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Multivariate Analysis in Food Production: Influence of Nutrition and Thermal Regulation

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Abstract

The objective of this research was to reduce the dimensionality of the original set of variables by eliminating redundant information and enabling the recommendation of variables to be evaluated in future experiments. A total of 240 European quail chicks (*Coturnix coturnix Japonica*), aged one day and with an average weight of 8 g, standard deviation ± 0.50 g, were analyzed in this study. It was observed that weight gain (32.75%), liver (37.19%), and intestine (33.54%) exhibited the highest coefficients of variation. On the other hand, cloacal temperature had the lowest coefficient of variation (0.88%), indicating low variability in respiratory rate (16.23%) and surface temperature (3.55%). In total, the three main components together explained 74.65% of the data variation, indicating that, among the 16 variables analyzed, 13 were significant in explaining the observed variability. The variables heart weight, liver, and gizzard were not considered relevant for this study once their impact on the multivariate analysis was minimal. These results have direct implications for the food industry, as they reveal factors that affect meat quality and consumer acceptance.

Keywords: carcass quality; dimensionality reduction; food industry impact; quail production.

Pratical application: Based on the patterns identified in the statistical analyses, it is possible to improve the efficiency of slaughter logistics and meat processing, ensuring higher carcass yield and reduced variation in product quality.

1 INTRODUCTION

Carcass evaluation is a fundamental process in determining the value and quality characteristics of production animals intended for slaughter. The commercial value is strongly related to carcass yield and composition, which includes the proportions of muscle, fat, and bone. As described by Ekiz et al. (2020), these characteristics vary significantly and have a direct impact on the commercial value of meat.

In animal production systems, the qualitative and quantitative characteristics of carcasses are crucial for the success of the sector, since they directly influence market acceptance of the product. To meet consumer demands, it is essential to obtain well-conformed carcasses with a high proportion of muscle and an adequate amount of intramuscular fat, which contributes to the juiciness and flavor of meat. Since poultry feed accounts for approximately 70% of total production costs, there is a continuous effort to find viable alternative feed sources that can replace traditional ingredients without compromising nutritional quality and the productive performance of animals (Ferreira et al., 2019).

Among the alternative feed sources, marine algae stand out, having been incorporated into the diets of broiler chickens (Gatrell et al., 2014; Petrolli et al., 2019; Qadri et al., 2019), laying hens (Carrillo et al., 2012), laying quails (Melo et al., 2008a), and meat quails (Abouelezz, 2017; Cheong et al., 2016; Melo et al., 2008b). Algae from the species *Sargassum sp.*, which are found abundantly along the Brazilian coast, have low lipid concentrations and high levels of proteins, polysaccharides, vitamins, and minerals (Carrillo et al., 2012; Costa et al., 2016). Additionally, this species possessess unique antioxidant properties that can aid in the metabolic regulation of animals (Boiago et al., 2019; Gatrell et al., 2014; Hajati et al., 2020).

Protein- and mineral-rich foods are considered promising alternatives to animal nutrition. In general, algae and microalgae have remarkable nutritional characteristics depending on the cultivation environment; besides high levels of proteins, carbohydrates, vitamins, and minerals, some species also contain natural pigments and ether extract (González López et al., 2010). Furthermore, certain species of marine algae possess unique metabolic properties that make them advantageous compared to conventional ingredients, positively influencing

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animal performance (Boiago et al., 2019; Gatrell et al., 2014; Hajati et al., 2020).

Micronutrients and macronutrients play an essential role in the quails' growth and development, which nearly triple their weight by 25 days of age. Among minerals, calcium and phosphorus are particularly important, as they not only promote an optimal growth rate but are also the primary components of the bone matrix, contributing approximately 95% of the organism's mineral structure (Gatrell et al., 2014).

When dealing with a large number of descriptors, many of them may be redundant, making their elimination beneficial, as they are not only uninformative but also increase the workload in evaluations (Jolliffe, 1972, 1973). Thus, variable reduction can be performed using principal components analysis, whose main objective is to summarize the information contained in the complex set of original variables, eliminating redundancies that arise due to correlations among them (Khattree & Naik, 2000).

Finally, the application of multivariate models allows for a deeper analysis of the relationships between various explanatory variables involved in carcass and animal nutrition studies. In particular, principal component analysis is a useful statistical tool for reducing data dimensionality and identifying relevant patterns to optimize production strategies.

The objective of this research was to reduce the dimensionality of the original set of variables by eliminating redundant information and enabling the recommendation of variables to be evaluated in future experiments.

1.1 Relevance of the work

The knowledge generated in this study can be applied to reduce variations in animal growth, improve diet formulation, and ensure a uniform final product that is well accepted by the consumer market. This approach can also be expanded to enhance other aspects of animal production, such as sustainability and food security.

2 MATERIAL AND METHODS

The procedures carried out in this research were approved by the Research Ethics Committee of the Federal University of Campina Grande, Paraíba, Brazil, under protocol nº 03/2021.

A total of 240 European quail chicks (*Coturnix coturnix japonica*) were examined, with an initial age of one day and an average weight of 8 g, standard deviation ± 0.50 g. They were acquired from a commercial hatchery, vaccinated, dewormed, and not sexed. The experimental period began on the first day and lasted until the birds were 42 days old.

The experiment was arranged in a completely randomized design with four treatments (four levels of algae inclusion: 0, 2.5, 5.0, and 7.5%) with six replicates per experimental unit. Throughout the experimental period, the birds were weighed at seven-day intervals, totaling six weighings. The lighting program was continuous, with 24 hours of uninterrupted daily light (12 hours natural and 12 hours artificial) throughout the entire experiment.

Live weight and weight gain of the birds were evaluated per treatment, measured weekly in grams through direct weighing using an analytical precision balance (resolution of 0.1 g). Feed and water consumption were calculated weekly based on the difference between the amounts supplied and the leftovers, divided by the number of animals, and adjusted according to bird mortality. Feed conversion was calculated as the ratio between feed intake per bird and weight gain.

The birds were subjected to a 12-hour fasting period before slaughter, with only water available *ad libitum*. After this period, slaughter was performed, including stunning, bleeding, scalding in hot water, and removal of feathers, feet, head, and viscera, obtaining the weight of the cleaned and eviscerated carcass.

Carcass yield was calculated by relating carcass weight to live weight, with the result multiplied by one hundred. The cuts performed included thighs and drumsticks, breast, wings, and back, using a set of knives, scalpels, and surgical scissors.

For organ yield assessment, the heart, liver, and gizzard were weighed using an analytical precision balance (± 0.1 g). To evaluate intestinal biometry, weight and length measurements of the intestines were taken, with the small and large intestines weighed using a precision scale and their length determined with the aid of a measuring tape.

Starting at 9 days of age, the quails were subjected to thermal stress treatments, with four birds identified per repetition to be used as a sample group. From the fifth day of the experiment, with the quails exposed to thermal stress and natural conditions, measurements of cloacal temperature, surface temperature, and respiratory rate were taken every three days between 11:00 and 13:00 at all phases.

For cloacal temperature measurement, a Bioland® T102 digital thermometer with a rigid probe and ± 0.1°C precision was used. The sensor (probe 400) was inserted into the cloaca of the birds until stabilization was indicated by an audible signal.

Respiratory rate collection was performed by capturing one bird at a time and waiting for breathing stabilization. Then, the pectoral movements were counted over an average period of 15 seconds, and the result was multiplied by four to obtain the total number of movements per minute (mov. min^{-1}).

The surface temperature of the birds was determined from images captured at a distance of 50 ± 0.5 cm using thermal infrared technology with a TI 55FT FlexCam thermographic camera from Fluke. The camera was calibrated before recording with an emissivity of 0.95 and a resolution of 0.05°C. The images were analyzed using SmartView software, version 4.3, considering three distinct body regions: head, foot, and wing. The average surface temperature was calculated by adapting the equation proposed by Richards (1971).

Data was analyzed using the PROC MEANS procedure in SAS OnDemand (2025) to obtain information on mean values, coefficients of variation, and maximum and minimum values. Additionally, Pearson's correlation was performed using the PROC CORR procedure in SAS. After standardization, a multivariate analysis test was carried out following the recommendations previously established by Sneath & Sokal (1973) to allocate the animals into groups based on similarity and verify the original variables' discriminant capacity. The principal component analysis allowed the assessment of overall variance, and the discriminant analysis described the variation among the different groups and identified the variables with greater discriminatory power between groups. The principal component analysis was performed by the PRINCOMP (Statistical Analysis System Institute, 2010) procedure, separately for each population.

3 RESULTS

It was observed that weight gain (32.75%), liver (37.19%), and intestine (33.54%) exhibited the highest coefficients of variation (Table 1). On the other hand, cloacal temperature presented the lowest coefficient of variation (0.88%), indicating low variability in respiratory rate (16.23%) and surface temperature (3.55%).

Analyzing Pearson's correlation, it was found that cloacal temperature and surface temperature showed a positive correlation above 70% with water intake, while maintaining an inverse correlation with feed intake and weight gain (Table 2). This suggests that water consumption may have a significant impact on animals' thermal regulation and, consequently, their metabolism and productive performance.

In the principal component analysis, the first principal component (PC1) explained 40% of the data variation; it consists of feed intake, water intake, weight gain, wing weight, cloacal temperature, and surface temperature (Table 3). Feed intake and weight gain showed an inverse correlation with water intake, wing weight, cloacal temperature, and surface temperature, with feed intake being the most influential variable in PC1.

The second principal component (PC2) explained 25% of the data variation; it comprises final weight, carcass weight, thigh weight, breast weight, back weight, and gizzard weight,

Table 1. Mean, maximum and minimum values, and coefficient of variation of the variables analyzed in quails that received algae in their diet.

Variables	Mean	Maximum	Minimum	CV (%)
Water consumption (grams)	912.32	1,034.08	810.50	7.96
Feed consumption (grams)	422.69	503.40	331.50	16.85
Weight gain (grams)	91.73	133.90	54.50	32.75
Final weight (grams)	222.19	256.64	181.92	8.25
Carcass weight (grams)	162.11	195.08	127.91	8.89
Thigh (grams)	30.07	34.87	24.48	8.66
Breast (grams)	58.46	73.34	41.07	10.17
Back (grams)	58.93	71.90	46.33	11.39
Wing (grams)	14.64	19.28	11.35	12.55
Heart (grams)	1.79	2.17	1.42	9.75
Liver (grams)	4.46	13.94	3.03	37.19
Gizzard (grams)	4.19	6.50	3.29	13.48
Intestine (grams)	19.35	34.95	8.50	33.54
Respiratory rate (mov./min)	68.75	132.25	54.25	16.23
Cloacal temperature (°C)	41.03	41.66	40.28	0.88
Surface temperature (°C)	36.00	37.77	34.19	3.55

CV: coefficient of variation.

Table 2. Pearson's correlation between the analyzed variables.

Variables	Respiratory rate (mov./min)	Cloacal temperature (°C)	Surface temperature (°C)
Water consumption (grams)	0.14	0.74*	0.89*
Feed consumption (grams)	−0.19	−0.81*	−0.95*
Weight gain (grams)	−0.18	−0.77*	−0.95*
Final weight (grams)	−0.21	−0.38*	−0.41*
Carcass weight (grams)	−0.26	−0.25	−0.28*
Thigh (grams)	−0.25	0.00	0.08
Breast (grams)	−0.21	−0.34*	−0.40*
Back (grams)	−0.30*	−0.36*	−0.43*
Wing (grams)	0.12	0.42*	0.56*
Heart (grams)	−0.01	−0.04	−0.11
Liver (grams)	0.16	−0.11	−0.04
Gizzard (grams)	−0.06	−0.19	−0.23
Intestine (grams)	0.05	−0.27	−0.37*

*Significant at 5%.

all of which showing positive correlation, with carcass weight being the most significant factor in PC2. The third principal component (PC3) explained 8% of the variation, represented by respiratory rate.

In total, the three principal components together explained 74.65% of the data variation, indicating that, among the 16 variables analyzed, 13 were determinant in explaining the observed variability. The variables heart weight, liver, and gizzard were not considered relevant for this study, as their impact on the multivariate analysis was minimal.

Figure 1 presents the graphical distribution of the variables, highlighting that cloacal temperature, surface temperature, and water intake are positioned inversely to feed intake, weight gain, carcass weight, breast weight, back weight, gizzard weight, and weight after fasting. This reinforces the influence of thermal regulation mechanisms on food consumption and animal growth.

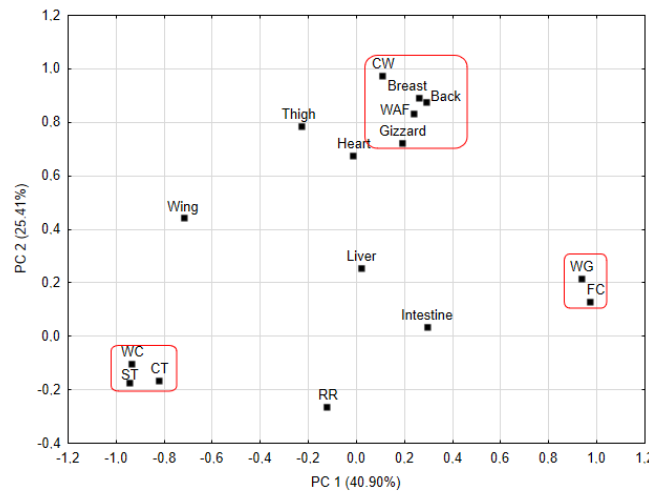
4 DISCUSSION

The coefficients of variation reflect the magnitude of data dispersion relative to the mean and can provide important insights into the variability of animals' physiological and metabolic responses. The high coefficients of variation in weight gain, liver, and intestine indicate that these variables exhibit significant variability among the analyzed individuals, which may be influenced by diet, as it includes increasing levels of algae.

In animal production systems, large variations in weight gain can be challenging as they affect carcass uniformity and product standardization. Meanwhile, variations in liver and intestine weight may be related to animals' metabolic efficiency and nutrient absorption capacity.

Marine algae species such as *Sargassum spp.*, *Gracilaria sp.*, and *Spirulina platensis* are excellent sources of minerals, carbohydrates, and essential amino acids such as arginine, tryptophan, and phenylalanine. They are also rich in beta-carotene and vitamins (Hajati et al., 2020). These algae and others of the same genus, when used in poultry feed, promote growth and increase intestinal flora (Fernandes et al., 2020; Hajati et al., 2020; Jha & Mishra, 2021), leading to positive results in egg production, improved animal performance, and increased feed and water intake (Carlos et al., 2011).

Abouelezz (2017) reported that the inclusion of *Spirulina* powder (1% in feed) increased weight and weight gain, resulting in better feed conversion rates in Japanese quails during the growth phase. The presence of fiber stimulates greater intestinal activity, aiming to improve digestion and nutrient absorption in a high-viscosity diet, consequently supporting the development of organs and the birds themselves.



WC: water consumption; FC: feed consumption; WG: weight gain; WAF: weight after fasting; CW: carcass weight; RR: respiratory rate; CT: cloaca temperature; ST: surface temperature.

Figure 1. Two-dimensional graph of the distribution of variables in the quadrants.

Table 3. Principal components for the analyzed variables in quails.

Variables	PC1	PC2	PC3
Water consumption (grams)	**–0.93**	–0.10	0.00
Feed consumption (grams)	**0.97**	0.12	–0.06
Weight gain (grams)	**0.93**	0.21	–0.04
Final weight (grams)	0.23	**0.83**	–0.00
Carcass weight (grams)	0.11	**0.97**	–0.07
Thigh (grams)	–0.22	**0.78**	–0.08
Breast (grams)	0.26	**0.89**	–0.01
Back (grams)	0.29	**0.87**	–0.13
Wing (grams)	**–0.71**	0.43	0.08
Heart (grams)	–0.01	0.67	0.32
Liver (grams)	0.02	0.25	0.69
Gizzard (grams)	0.19	**0.72**	0.25
Intestine (grams)	0.29	0.03	0.18
Respiratory rate (mov./min)	–0.12	–0.26	**0.76**
Cloacal temperature (°C)	**–0.82**	–0.16	–0.04
Surface temperature (°C)	**–0.94**	–0.17	0.02
Eigenvalue	6.54	4.06	1.33
Cumulative (%)	40.90	66.32	74.65

On the other hand, the cloacal temperature, by showing the lowest coefficient of variation, suggests a more stable thermal regulation among individuals, regardless of environmental or physiological conditions. Since body temperature is directly linked to metabolism and water regulation, a low variation may indicate that animals maintain an effective thermal balance, which can be beneficial for their health and productive performance. Respiratory rate and surface temperature, despite showing some variability, follow the same trend, suggesting a consistent regulatory mechanism.

Quails kept in warm environments, as a way to dissipate body heat, may increase their respiratory and heart rates, leading to lower development of organs such as heart weight (Siqueira et al., 2007).

The positive correlation between cloacal temperature and surface temperature with water consumption suggests that water intake plays a central role in the thermal regulation of animals. This effect may be related to the necessity for body temperature control, particularly in challenging environmental conditions. Proper hydration helps cool the body, reducing the impact of thermal stress and ensuring physiological balance in animals (Fernandes et al., 2020).

On the other hand, the inverse correlation between body temperature and feed intake and weight gain indicates that when water intake increases, there is a tendency for a reduction in solid food consumption and, consequently, in weight gain. This behavior can be explained by energy regulation mechanisms, in which animals adjust their nutrient intake based on thermal demand. In hot environments, for example, it is common to observe lower feed intake and higher water consumption, which can directly impact productive performance (Jha & Mishra, 2021).

Principal component analysis helps reduce data complexity and identify the most influential variables. The fact that feed intake is the most significant variable in PC1 demonstrates its direct impact on animals' metabolism. The second principal component is strongly related to final weight and carcass composition, which is fundamental in the food industry. This result reinforces that the physical characteristics of the animal and carcass yield are highly interconnected, being key determinants of meat quality. Carcass weight, as the most significant variable in PC2, indicates that this characteristic should be prioritized in nutritional management strategies.

The analysis of these relationships is essential for high-quality meat production. The influence of water consumption on body temperature and animal metabolism can affect feed efficiency, growth, and carcass composition, which are key aspects for the industry. Additionally, understanding these correlations allows for adjustments in nutritional strategies to optimize animal performance and reduce variations in production.

In summary, the results provide a foundation for decision-making that seeks to balance nutrition, hydration, and body temperature, ensuring animal welfare and higher yields in food production.

5 CONCLUSIONS

The principal component analysis revealed that variables such as feed intake and body temperature directly influence carcass composition, with carcass weight being one of the most relevant factors in explaining data variation. These findings are essential for the development of nutritional and management strategies aimed at improving production efficiency, reducing growth variations, and ensuring greater uniformity in production.

Furthermore, these results have direct implications for the food industry, as they highlight factors that affect meat quality and consumer acceptance. Understanding these relationships enables adjustments in animal nutrition and housing conditions, optimizing zootechnical performance and ensuring a high-quality final product.

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