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Multivariate Analysis in Food Production: Thermal Regulation Discriminant Analysis in Meat Quality

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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 1 day and with an average weight of 8 ± 0.50 g, were used. 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 explain 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, as 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.

Practical 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 (CY) 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 the meat.

In animal production systems, the qualitative and quantitative characteristics of carcasses are crucial for the success of the sector, as 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 (Liao et al., 2025), which contributes to the juiciness and flavor of the 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 the 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., 2015; Melo et al., 2008b). Algae from the species *Sargassum sp.*, which are abundantly found 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, algae possess 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 in animal nutrition. Algae and microalgae, for example, have remarkable nutritional characteristics: depending on the cultivation environment, some species contain high levels of proteins, carbohydrates, vitamins, minerals, natural pigments, and ether extract (Chisti, 2007). Additionally, certain species of marine algae possess unique metabolic properties that make them advantageous compared to conventional ingredients,

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

Micronutrients and macronutrients play an essential role in the growth and development of quails, which nearly triple their weight by 25 days of age (Maciel et al., 2010). 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 (Couce & Pipaon, 2021; Xiang et al., 2025).

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 an in-depth analysis of the relationships between various explanatory variables involved in carcass and animal nutrition studies. Discriminant analysis, in particular, is a useful statistical tool for reducing data dimensionality and identifying relevant patterns to optimize production strategies.

A better interpretation of the dataset can be obtained through multivariate analysis techniques, as they are more appropriate for the study of a set of correlated variables that will be analyzed simultaneously. Thus, multivariate analysis techniques are shown to be extremely efficient alternatives when the situation requires the combination of multiple pieces of information from an experimental plot (i.e., an observational vector), to associate or predict biological phenomena from a complex of variables essential for the development of the experimental plan (Dillon & Goldstein, 1984).

Canonical discriminant analysis is a multivariate technique for reducing data dimensionality, similar to the principal component technique and canonical correlation analysis. However, this technique is a specialty of discriminant analysis and is used to represent different populations in a small subspace (Guedes et al., 2018).

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 current research was conducted at the Laboratory of Rural Constructions and Environment (LaCRA), located at the Federal University of Campina Grande in Paraíba, Brazil, with geographical coordinates of 7°13′51″ South and 35°52′54″ West.

The procedures carried out in this research received approval from the Research Ethics Committee (CEP) at the Federal University of Campina Grande, located in Paraíba, Brazil, under Protocol CEP No.11/2024.

A total of 864 1-day-old Japanese quails (*Coturnix coturnix japonica*), averaging 6.7 ± 0.5 g in weight, were sourced from FUJIKURA farm in Suzano, São Paulo. The formulation of the feed, including the composition and nutritional values of its ingredients (58.37% corn, 34.16% soybean meal, 0.14% dicalcium phosphate, 2.33% soybean oil, and 5% nucle), was established according to the dietary needs of Japanese quails. The feed was provided both manually and ad libitum, ensuring that feeders and waterers were consistently replenished.

The climate chambers (Figure 1) were outfitted with a system to control temperature and relative humidity (RH), ensuring that the environmental conditions for the research closely matched the target values of 25.0, 29.0, and 33.0°C. Air temperature (AT) and RH were recorded and tracked with a HOBO U12-012 ONSET Comp® datalogger at 30-min intervals throughout the duration of the experiment.

The respiratory rate (RR) was assessed by counting the chest movements over a span of 20 s and multiplying the result by three to convert it to movements per minute (mov min^{-1}).

The average surface temperature (AST) of the birds was measured by taking temperature readings from various body points (head, back, foot, and wing) using a digital infrared thermometer, which has an accuracy of 0.5°C and was held about 10 cm away from the quail's skin.

Equation 1, proposed by Richards (1971), was used to calculate AST.

$$AST = (0.12 * WT) + (0.03 * HT) + (0.70 * PT) \tag{1}$$

Where

AST: average surface temperature (°C);

WT: wing temperature (°C);

HT: head temperature (°C);

PT: paw temperature (°C).

Figure 1. The internal layout of the climatic chamber and monitoring room.

Rectal temperature (RT) was assessed with a clinical thermometer, specifically the Incoterm® model MC-245, which has an accuracy of 0.1°C. The thermometer was gently inserted into the cloaca of the immobilized quail to a depth of around 2 cm, ensuring that the metal rod was entirely inserted for reference while minimizing any external disturbances. After the thermometer emitted a beep, the displayed reading was noted and documented.

The following performance metrics were assessed: weight gain, consumption of feed and water, feed conversion ratio, live weight (LW), carcass weight (CW) and CY, various cuts (thigh, wing, breast, and back), organ weights (liver, heart, and gizzard), and intestinal weight.

LW and weight gain for each bird under each treatment were recorded weekly in grams by directly weighing the birds on a precision analytical scale with a resolution of 0.1 g. Body weight gain (BWG) was calculated by taking the difference between the initial and final weights for each week, with the cumulative weight calculated by the end of the experimental period.

Weekly feed and water intake were determined by subtracting the leftovers from the amounts provided, yielding total feed and water intake (IF and IW, respectively) for each week. To compute consumption per individual bird (Equation 2), the IF and IW were divided by the number of birds in each treatment group, adjusted for any bird mortality (Sakomura & Rostagno, 2007).

$$IF = \frac{\mathrm{FS} - LF}{NA} \quad (2)$$

Where

IF: Feed intake (g);

FS: Feed supplied (g);

LF: Leftover feed (g);

NA: Number of animals.

Feed conversion was calculated by the ratio of the amount of feed consumed to the weight gained over the same period, expressed in the same unit of weight (Equation 3):

$$FC = \frac{\mathrm{BFC}}{WG} \quad (3)$$

Where

FC: Feed conversion (g/g),

BFC: Bird feed consumption (g),

WG: Weight gain (g).

The birds underwent a fasting period of 12 h prior to their slaughter, during which they had access only to water. Following this fasting, they were slaughtered, rendered unconscious, and bled. They were then immersed in boiling water for feather removal, after which the feathers, feet, head, and internal organs were extracted. The weight of the cleaned and eviscerated carcass was recorded. The CY% was determined by calculating the ratio of CW to LW, with the result being multiplied by 100. This calculation was performed for all relevant variables.

The cuts obtained from the birds included thighs, breasts, wings, and backs. In addition, the weights of the organs and intestines were measured, specifically the heart (HY), liver (LY), gizzard (GY), and intestines (IY), using a precision analytical scale with an accuracy of ± 0.1.

Pearson's simple correlation analysis was adopted, which is a technique for measuring whether two variables are linearly related.

For this purpose, the mathematical model $D(x) = L'.x = [x1-x2]'S^{-1}.x$ was employed, where D(x) represents Fisher's linear discriminant function, L is the estimate of the discriminant vector, x1 is the sample mean of population p, and x is the sample mean of population p. The selection of variables with the highest discriminatory power was carried out using the stepwise method, which combines the addition of variables with the greatest discriminatory power and eliminates those with lesser contributions, based on the F-statistic or Wilks' lambda value. The primary objective of this procedure was to identify the best set of variables to compose the discriminant function.

Statistical analyses were performed using Statistica 8.0 software.

3 RESULTS

Considering the correlations, carcass and breast showed a correlation of 65%, and carcass and back had a correlation of 63% (Table 1). Thigh and breast showed a high correlation (52%), while thigh and back had an inverse correlation (−46%). RR and RT were highly correlated (58%), as were RR and surface temperature (ST), and RT and ST, with correlations of 79 and 78%, respectively.

According to the stepwise method, only the physiological variables were significant and relevant to the model (Table 2).

Using Mahalanobis distance, a significant distance was observed (Table 3) between the groups according to temperature, with the greatest distance between 25°C and 33°C. Regarding group classification, animals were 100% correctly assigned to their respective groups (Table 4).

Function classification by temperature (Table 5) shows that the most influential variables were physiological, with cloacal temperature (CT) having the greatest weight, followed by ST, which increased in importance with rising temperature. Heart rate had more influence than RR.

In Canonical Function 1 (CAN 1), the variable with the greatest weight was ST, explaining 90% of the data variation. In Canonical Function 2 (CAN 2), CT had the greatest weight, explaining 1% of the variation (Table 6). Heat dissipation plays a key role in preventing carcass quality loss and deterioration of quail cuts.

In the two-dimensional graph (Figure 2), the groups are clearly separated by temperature. At the heat stress temperature (33°C), there is less dispersion among animals, indicating similar behavior under thermal stress. At lower temperatures, dispersion is greater.

4 DISCUSSION

The coefficients of variation reflect the magnitude of data dispersion relative to the mean and offer important insights into the variability of physiological and productive responses in quails under different thermal conditions. High coefficients observed for weight gain, liver weight, and intestinal weight indicate considerable inter-individual variability, likely associated with how each animal responds to thermal stress. Such variability directly affects carcass uniformity and the standardization of cuts—critical factors for final product quality in poultry production systems.

Multivariate analysis revealed that physiological variables such as ST, cloacal temperature (CT), RR, and heart rate played a determining role in distinguishing groups exposed to different temperatures. Among them, ST stood out as the most important in Canonical Function 1, explaining 90% of the variance between groups. This underscores the central role of ST as a sensitive physiological indicator of thermal stress, reflecting peripheral heat dissipation mechanisms.

ST is directly involved in sensible heat loss, particularly in birds, which lack sweat glands. Under high ambient temperatures, peripheral blood flow increases to transfer heat from the body core to the surface, raising ST levels. Thus, measuring ST provides a reliable estimate of the effectiveness of thermoregulatory responses and is essential for monitoring thermal comfort and animal welfare.

In this context, the use of Mahalanobis distance was crucial to quantify the degree of separation between thermal groups based on multiple correlated variables. By simultaneously

Table 3. *Mahalanobis* distance between the evaluated temperatures.

Temperature (°C)	25	29	33
25	-	43.32726**	138.6764**
29		-	28.6618**
33			-

**Significant at 5% probability.

Table 4. Matrix for classifying animals by temperature.

Temperature (°C)	Percent corrected	25	29	33
25	100.0000	24	0	0
29	100.0000	0	24	0
33	100.0000	0	0	24

Table 1. Pearson's correlation of the analyzed variables.

Variables	Thigh	Breast	Back	Wing	Heart	Liver	Gizzard	Intestine	RR	CT	ST
Carcass	0.27*	0.65*	0.63*	0.21	0.21	0.06	0.33*	0.09	0.06	−0.00	−0.02
Thigh	-	0.52*	−0.46*	0.23*	0.12	0.25*	0.13	0.21	0.22	0.11	0.13
Breast		-	−0.07	0.34*	0.34*	0.21	0.17	0.36*	0.20	0.22	0.20
Back			-	−0.16	−0.00	−0.17	0.22	−0.22	−0.16	−0.18	−0.21
Wing				-	0.14	0.19	0.01	0.25*	0.20	0.11	0.16
Heart					-	−0.06	0.09	0.13	−0.02	−0.25*	−0.13
Liver						-	0.02	0.42*	0.33*	0.29*	0.29*
Gizzard							-	0.04	−0.16	−0.25*	−0.30*
Intestine								-	0.17	0.04	0.17
RR									-	0.58*	0.79*
CT										-	0.78*
ST											-

RR: respiratory rate; CT: cloacal temperature; ST: surface temperature.
*Significant at 5%.

Table 2. Variables selected and excluded by the *stepwise method*.

Variables	Wilks lambda	Partial lambda	*p*-value
Thigh	0.030783	0.978159	.521282
Breast	0.030627	0.983136	.605476
Back	0.031115	0.967720	.379856
Wing	0.030652	0.982316	.590759
Heart	0.031297	0.962078	.319674
Liver	0.031757	0.948162	.207984
Gizzard	0.030921	0.973798	.456912
Intestine	0.030895	0.974596	.468093
Respiratory rate	**0.041029**	**0.733881**	**.000109**
Cloacal temperature	**0.034576**	**0.870855**	**.016920**
Surface temperature	**0.109131**	**0.275910**	**.000000**

Statistically significant values are denoted in bold.

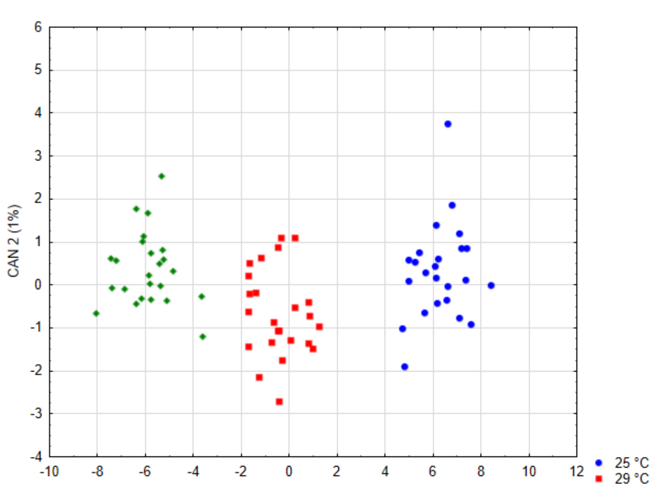
Table 5. Classification of functions for temperature.

Variables	Temperature (°C)		
	25	29	33
Thigh	21.9	22.2	22.6
Breast	−18.1	−17.7	−17.5
Back	11.2	11.4	11.5
Wing	−5.1	−5.9	−6.0
Heart	81.5	77.7	75.2
Liver	−27.0	−26.5	−25.4
Gizzard	−20.3	−24.0	−26.8
Intestine	44.1	44.4	44.2
Respiratory rate	50.9	52.6	54.2
Cloacal temperature	1,661.8	1,677.2	1,683.8
Surface temperature	281.5	299.2	313.6
Constant	−40,989.5	−42,364.0	−43,294.9

Table 6. Standardized canonical coefficients for the canonical variables of physiological variables.

Variables	CAN 1	CAN 2
Thigh	−0.17906	0.262630
Breast	−0.17475	−0.193330
Back	−0.15379	−0.385981
Wing	0.06857	0.290774
Heart	0.22209	0.150468
Liver	−0.16005	0.480760
Gizzard	0.18074	0.029403
Intestine	−0.01547	−0.453171
Respiratory rate	−0.55316	0.279813
Cloacal temperature	−0.31881	**−0.566755**
Surface temperature	**−0.92734**	0.038866
Eigenvalue	25.95217	0.232226
Cum. prop	0.99113	1.000000

CAN: canonical variables.



CAN: canonical variables.

Figure 2. Two-dimensional graph of the distribution of the temperatures studied.

accounting for variances and covariances, this multivariate statistical measure provided a robust understanding of overall differences in physiological profiles, outperforming the limitations of univariate analyses. The greatest distance was observed between animals exposed to 25°C and 33°C, indicating that increasing environmental temperatures elicit intense and consistent physiological changes with a direct impact on adaptive responses and carcass quality.

Moreover, the 100% correct classification of individuals into their respective temperature groups highlights the discriminatory accuracy of the model. It confirms that the selected physiological variables, especially ST and CT, are effective indicators to differentiate between thermal comfort and heat stress conditions. Under 33°C stress, the birds showed less dispersion in their physiological responses, suggesting a uniform behavioral pattern likely related to the limits of thermal adaptation.

These findings reinforce the importance of monitoring physiological variables to preserve welfare and ensure carcass standardization. Under thermal stress conditions, thermoregulatory efforts such as increased RR and ST often occur at the expense of growth and feed efficiency, which may compromise product quality.

Therefore, understanding how thermal variations affect quail metabolism and performance is essential for making informed decisions regarding environmental management. Thermal comfort strategies contribute not only to animal welfare but also to uniformity and value of poultry products in the marketplace.

In summary, this study provides solid evidence that ambient temperature exerts a strong influence on quail physiological parameters, with ST serving as a key marker of heat dissipation efficiency. The use of Mahalanobis distance to integrate these multiple responses proved to be an effective analytical tool to characterize and differentiate physiological states, making it highly useful to guide actions aimed at producing high-quality poultry meat.

5 CONCLUSIONS

The results obtained in this study demonstrate that physiological variables, particularly ST and CT, play a fundamental role in assessing the response of quails to thermal stress. The strong correlation between these variables and productive parameters, such as CY and commercial cuts, indicates that physiological monitoring can be a strategic tool for preserving final product quality.

Discriminant analysis showed a high classification accuracy of animals according to ambient temperature ranges, with 33°C standing out as the condition where individuals exhibited homogeneous behavior, suggesting a typical heat stress response. The lower dispersion in this scenario reinforces the importance of implementing thermal management strategies in production environments.

Identifying the most relevant physiological variables contributes to the development of more effective protocols for decision-making, aimed at maintaining animal welfare and achieving superior product quality. Therefore, it is concluded that continuous monitoring of physiological parameters is essential to mitigate the effects of thermal stress and ensure the standardization and added value of quail meat products under tropical conditions.

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