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Impacts of rearing-related factors on the slaughter characteristics of broilers

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ABSTRACT - We investigated the influence of poultry rearing factors, including strain, type of ventilation, and sex on the slaughter characteristics of broiler chickens. Factorial analysis of mixed data was employed to analyze the data from broiler flocks slaughtered between 2018 and 2020 in Mato Grosso do Sul, comprising 2,684 flocks and 82,486,500 birds. The characterization information considered included age at slaughter, average weight, date of slaughter, percentage of pododermatitis, percentage of scratches, percentage of pre-slaughter condemnations, percentage of slaughter condemnations, percentage of total condemnation, percentage of field mortality, type of ventilation, strain, and sex. The factorial analysis of mixed data aimed to identify the relationships between pre-slaughter factors and slaughter characteristics. Five main components, explaining 85.5% of the total data variance, were derived from the analysis. Age, generated value per kilo of product, and percentage of pre-slaughter condemnations exhibited positive correlations. Negative pressure ventilation was found to be more closely associated with the percentage of pododermatitis, while the dark house system showed a stronger association with the percentage of total condemnation and percentage of pre-slaughter condemnation. The Cobb strain and female sex were found to be more strongly related to the generated value of the product. Strain, sex, and type of ventilation were identified as decisive factors influencing the characteristics of meat yields and the economic results of poultry activity in slaughterhouses. Moreover, it was observed that percentages of scratches and pododermatitis were negatively correlated with the value generated ($/kg) by broiler flocks, and they were more closely associated with positive pressure ventilation systems, Ross strain, mixtures of strains within the same flock, and male chickens. It was possible to prove the strong interdependence between the rearing stage of broiler chickens and the slaughterhouse, which needs to be considered in decision making by agroindustry to achieve an ideal rearing model.

Keywords: mixed data factorial analysis, poultry agroindustry, scratches, slaughterhouse condemnation, strains

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1. Introduction

The Brazilian poultry industry is globally recognized for its integrated production system, which involves small poultry farmers working in collaboration with companies, resulting in efficient large-scale

production (Mores et al., 2022). In this system, the success of the final product depends on the seamless coordination between the rearing and slaughter (Sartin, 2015; Pohlmann et al., 2020).

The rearing stage, particularly the pre-slaughter phase, plays a crucial role in providing the raw material for slaughterhouses. During this stage, several factors need to be considered when determining which birds to raise and under what conditions. One important decision to be made is the selection of the appropriate strain, which involves analyzing various aspects and identifying the one that best aligns with the breeding objectives (Stringhini et al., 2003).

Different breeding systems can influence the development of specific behaviors inherent to the species. The expression of these behaviors during the growth and development period of broilers is a critical factor in poultry production. It can affect meat attributes, production volume, and types of cuts produced, and is influenced by both strain and stressors (Nogueira et al., 2019). Changes in bird behavior can lead to scratches caused by overlapping nails, which are a significant cause of poor carcass quality (Mendes et al., 2010; Sakamoto et al., 2020).

The presence of pododermatitis is assessed during the chicken slaughter process and is a primary factor limiting the export of chicken feet to consumer markets that demand high-quality cuts. Its incidence is related to the rearing conditions and field management practices (Mendes and Komiyama, 2011).

The appearance of skin and feet abnormalities in broiler carcasses, along with other changes, are evaluated by the Federal Inspection System and may result in total or partial condemnations. Total condemnation involves discarding the entire carcass, whereas in partial condemnation, only the affected parts are discarded, and the unaffected parts can still be utilized (Jaguezeski et al., 2020).

The agroindustry generates data concerning both the pre-slaughter and meat processing stages. However, processing and analyzing such data to identify the causes of total and partial condemnations, as well as variations between strains, their respective behaviors, production systems, and types of facilities used, poses significant challenges. Overcoming these challenges would enable more accurate decision-making regarding the progress of the production chain. Selecting appropriate ventilation technology for poultry houses and specific lineages is crucial for maximizing profitability and expanding poultry farming while ensuring the quality of the final product.

Perhaps, the dataset generated by agroindustry is extensive and needs a powerful tool to analyze it. Factorial Analysis of Mixed Data (FAMD), an alternative of Principal Component Analysis tool, is used to make possible to evaluate the positive or negative relationships between quantitative and qualitative factors using the Cartesian position of the principal component axes, known by dimensions. In this sense, evaluating the data distribution and grouping in the generated dimensions explains data variability and factors relationship.

Hence, the objective of this study was to investigate the relationship among rearing-related factors such as sex, strain, and ventilation system, and total and partial condemnations, as well as the characteristics of the slaughterhouse in terms of product quality and the corresponding generated value. This will be accomplished through the application of mixed data factorial analysis.

2. Material and Methods

This study utilized data obtained from broiler chicken flocks slaughtered between 2018 and 2020 at a slaughterhouse belonging to an agroindustry located in Dourados, Mato Grosso do Sul, Brazil (latitude: −22.2218, longitude: −54.8064, 22° 13' 18" South, 54° 48' 23" West). The region is characterized by a tropical climate, with predominance of rain during summers and low humidity in winters. The agroindustry follows an integrated production system, whereby the integrating company provides financing for warehouses, supplies broiler chicks, feed, and technical assistance, and is responsible for transportation, slaughter, processing, and commercialization of meat products. A total of 2,684 flocks, comprising 82,486,500 birds slaughtered over the three-year period, were considered for analysis. A flock is defined as all birds from a single nucleus, which can consist of one to four warehouses, all slaughtered on the same day.

Quantitative data for flock characterization included age at slaughter, average weight, date of slaughter, percentage of foot calluses, percentage of scratches, percentage of total condemnation due to pre-slaughter causes, percentage of condemnation due to slaughter causes, percentage of total condemnation, and percentage of field mortality.

Pre-slaughter condemnations result from health-related changes in birds that occur during their time in the housing environment. They can be caused by various factors, such as aerosacculitis, arthritis, disgusting appearance, cachexia, cellulitis, dermatoses, myositis, septicemia, ascitic syndrome, and hemorrhagic syndrome. Slaughter condemnations are the result of contamination or technological failures, leading to changes in the appearance and quality of carcasses during the slaughter and processing stages. Common causes of slaughter failures include contamination, contusion/fracture, excessive scalding, delayed evisceration, and poor bleeding. Condemnations can be total, where the entire carcass is discarded and not utilized, or partial, where only the affected part is discarded, allowing the use of the remaining cuts by the industry.

To determine the percentage of pododermatitis, an evaluation was conducted in the slaughterhouse after the birds were slaughtered and their feet removed. A total of 100 feet from each group of 4,700 birds were collected, representing the total number of birds transported in a single truck from the production centers to the slaughterhouse. The evaluation involved assessing the presence or absence of calluses, and the pododermatitis percentage was calculated based on the slaughtered volume.

The evaluation of scratch percentage considered the presence of old scratches that occurred during the poultry rearing stage, without classifying them according to severity. New scratches resulting from pre-slaughter handling and transportation were not considered in this study. The evaluation was performed in the slaughterhouse after the plucking stage, where the skin on the back and thighs of birds was visually assessed. A total of 100 carcasses from each group of 4,700 birds were collected, representing the total number of birds transported in a single truck from the production centers to the slaughterhouse. The scratch percentage was calculated based on this sample.

Qualitative data for flock characterization included the type of ventilation (positive, negative, or dark modal), strain (Cobb, Ross, or mixed), and sex (male or female). Regarding the different types of ventilation used in warehouses, positive ventilation involves introducing external air into the facility using fans, while negative ventilation expels internal air to the external environment through exhaust fans. Dark modal ventilation includes temperature and humidity control through artificial ventilation, with air speed and quality regulated based on the presence of gases such as NH_3 and CO_2, along with luminosity control.

The dataset was carefully examined for consistency to ensure accurate and high-quality analyses; observations of slaughter characteristics with values above or below three standard deviations in relation to the average of each variable were removed, as outliers can distort the reality of daily slaughter and its characteristics.

A financial variable was developed to indicate the value generated by the daily production mix, which varies based on the characteristics of the birds received for slaughter. This financial variable was included in the database along with the information on slaughtered flocks. It represents the value generated per day of poultry slaughter, considering the types of cuts produced, their proportion in the total volume, and their sales value. The products were categorized into cuts and raw materials.

The cuts category includes boneless whole chickens, boneless and skinless breasts, tenderloins, bone-in thighs and drumsticks, boneless and skinless thighs and drumsticks, thighs and drumsticks in cubes, whole wings, wing drumsticks, wing mid-sections, feet with calluses, feet without calluses, heart, gizzard, liver, breast cartilage, and knee cartilage. The raw material category includes mechanically separated meat, mechanically ground meat, skin, fat, breast flap, and leg flap.

For cut items, a distinction was made between standard 1, intended for the foreign market, and standard 2, intended for the domestic market. This differentiation accounts for the price difference between markets and the stricter quality criteria for the foreign market. Raw material items were not

divided in this manner, as the entire volume is directed to the domestic market for use in the production of processed goods.

The market value of each product was determined based on current dollar value per kilogram ($/kg). It should be noted that the company under study worked with different brands and price variations for each product. Therefore, an average value was calculated for each product, considering the division between standard 1 and standard 2, whenever applicable. Using the average value per kilogram for each product, the total value generated on each day of slaughter was calculated by multiplying the volume produced for each product by its value. The sum of the amounts generated for each product determined the total value for that day of slaughter and processing. This value was then divided by the total production volume of the day, resulting in the daily average value indicator ($/kg).

Using Principal Component Analysis (PCA), the dataset was analyzed to reduce the set of variables into principal components and explore their relationships. The aim was to identify the associations between the rearing-related variables (strain, sex, and ventilation type) and variables related to flock results, including scratch percentage, foot callus percentage, condemnations, and financial index. To analyze the data, the FAMD method was applied, which extends the PCA to handle mixed data types (Pagès, 2004).

Descriptive statistics, including means, standard deviations, and minimum and maximum values for weight, scratch percentage, condemnations, and foot callus percentage, were calculated for each broiler strain, sex, and type of ventilation in the poultry warehouses using the R software. Pearson's correlation coefficients were generated to determine the relationships between the quantitative variables for each broiler strain, sex, and type of ventilation, resulting in a correlation matrix. This matrix served as the primary data for generating the principal components.

The suitability of the dataset for FAMD was assessed using the Kaiser-Meyer-Olkin (KMO) sampling suitability measurement, which measures how well the dataset aligns with the requirements of FAMD. A KMO measurement equal to or greater than 0.60 is considered adequate (Eyduran et al., 2010).

The variables x_1, x_2, ..., X_p from the multivariate dataset were transformed into new uncorrelated variables y_1, y_2, ..., y_p, which account for decreasing proportions of total variance in the original variables. This transformation is defined as follows (Everitt and Dunn, 2001):

$$y_1 = a_{11}x_1 + a_{12}x_2 + \ldots\ldots + a_{1p}x_p.$$

$$y_2 = a_{21}x_1 + a_{22}x_2 + \ldots\ldots + a_{2p}x_p.$$

$$y_p = a_{p1}x_1 + a_{p2}x_2 + \ldots\ldots + a_{pp}x_p.$$

Based on these new variables, referred to as principal components, which explain the greatest variability in the data, the relationships between bird strain, sex, type of ventilation, and variables related to flock results, including scratch percentage, foot callus percentage, condemnations, and financial index, were examined.

A total of 16 individuals were selected for distribution across dimensions, representing all combinations of qualitative variables (strain, sex, and type of ventilation) that occurred in the flocks included in this study. It should be noted that some combinations, such as negative ventilation, Ross strain, and female sex, were not found in the database and thus are not represented in the analysis.

3. Results

Initially, after analyzing the data consistency, the number of samples (N) was reduced from 2,684 flocks to 1,761 flocks by removing data that did not accurately represent the reality experienced by the agroindustry.

Mean values were calculated for the quantitative variables, including average weight, age, percentages of mortality, callus on the paws, old scratches, total condemnation due to pre-slaughter causes, total condemnation due to slaughter causes, total condemnation, and generated value (Table 1).

Table 1 - Descriptive statistics of the variables evaluated

Characteristic	N	Minimum	Maximum	Mean±SD
Body weight (kg)	1,761	2.19	3.56	2.87±0.25
Age (days)	1,761	36.00	50.00	43.11±2.81
Mortality[1] (%)	1,761	1.42	8.53	4.45±1.53
Pododermatitis (%)	1,761	0.00	100.00	61.28±27.53
Scratches (%)	1,761	0.00	64.69	30.45±13.61
Slaughter condemnation (%)	1,761	0.00	1.04	0.46±0.21
Pre-slaughter condemnation (%)	1,761	0.00	1.30	0.49±0.28
Total condemnation (%)	1,761	0.00	2.15	0.95±0.42
Value[2] (US$/kg)	1,761	1.46	1.73	1.59±0.05

[1] Flock mortality percent.
[2] Average daily value indicator.

The suitability of the dataset for FAMD was assessed using the KMO sampling adequacy measurement. The accumulated eigenvalues explained 85.56% of the total data variance (Table 2). Only dimensions with eigenvalues greater than 1, indicating a greater variation than the original variables in standardized data, were considered to explain the sources of variation in the data. The first dimension accounted for 34.2% of the total data variance, followed by the second dimension, which explained 16.2%. The first two dimensions accounted for 50.4% of the accumulated variance, while the first five dimensions explained 85.56% of the variance.

Table 2 - Eigenvalues, explained and cumulative variance of the dimensions considered in this study

Dimension	Eigenvalue	Explained variance (%)	Cumulative variance (%)
1	5.13	34.22	34.22
2	2.42	16.15	50.37
3	2.24	14.92	65.29
4	1.64	10.9	76.22
5	1.40	9.34	85.56

In the analysis of the database, 16 individuals were defined, each representing a combination of qualitative variables (strain, type of ventilation, and sex) and the average results of quantitative characteristics (Table 3).

The distribution of individuals in the first two dimensions revealed that individuals with similar profiles were close to each other on the dimension map (Figure 1). Similarly, the dendrogram of individual observations displayed a tree with 16 “leaves”, each representing an individual. The formation of three distinct groups indicated similarities among these individuals (Figure 2).

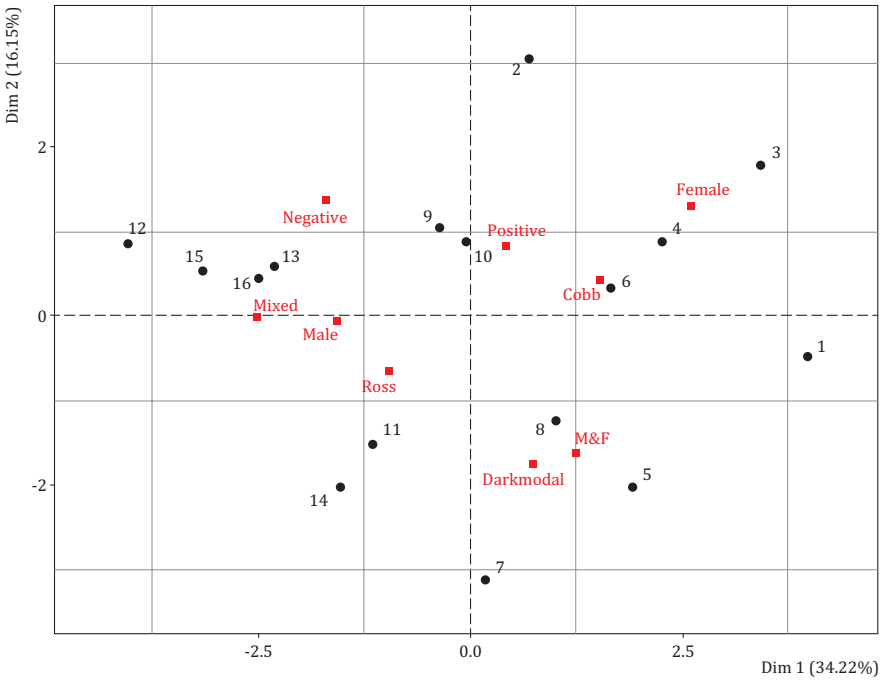
Analyzing the spatial projection of qualitative variables and individuals, along with the dendrogram of individual observations (Figures 1 and 2), it was observed that individuals 1, 2, 3, 4, and 15, representing females of the Cobb strain reared under positive pressure, exhibited similarities and grouped together. Individuals 9, 10, 12, and 13, representing mixed lots of Ross strain reared in a dark modal system, also formed a distinct group. Lastly, individuals 5, 6, 7, 8, 10, 11, and 14 shared similar characteristics as males with no defined strain reared under negative pressure.

Dimensions 1 and 2 were deemed the most relevant for representing the variables. Dimension 1 was primarily influenced by the percentage of total pre-slaughter condemnation, percentage of scratches, percentage of total condemnation, and sex. Dimension 2 was most influenced by the type of ventilation, percentage of pododermatitis, sex, and age (Figure 3). The variables that contributed the most to each dimension were the ones explaining the greatest variation in the productive results of the evaluated chicken flocks.

Table 3 - List of individuals formed from the combination of qualitative variables and their respective values obtained in each quantitative variable

Id	Ventilation	Lineage	Sex	BW (kg)	Age (d)	Mortality (%)	Podo (%)	Scratches (%)	SLCondem (%)	PSCondem (%)	TotalCondem (%)	Value (US$/kg)
1	Dark house	Cobb	Female	2.9	47.20	2.57	29.99	18.04	0.45	0.78	1.22	1.63
2	Negative	Cobb	Female	2.7	47.33	3.45	63.59	28.27	0.45	0.30	0.75	1.67
3	Positive	Cobb	Female	2.6	48.34	4.2	43.16	14.47	0.48	0.66	1.14	1.64
4	Positive	Ross	Female	3	50.00	3.84	48.62	12.02	0.38	0.72	1.10	1.59
5	Dark house	Cobb	Male	2.9	42.18	3.56	47.89	29.63	0.53	0.61	1.14	1.62
6	Negative	Cobb	Male	2.9	43.50	4.14	71.07	30.81	0.5	0.52	1.03	1.62
7	Positive	Cobb	Male	2.9	43.77	4.41	72.79	27.14	0.48	0.53	1.01	1.61
8	Dark house	Ross	Male	2.90	42.24	4.42	40.26	41.67	0.49	0.44	0.93	1.57
9	Negative	Ross	Male	2.9	42.93	5.13	76.62	35.39	0.49	0.34	0.83	1.54
10	Positive	Ross	Male	2.8	43.13	5.3	68.09	30.14	0.39	0.36	0.74	1.56
11	Dark house	Mixed	Male	2.9	41.75	3.63	50.06	37.98	0.46	0.52	0.98	1.59
12	Negative	MIxed	Male	2.8	41.67	4.28	61.00	39.55	0.34	0.20	0.54	1.58
13	Positive	Mixed	Male	2.9	42.61	5.2	71.70	32.33	0.44	0.42	0.86	1.58
14	Dark house	Cobb	M&F	2.7	40.60	2.64	28.34	23.93	0.42	0.58	1.00	1.62
15	Positive	Cobb	M&F	2.7	43.50	4.31	65.00	23.14	0.54	0.58	1.12	1.64
16	Dark house	Ross	M&F	2.9	43.50	5.52	20.79	32.88	0.38	0.66	1.04	1.59

BW - body weight; age - days for slaughter; Mortality - mortality during rearing phase; Podo: percentage of pododermatitis in evaluated flocks; SLCondem - slaughter condemnation; PSCondem - pre-slaughter condemnation; TotalCondem - percent of carcass totally discarded in flocks; Value - average daily value.



1-16 - individuals formed; Negative - negative pressure ventilation system; Positive - positive pressure ventilation system; Darkmodal - dark house ventilation system; M&F - Cobb and Ross mixed strain flock.

Figure 1 - Spatial projection of qualitative variables and individuals formed in the analysis of mixed factors between the first and second dimensions.

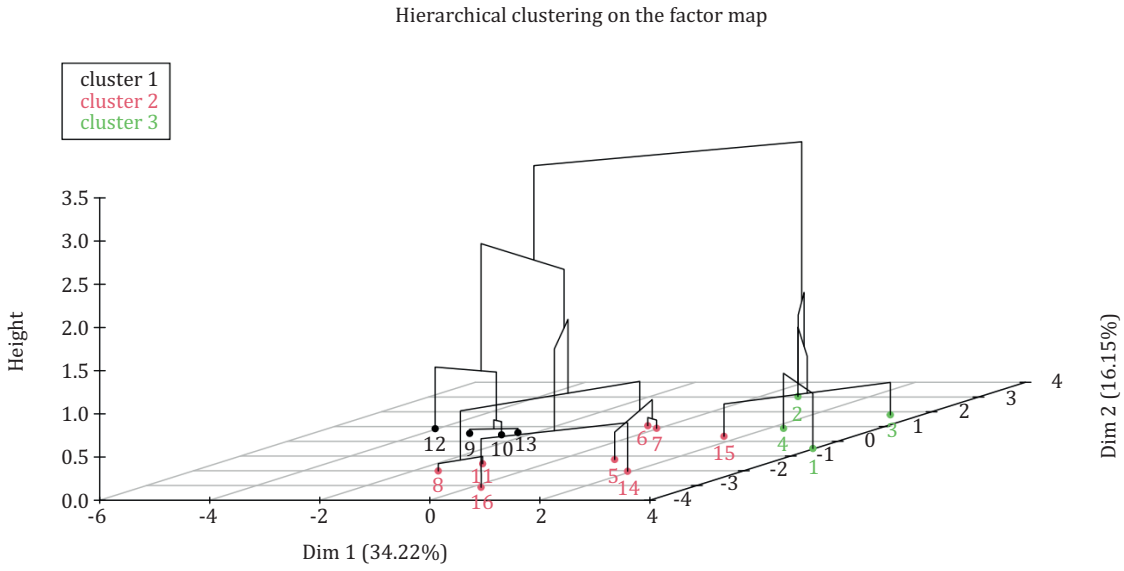
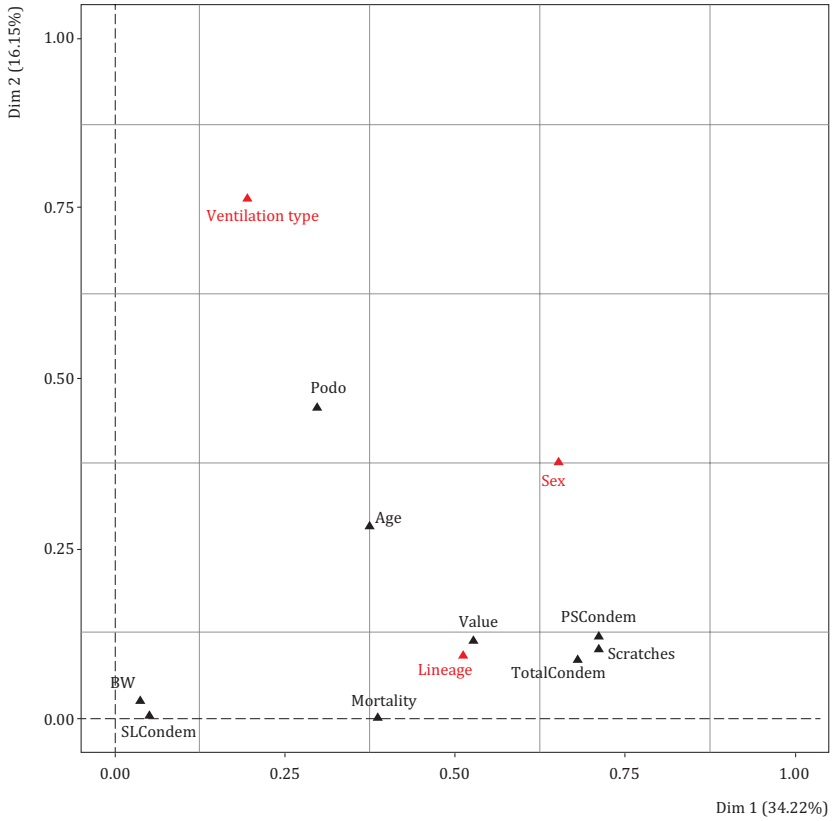


Figure 2 - Dendrogram of observations of individuals formed (1-16) in the analysis of mixed factors between the first and second dimensions.

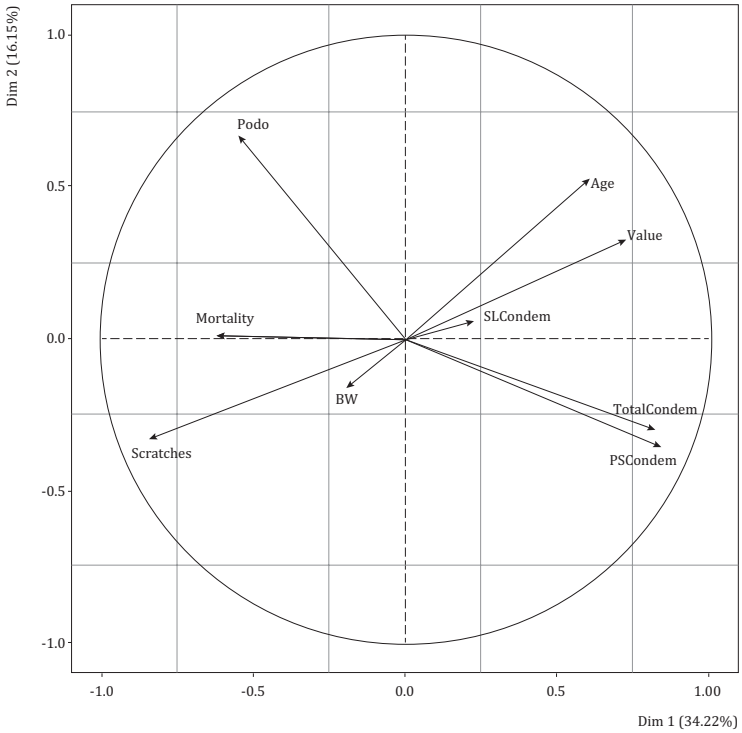


Podo - percentage of pododermatitis in evaluated flocks; Age - days for slaughter; SLCondem - slaughter condemnation; PSCondem - pre-slaughter condemnation; Value - average daily value (US$/kg); Scratches - percentage of scratches in evaluated flocks; Lineage - Cobb, Ross, or mixed; TotalCondem - percent of carcass totally discarded in flocks; Mortality - mortality during rearing phase.

Figure 3 - Distribution of quantitative and qualitative variables and their correlations with the first and second dimensions.

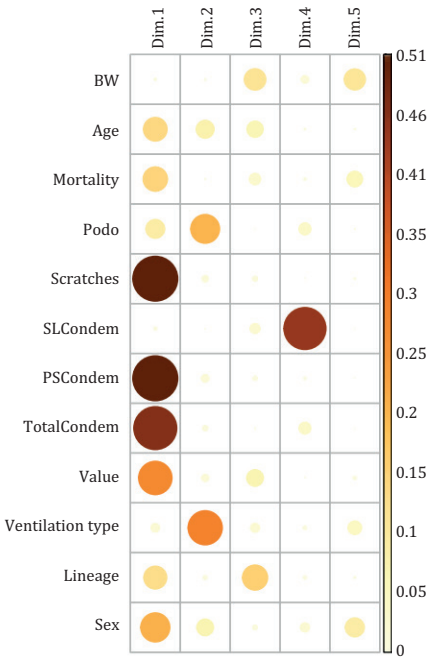
The relation graph between the studied variables (Figure 4) revealed relationships between all quantitative variables distributed across the first two dimensions. This representation enabled the observation of positive or negative correlations based on the quadrants in which the variables were positioned. Variables in opposite quadrants were negatively correlated, while variables in the same quadrant and grouped together were positively related. It was observed that scratches and generated value were negatively related, suggesting that a higher percentage of scratches led to a lower generated value. Age, value generated per kilogram of product, and percentage of total condemnation due to slaughter causes were grouped together and were positively related (Figure 4).

The squared cosines of each variable in the factorial map indicated the quality of their representation or association with the dimension. Components with larger squared cosine values contributed a relatively larger portion to the total distance and were therefore considered more important for the observation. Values close to or above 0.5 were recommended, indicating a strong relation with the represented dimension. Considering the quality of the observations, it was inferred that scratching, total general condemnation, and total pre-slaughter condemnations were the quantitative variables that most influenced production items or individuals and their respective variations. Total condemnation due to the slaughter process, despite having a cosine squared value of 0.4426 in dimension 4, ranked among the last dimensions and thus made a low contribution (Figure 5).



Podo - percentage of pododermatitis in evaluated flocks; Age - days for slaughter; SLCondem - slaughtering condemnation; PSCondem - pre-slaughter condemnation; Value - average daily value (US$/kg); Scratches - percentage of scratches in evaluated flocks; TotalCondem - percent of carcass totally discarded in flocks; Mortality - mortality during rearing phase; BW - body weight.

Figure 4 - Spatial projection of quantitative variables in the correlation circle distributed between the first two dimensions.



BW - body weight; Podo - percentage of pododermatitis in evaluated flocks; Age - days for slaughter; SLCondem - slaughter condemnation; PSCondem - pre-slaughter condemnation; Value - average daily value (US$/kg); Scratches - percentage of scratches in evaluated flocks; Lineage - Cobb, Ross, or mixed; TotalCondem - percent of carcass totally discarded in flocks; Mortality - mortality during rearing phase.

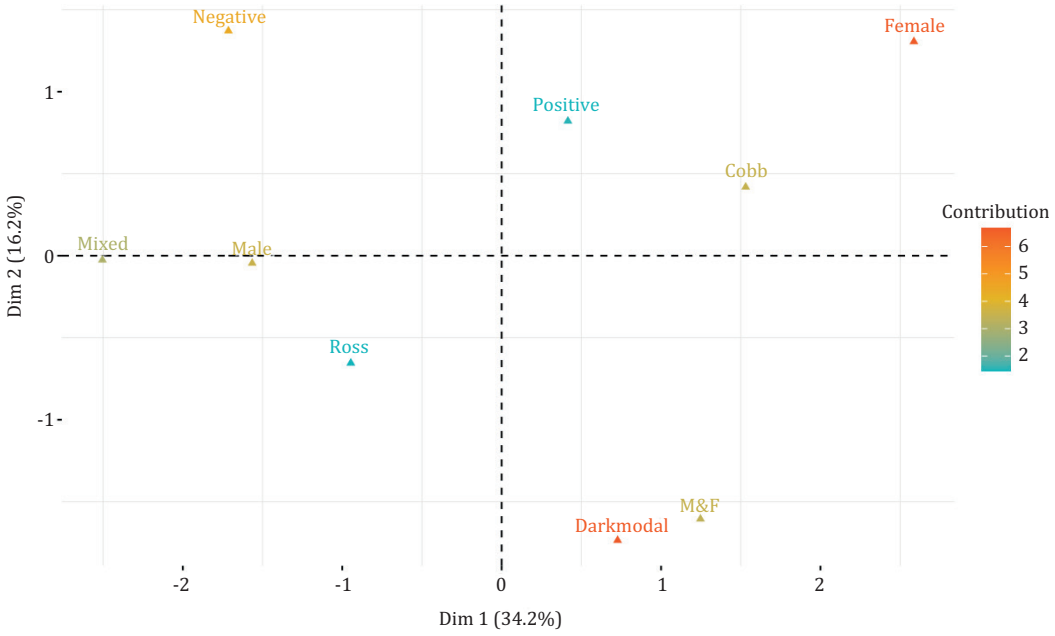
Figure 5 - Associations between the quantitative and qualitative variables evaluated and the five dimensions with quality of representation by squared cosines shown in different color scales.

The qualitative characteristics with the highest contribution were females and the dark modal ventilation type, while positive pressure ventilation type and Ross strain characteristics had the smallest contribution to these dimensions. A color scale was used to represent the qualitative characteristics in the first two dimensions and indicate their contributions (Figure 6).

The distribution of individuals in the first two dimensions, represented as ellipses based on the type of ventilation characteristic (Figure 7), showed that negative pressure ventilation (yellow) was associated with a higher percentage of pododermatitis. This type of ventilation was also in close proximity to positive pressure ventilation. The dark house system was closer to the variables representing the percentage of total condemnation and the percentage of condemnation due to pre-slaughter causes.

The distribution of individuals in the first two dimensions, represented as ellipses based on strain characteristics (Figure 8), indicated that the Cobb strain was closely related to the variables of age and generated value. On the other hand, the Ross strain exhibited a stronger relationship with the variables representing the percentage of scratches, percentage of field mortality, percentage of overall total condemnation, percentage of condemnation due to pre-slaughter causes, and percentage of pododermatitis. The mixed breed showed a greater relationship with the percentage of scratches, percentage of pododermatitis, and percentage of mortality. The ellipse corresponding to the Ross strain encompassed the variable representing the percentage of scratches.

The distribution of individuals in the first two dimensions, represented as ellipses based on sex characteristics (Figure 9), showed that the female group was more related to the variables representing the generated value and age.



1-16 - individuals formed; Negative - negative pressure ventilation system; Positive - positive pressure ventilation system; Darkmodal - dark house ventilation system; M&F - Cobb and Ross mixed strain flock.

Figure 6 - Distribution of qualitative variables in dimensions 1 and 2 and their respective contributions to dimensions shown in a color scale.

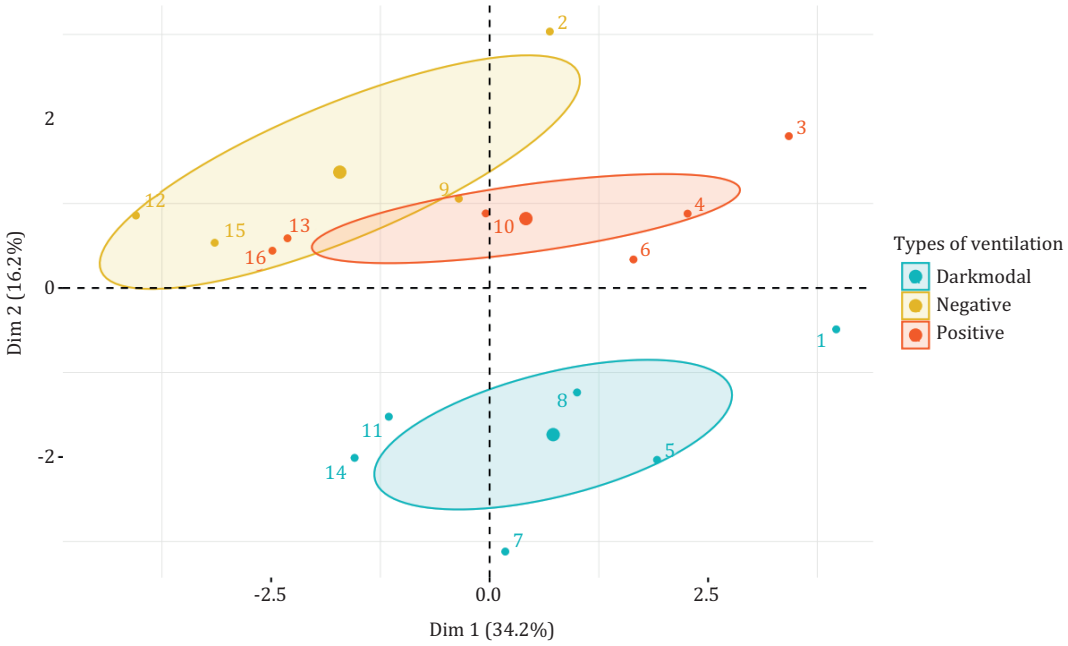


Figure 7 - Factor map of individuals (1-16) distributed in dimensions 1 and 2 with ellipses determining their respective groupings according to the ventilation type of similar individuals.

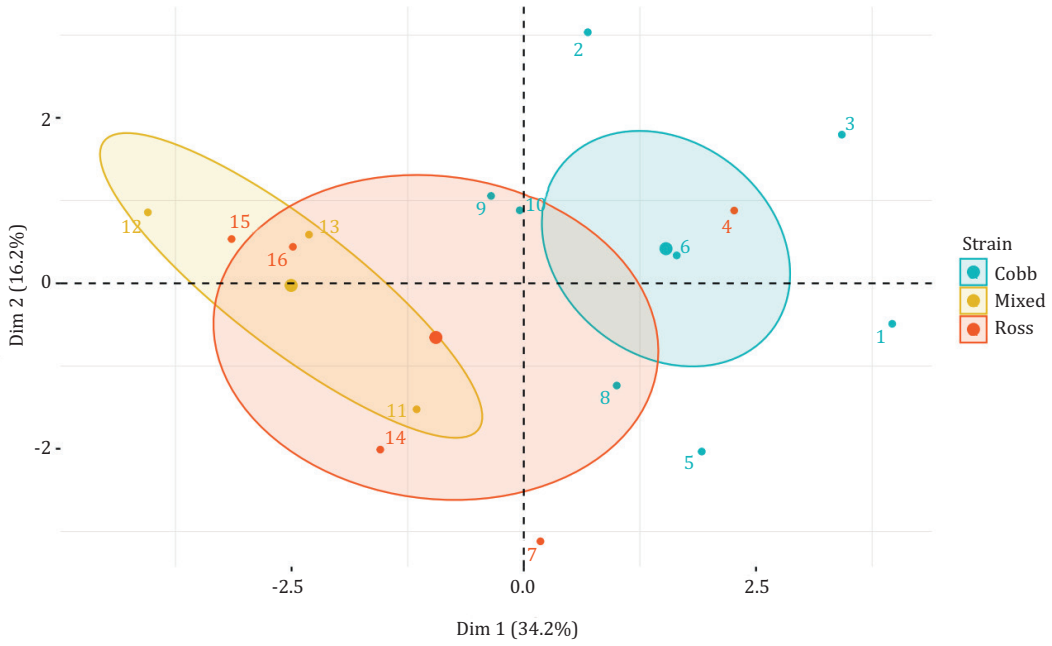


Figure 8 - Factor map of individuals (1-16) distributed in dimensions 1 and 2 with ellipses determining their respective groupings according to the strain of similar individuals.

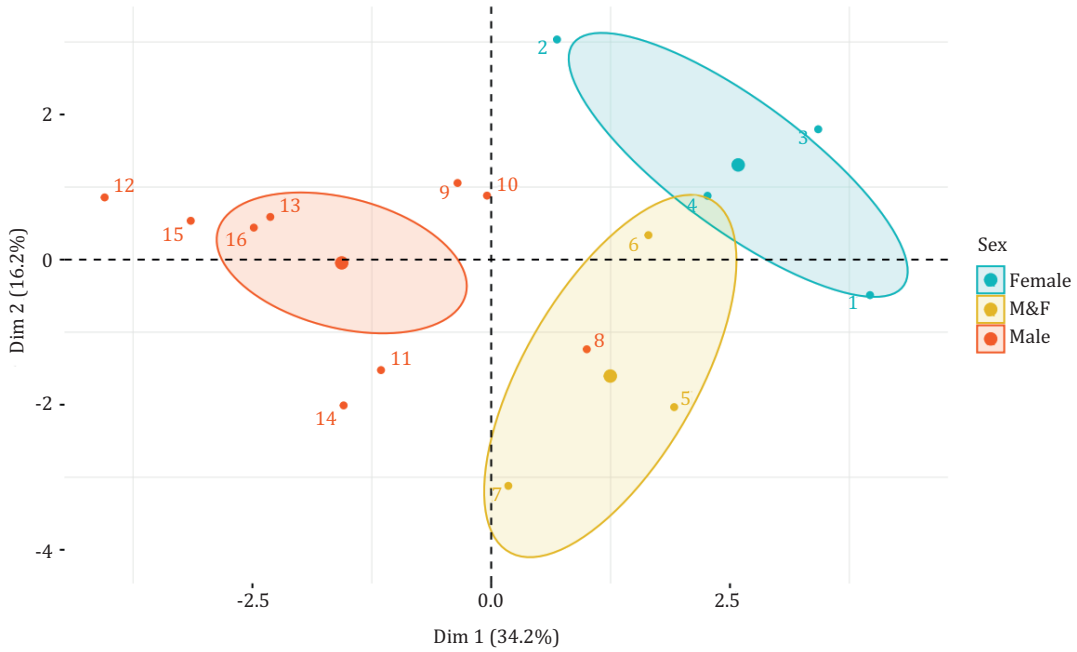


Figure 9 - Factor map of individuals (1-16) distributed in dimensions 1 and 2 with ellipses determining their respective groupings according to the sex of similar individuals.

4. Discussion

In the present study, it is important to highlight the quality of the factorial analysis of mixed data performed. Considering the first five principal components, it was found that they explained 85.56% of the variance, effectively summarizing the total sample variance. This indicates that FAMD is suitable for studying the dataset (Kuppusamy and Giridhar, 2006; Zarei and Bilondi, 2013).

Factorial analysis of mixed data is a type of principal component analysis that allows for inferences about the relationships between quantitative and qualitative data. It enables the explanation of the causes of data variation by evaluating the similarity between individuals and can be considered as an empirical measure of similarity, where higher similarity levels indicate stronger correlations between variables in the grouping. The proximity of individuals reflects similarities in terms of their production indexes, which are the quantitative variables of the study.

Based on the current findings, we observed that scratches and generated value were negatively related, indicating that a higher percentage of scratches led to a lower generated value. This can be explained by the fact that carcasses with scratching incidences require the removal of skin from cuts such as thighs and drumsticks, as they do not meet the required quality standards (Kassai, 2008). This results in a decrease in the weight of the cuts and, consequently, the price of the product without skin.

Age, value generated per kilogram of product, and percentage of total condemnation due to slaughter causes were positively related. While it is not common to slaughter broilers at different ages, operational issues often require waiting until a certain live weight is reached, which can vary with age. Among older birds, female flocks take longer to reach the slaughter weight, resulting in a longer time spent in the field. This may influence the yields of prime cuts, as identified by Api et al. (2017), who found that female carcasses showed better yields of cuts such as breasts, thighs, drumsticks, and wings compared with male carcasses.

Furthermore, the relationship between age and the percentage of total condemnation due to slaughter causes indicates that as bird age increases, the density of the aviary (birds/m^2) also increases. This contributes to the lack of flock uniformity (Mendes and Komiyama, 2011). Paschoal et al. (2012) associated non-uniformity with slaughter condemnations due to poor bleeding and contusion/fracture, as equipment cannot be adjusted individually for each bird. Instead, parameters are set based on average size and weight values for the entire flock. The equipment associated with these condemnation causes includes the stunner and the plucker, which may not work effectively on birds with high weight variations compared with the average.

The non-uniformity of flocks, exacerbated by bird age, is also related to total condemnation due to contamination. Contamination by residues from ruptured viscera occurs due to unevenness and equipment adjustments. The equipment with the highest proportion of contamination includes the cloaca extractor, the eviscerator, and the abdomen opener (Paula and Groff, 2021).

The variables of total condemnation and pre-slaughter condemnations were positively related and grouped in the same quadrant of the graph. An increase in total condemnation due to pre-slaughter changes, such as diseases in the field, has a greater impact on the final total condemnation of the flock compared with condemnation due to the slaughter process, such as contamination. Coldebella et al. (2021) analyzed the causes of condemnation in Gallus birds between 2016 and 2019 and found that 68.2% of the total condemnations were due to pre-slaughter causes, while 29.42% were classified as slaughter causes, and 2.3% were other unspecified causes of condemnation, which aligns with the findings of this study.

The rearing stage is extremely important for the poultry chain, as a completely condemned carcass no longer generates a return on the investment made during rearing and adds disposal costs. Completely condemned birds are usually sent to waste processing facilities, where they are transformed into viscera meal through a water-filled pipeline (Giusti et al., 2022). The disposal of carcasses in integrated poultry production systems results in losses for the industry in terms of production volume and product value, as well as for the producers, who face reduced returns due to a decrease in the number of intact carcasses produced (Kruger et al., 2011).

The type of ventilation plays a crucial role in poultry rearing systems and influences performance and slaughter characteristics, as demonstrated in the present study. Negative pressure ventilation was found to be most closely associated with higher percentages of pododermatitis. This association differs from some previous studies that showed higher pododermatitis percentages in dark house systems, primarily influenced by density, where higher densities lead to a higher percentage of calluses (Rovais, 2013; Carvalho et al., 2015; Kairuz and Freitas, 2018). However, when comparing only positive and negative pressure systems, Jacob et al. (2016) identified a higher incidence of pododermatitis in positive pressure warehouses, primarily due to the surface temperature of the litter. Higher litter surface temperatures were associated with a higher percentage of pododermatitis.

Despite higher densities, the dark house ventilation system allows for better control of rearing parameters, including temperature, leading to improved bedding conditions and the absence of paw lesions. Ferneda et al. (2016) showed a 24% higher percentage of pododermatitis in conventional warehouses compared with the dark house system, provided that it is well controlled by poultry farmers. The absence of pododermatitis in chickens is also important due to the value it adds to the industry, especially considering the increasing sales of this cut in the Asian market, where it is considered a premium cut (Alcover and Crowley, 2020).

The dark house system was found to be most closely related to total condemnation and the percentage of condemnation due to pre-slaughter causes. In the dark house system, there is a higher occurrence of pathologies such as aerosacculitis, arthritis, disgusting appearance, cachexia, cellulitis, dermatoses, myositis, septicemia, ascitic syndrome, and hemorrhagic syndrome (Santos et al., 2019), resulting in a higher percentage of total condemnation. Additionally, mismanagement of these facilities may also contribute to increased total bird condemnations (Santos et al., 2019).

Chicken strain is another factor that influences the slaughter process and meat production, as the behavior and phenotypical characteristics differ between Cobb and Ross chickens. In the present study, the Cobb chicken was found to be most closely related to the generated value, indicating that Ross chicken may experience more losses during field and slaughter processes. Api et al. (2017) found a 1.49% higher breast yield in Cobb birds than in Ross birds. Furthermore, in the present study, the Cobb strain was not grouped in the same quadrant as the percentage of pododermatitis, which is consistent with the findings of Sanotra et al. (2003), who reported a lower incidence of pododermatitis in Cobb birds than in Ross birds. The Cobb strain was also distant from the variable representing the percentage of scratches, indicating that it is not a characteristic that stands out in this strain, allowing for a greater proportion of thigh and drumstick volume to be marketed with skin. Greater breast yield, a higher volume of paw without lesions, and thighs and drumsticks with skin are factors that greatly influence the generated value ($/kg) of flocks, explaining the proximity of the Cobb strain to the value generated by the flocks.

The Ross strain is characterized by more agitated chickens that are easily startled by new stimuli in the environment, resulting in crowding and scratching. Additionally, Ross birds have later feathering compared with the Cobb strain, exposing more skin to scratching for a longer period.

The mixed breed, represented by mixed flocks of Cobb and Ross strains in the same breeding environment, shows that birds with different behaviors and performances compete with each other due to varying levels of locomotor activity, weight gain, and reaction to environmental stimuli. This increases the incidence of scratches on the skin of birds (Pophal, 2004; Pilecco et al., 2011).

Regarding bird sex, female chickens exhibited lower daily weight gain, requiring more time to reach the ideal slaughter weight and consequently increasing their age at slaughter (Shim et al., 2012). The female group showed a lower association with the percentage of pododermatitis and scratches, which is consistent with the findings of Garcia et al. (2002), who observed a lower percentage of scratches in female birds, with an 8% difference compared with male birds. The lower incidence of scratches in females may be explained by the difference in the rate of feather development between the sexes. Females have a faster rate of feathering, and their skin is less exposed than that of males of the same age (Vaillancourt and Barnes, 2008).

The main findings of the FAMD indicate that pre-slaughter factors have a significant impact on the condemnation of broiler carcasses during the industrialization process in the poultry chain. Factors such as the behavior expressed by birds of each strain during their time in the rearing systems, as well as environmental factors, affect the occurrence of lesions such as pododermatitis and scratches, which reduce the value of the set of products generated by poultry slaughter. Although failures during the rearing period and industrialization stage are often identified by the agroindustry, the integration of these findings is less frequent due to the large volume of data generated and the absence of methodologies that effectively link field results and the industrial process. Thus, FAMD proves to be an efficient tool for elucidating the relationships between the results of both productive stages of the poultry chain, which can help in decision-making for adjustments and ultimately lead to greater productivity and financial returns.

5. Conclusions

Strain, sex, and type of ventilation were determinant factors for meat yields, product destination, and economic outcomes in poultry farming. The percentages of scratches and pododermatitis are negatively correlated with the generated value ($/kg) of broiler flocks and are more closely associated with positive pressure ventilation systems, Ross strain, and male chickens. These findings contribute to decision-making in poultry production by highlighting the intimate relationship between sex, type of warehouse ventilation, and poultry strain with the characteristics of the products generated during the slaughter process for commercialization. Moreover, there is a strong interdependence between the rearing stage of broiler chickens and the slaughterhouse. In poultry integration systems, where the agroindustry controls both the rearing and slaughter stages, it becomes possible to guide decisions

made in both the field and the industry to achieve an ideal rearing model. This would result in a greater volume of high-value cuts and lower losses due to condemnations during the slaughter process.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: Garcia, R. G.; Seno, L. O.; Caldara, F. R.; Komiyama, C. M. and Binotto, E. **Data curation:** Borges, H. G. and Seno, L. O. **Formal analysis:** Seno, L. O. and Burbarelli, M. F. C. **Funding acquisition:** Binotto, E. **Investigation:** Borges, H. G. and Burbarelli, M. F. C. **Methodology:** Garcia, R. G. and Seno, L. O. **Project administration:** Garcia, R. G. and Caldara, F. R. **Resources:** Garcia, R. G.; Caldara, F. R. and Binotto, E. **Software:** Seno, L. O. **Supervision:** Garcia, R. G.; Seno, L. O. and Burbarelli, M. F. C. **Visualization:** Binotto, E. **Writing – original draft:** Borges, H. G.; Burbarelli, M. F. C. and Komiyama, C. M. **Writing – review & editing:** Borges, H. G.; Burbarelli, M. F. C. and Komiyama, C. M.

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