade do produto final. Dissertação de mestrado. Piracicaba:University of São Paulo.

Carioca Júnior HR, Freitas HJ, Cordeiro MB, Gomes FA. 2015. Efeito da granulometria do milho sobre o desempenho zootécnico e rendimento de carcaça de frangos de corte de linhagem caipira. Enc. Biosf. 11:851–860.

Classen H. 2017. Diet energy and feed intake in chickens. Anim. Feed Sci. Technol. 233:13–21. doi: 10.1016/j.anifeedsci.2016.03.004.

Clegg SM, Owens IPF. 2002. The "island rule" in birds: medium body size and its ecological explanation. Proc Biol Sci. 269(1498):1359–1365. doi: 10.1098/rspb.2002.2024.

Fahey G, Marchant-Forde RM, Cheng HW. 2007. Relationship between body weight and beak characteristics in one-day-old white leghorn chicks: its implications for beak trimming. Poult Sci. 86(7):1312–1315. doi: 10.1093/ps/86.7.1312.

Forlay-Frick P, Van Gyseghem E, Héberger K, Vander Heyden Y. 2005. Selection of orthogonal chromatographic systems based on parametric and non-parametric statistical tests. Anal. Chim. Acta. 539(1–2):1–10. doi: 10.1016/j.aca.2005.02.058.

Gentle MJ. 1979. Sensory control of feed intake. In: Boorman, K.N., Freeman, B.M. Editors., Food Intake Regulation in Poultry. British Poultry Science Ltd, Edinburg; p. 259–273.

Gouveia KG, Vaz-Pires P, Costa PM. 2009. Welfare assessment of broilers through examination of haematomas, foot-pad dermatitis, scratches and breast blisters at processing. Anim Welf. 18(1):43–48. doi: 10.1017/S0962728600000051.

Hair Jr. JF, Black WC, Babin BJ, Anderson RE. 2009. Multivariate data analysis. 7th ed. Upper Saddle River: Prentice Hall; p. 761.

Laiolo P, Rolando A. 2003. The evolution of vocalizations in the genus Corvus: effects of phylogeny, morphology, and habitat. Evol. Ecol. 17(2):111–123. doi: 10.1023/A:1023003110969.

Moran ET. 1982. Comparative nutrition of the fowl and swine. In Moran, E. T. (Ed.), The gastrointestinal system. Guelph, Ontário, Canada: University of Guelph, p. 185–189.

Nir I, Melcion JP, Picard M. 1990. Effect of particle size of sorghum grains on feed intake and performance of young broilers. Poult. Sci. 69(12):2177–2184. doi: 10.3382/ps.0692177.

Rasband W. 1997. Image Processing and Analysis in Java – ImageJ. Nacional Institutes of Health. Version 1. Disponível em: <https://imagej.nih.gov/ij/>. Acesso em: maio, 2018.

Rostagno HS, Albino LFT, Donzele JL, et al. 2011. Tabelas brasileiras para aves e suínos: composição de alimentos e exigênciasnutricionais. 3.ed. Viçosa: UFV; p. 252.

Serrano MP, Frikha M, Corchero J, Mateos GG. 2013. Influence of feed form and source of soybean meal on growth performance, nutrient retention, and digestive organ size of broilers. 2. Battery study. Poult Sci. 92(3): 693–708. doi: 10.3382/ps.2012-02372.

Palacios MG, Tubaro PL. 2000. Does beak size affect acoustic frequencies in woodcreepers? Condor. 102(3):553–560. doi: 10.1650/0010-5422(2000)102[0553:DBSAAF]2.0.CO;2.