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Likelihood of obtaining tender meat from confined calf

Probabilidade de maciez da carne de novilhos confinados

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Abstract
The objective was to evaluate the main factors that influence the shear strength of meat from confined steers and the probability of obtaining soft meat. For this purpose, we evaluated the literature on carcass and/or meat of beef steers in Brazil published between January 1999 and April 2019 and extracted the content from three sections for analysis: materials and methods, results, and discussion. Pearson's correlation was used to analyze the data, and the stepwise statistic was used to determine the proportion of the synchronized effect of variables on shear force. For determining the probability of tenderness, meat with a shear force lower than 4.6 kgf/cm^3 was classified as soft; meat with a higher sheer force was classified as hard. Following the classification, logistic regression analysis and odds ratio test were performed. The factors of study location, the proportion of zebu background in the genome, finishing weight, the percentage of concentrate in the diet, and finishing period and meat marbling explained 62.45% of the variability in the shear strength of beef. The following strategies were found to increase the chances of effectively obtaining soft meat from confined steers: starting the termination phase early even in animals with lower weights, prolonging the confinement time, increasing concentrate percentage in the diet, and a higher marbling degree. It is possible to estimate a large proportion of shear force variability using the production variables (*ante-mortem*), and the process can be adjusted accordingly to considerable increase the possibility of obtaining soft meat.
Keywords: *ante-mortem*, concentrate, shear force, marbling, termination

Resumo
Objetivou-se avaliar os principais fatores que influenciam a força de cisalhamento da carne de novilhos confinados e a chance de obtenção de carne macia. Para isso, foram avaliados os artigos de trabalhos científicos realizados no Brasil sobre carcaça e/ou carne de novilhos de corte, publicados entre janeiro de 1999 a abril de 2019. Foram extraídas da literatura informações do material e método e resultados e dos discussão. Para análise dos dados foi utilizado correlação de Pearson, e a estatística *stepwise* para a determinação da proporção do efeito sincronizado das variáveis sobre a

força de cisalhamento. Para a determinação da chance de maciez, as carnes foram classificadas como macia quando apresentavam força de cisalhamento inferior a 4,6 kgF/ cm^3 e dura quando superior a 4,6 kgf/ cm^3, seguido de análise de regressão logística e teste de *ods ratio*. O local em que o estudo foi desenvolvido, o percentual de zebuíno no genótipo, o peso inicial da terminação, o percentual de concentrado na dieta, o período de terminação e marmoreio da carne, explicaram 62,45% da variabilidade da força de cisalhamento da carne. Iniciar precocemente a fase de terminação, mesmo que com pesos mais leves; prolongar o tempo de confinamento; elevar a participação de concentrado na dieta e aumentar o grau de marmoreio da carne; são estratégias que efetivamente aumentam a chance de obtenção de carne macia de novilhos confinados. A partir de variáveis de produção (*ante-mortem*), pode-se estimar grande parte da variabilidade da força de cisalhamento, sendo que sua correta manipulação possibilitará incrementos significativos na chance de obtenção de carne macia.
Palavras-chave: *ante-mortem*, concentrado, força de cisalhamento, marmoreio, terminação

Introduction

The production of beef with better tenderness is an ongoing challenge in beef farming because it is one of the most relevant factors affecting consumer acceptance and reflects the decisions along the production chain by the producers and industry. Although the consumer perception of tenderness is quite subjective, there are indications that shear force of up to 4.6 kgf/cm^3 is close to the cutoff for classifying meat as tender[1].

There are several factors that influence meat tenderness, including genetic aspects[2], characteristics of production systems[3-6], and *post-mortem* factors[7]. Therefore, it is essential to model the main variables that explain variations in the tenderness of meat from beef cattle to better substantiate decisions within the scope of animal husbandry.

In Brazil, a reasonable number of scientific publications are related to the tenderness of beef from animals who mostly finished in confinement. The scientific basis of these studies is derived from the Newtonian and Cartesian philosophy of research, which analyzes an event from its decomposition into factors, which may still be decomposed into more factors up to the lowest level[8]. This way of thinking makes complex biological variables with great economic impact, such as meat tenderness, difficult to understand and manipulate owing to the influence of a large number of factors.

In this context, meta-analytical procedures using multivariate statistics can help understand these responses and can help model variables according to the results obtained from other characteristics that are easy to identify and control. In this study, we aimed to evaluate the main factors that influence meat tenderness and the probability of obtaining tender meat from confined calves.

Materials and methods

We evaluated the previously published studies on carcasses and beef from steers that were published between January 1999 and April 2019 and could be accessed through SciELO and Google Academic search platforms. The phrase "carcass and beef from steers" was used to select relevant publications in Portuguese and English, and a list 76 articles was obtained.

Studies meeting the following requirements were included in the analyses: (i) the calves should be finished in confinement; (ii) reported data should include the genetic group and/or breed of the calves, the weight at the beginning of termination, percentage of diet concentrate, termination period, and sensory characteristics of meat; (iii) shear strength should be evaluated; (4) the methodology for determining the sensory characteristics of the meat should follow that described by Metz *et al.*[9]; and (v) should include all variables used in this study for logistic regression analysis.

After filtering using these criteria, 35 articles remained. Individual treatments in each article was considered a sample unit (one line) in the database (Annex 1). For each sample unit, relevant information was extracted from the material and methods and results sections, and the treatment was discussed.

The factors and variables considered for the research were as follows: the region of study (South - 1, Southeast - 2, Midwest - 3, North – 4, and Northeast - 5), genetic predominance (Zebu – 1, Continental Taurine – 2, British Taurine – 3, Synthetic – 4, and Cross - 5), percentage of Zebu background in the genome, body weight at the beginning of termination, percentage of diet concentrate, period of termination, age at slaughter, weight at slaughter, weight of warm carcass, thickness of subcutaneous fat, loin eye area, conformation, shear strength, marbling, juiciness, texture, and coloring of meat.

Pearson's linear correlation was performed to analyze the relation between the shear force and each variable in the database. A diagnosis of multicollinearity among the predictor variables was performed through the analysis of Pearson's correlation matrix and the measures of variance inflation factor, condition index, eigenvalues (λ), and proportions of variance associated with each λ[10]. The variables that correlated with a maximum of 15% significance by Pearson's correlation and that did not demonstrate collinearity were further analyzed using the statistics tool *stepwise* for the determination of the proportion of the synchronized effect of variables with the shear force using the partial and total determination coefficients (R^2). Subsequently, the data were subjected to logistic regression test using the SAS LOGISTIC procedure. Meat with a shear force value lower than 4.6 kgf/cm³ was classified as soft; meat with an higher sheer force value was considered hard [1]. Several multiple regression models with linear, quadratic effects, and interactions between the effects were tested using the *stepwise* software using 25% significance level to enter and 30% to remain in the model [11]. The choice of the best model to be adopted was based on Hosmer and Lemeshow's test of fit quality[11]. After model fitting (estimation of βi parameters), the quality of the fitted model and the individual significance values of the parameters were tested by the Likelihood Ratio Test at 5% significance.

The best calculated multiple regression mathematical model adjusted for the probability of the i-th calf providing soft meat and, accordingly, considered for data analysis is described as follows.

$$\left(\frac{P_{ijkjlmno}}{1-P_{ijklmno}}\right) = \beta_0 + \beta_{1\chi 1i} + \beta_{2\chi 2j} + \beta_{3\chi 3k} + \beta_{4\chi 4l} + \beta_{5\chi 5m} + \beta_{6\chi 6n} + \beta_{7\chi 7o} + \varepsilon_{ijklmno}$$

where $P_{ijklmno}$ is the probability of obtaining tender meat from a calf with variables live weight $i(\chi_{1i})$, percentage of concentrate in the diet $j(\chi_{2j})$, period of termination $k(\chi_{3k})$, age at slaughter $l(\chi_{4l})$, degree of meat marbling $m(\chi_{5m})$, interaction between the termination period and concentrate percentage in the diet $n(\chi_{6n})$, and interaction between the weight at the beginning of the term and percentage of concentrate in the diet (χ_{7o}). The multipliers β_0 to β_7 are the regression coefficients associated with the regression variables χ_0, and $\varepsilon_{ijklmno}$ is the random error associated with each observation.

The odds ratio estimated by OR = exp (*bk)*, which is the ratio of the proportions for two possible results, *i.e.*, the ratio between success (πj) and failure (1 - πj) to obtain soft or not soft meat, respectively, was used for the interpretation of the coefficients. The odds ratio was based on the mean denominator of the data set for each model. The units of changes of regression variables were determined according to the researchers' experience for the best interpretation of results as 1 month for the slaughter age, 10 kg for the initial weight, 5% for the percentage of concentrate in the diet, one day for the finishing period, and 0.5 points for the degree of marbling.

Results

The percentage of zebu blood in the genotypes of the calves evaluated in this study was 42.42% (Table 1). The average body weight (BW) of calves was 293.8 kg at the beginning of termination, and they received approximately 42.6% of concentrate in the diet (based on dry matter) with an average termination period of 114 days. The average age and weight at slaughter were 20.7 months and 430.3 kg of BW, respectively. On average, subcutaneous fat thickness in the carcass was 4.62 mm, the marbling score of the meat was 5.05 points, and the shear force was 5.34 kgf/cm³.

The region of study contributed 2% to the variation in shear strength (Table 2). The zebu background in the genome contributed 11.8% of the variation in softness, while 31.4% of the variation was related to the percentage of concentrate used in diets. The weight at the beginning of termination (4.44%), termination period (4.49%), slaughter age (2.39%), and degree of marbling of the meat (2.89%) explain 14.21% of the variation in shear strength. There was an interaction between the termination period and the percentage of concentrate in the diet (2.97%). Together, these factors explain 62.45% of the shear strength of confined calf meat included in studies in Brazil in the last 20 years.

Table 1. Characterization of the data used in the search

Variable	n	Average	Standard deviation	Minimum	Maximum
Percentage of zebu genotype, %	62	42.42	31.9	0	100
Initial weight, kg	62	293.8	62.3	163.3	441.8
Percentage of concentrate, %	62	42.6	15.7	20	89
Termination period, days	62	114.1	29.3	47	194
Age at slaughter, months	62	20.7	4.5	11	26
Slaughter weight, kg	44	430.3	47.1	340.0	524.3
Subcutaneous fat thickness, mm	43	4.62	1.61	1.90	8.70
Marmoreio, points	62	5.05	2.17	1.60	10.35
Shear force, kgf/cm³	62	5.34	2.06	1.92	10.80

Source: Own elaboration.

Table 2. Partial and total determination coefficients (R^2) of the regressor variables of the logistic regression equation for the shear force of confined calf meat

Factor	R^2 - Partial	R2 - Total accumulated
Research region	0.0203	0.0203
Percentage of zebu genotype	0.1186	0.1389
Initial weight	0.0441	0.1830
Percentage of concentrate	0.3141	0.4971
Termination period	0.0449	0.5420
Age at slaughter	0.0239	0.5659
Marmoreio	0.0289	0.5948
Period*focused on diet	0.0297	0.6245

Source: Own elaboration.

The weight at the beginning of termination, percentage of concentrate in the diet, termination period, age at slaughter, and the degree of marbling of the meat were the factors in the logistic regression equation to explain the chance of tenderness (Table 3). By Hosmer and Lemeshow's test (p = 0.8176), this model predicts satisfactorily the variation in softness. By the odds ratio test, it was possible to identify that for every 10 kg increase in the initial weight of the termination of 430.3 kg of BW, a reduction in the probability of softness of 61.6% is expected. For each 5% increase in the concentrate in diet, on top of besides the 42.6% on average received, there will be a 2.7-fold increase

in the probability of obtaining tender meat. The longer the confinement time is, the greater the chance of obtaining tender meat. Every day beyond the 114-day period that the calves remain in confinement, a 2-fold increase in the chance of obtaining tender meat is expected. Age, which shows an inverse effect, reduces the chance of obtaining tender meat; for each month added to the slaughter age of 20.7 months, there was a 31.9% reduction in the chance of obtaining tender meat. Marbling had a positive effect, where an increase of 0.5 points from 5.05 points results in 74.5% increase in the probability of obtaining tender meat.

Table 3. Probability of tenderness of confined calf meat

Tenderness parameter	Value	Standard error	Unit of change	*Odds ratio*	HLT
Intercept	-70.7282	26.0984		-	0.8176
Initial weight	-0.0954	0.0494	10 kg	0.385	
Percentage of concentrate	1.9954	0.6701	5%	2.712	
Termination period	0.7134	0.2053	1 day	2.041	
Age at slaughter	-0.3842	0.1493	1 month	0.681	
Marmoreio	1.1134	0.3299	0.5 points	1.745	
Period*concentrate in the diet[1]	-0.0167	0.00468	-	-	
Initial weight*concentrate in the diet[2]	0.00271	0.00116	-	-	

[1] Interaction between the period of termination and the percentage of concentrate in the diet; [2] Interaction between the weight at the beginning of termination and the percentage of concentrate in the diet.
HLT= Hosmer and Lemeshow test
Source: Own elaboration.

Discussion

The characteristics of the production systems analyzed in most studies on confined cattle in Brazil reflect the main technical recommendations that are applicable to the rural areas in the country: a volume to concentrate ratio of 60:40; finishing period of up to 120 days; fat cover median of 3 to 6 mm; and slaughter weight between 400 and 450 kg of BW. An exception was the warm carcass weight (230 kg, considering a yield of approximately 54%), which could incur a penalty because of the low weight required in certain more demanding carcass-quality programs. The other production variables such as age at slaughter, period of confinement, and subcutaneous fat thickness, had values that would fit in most carcass quality programs in the country and that payed above the usual market values[12].

The average shear strength was above the values considered between intermediate and soft, up to 4.6 kgf/cm^3[1], indicating that most surveys produced meats that were not considered soft. The high proportion of zebu blood in animal genotypes was one

of the main causes for higher meat shear strength. Currently, it is estimated that 80% of the Brazilian herd is composed of animals of zebu origin owing to the tolerance their tropical climate and better resistance to ectoparasites[13]. Pacheco et al.[5] used meta-analysis to evaluate the characteristics of meat from slaughter cows in Brazil by contrast analysis and found that animals with defined zebu genotypes had increased shear strength by 1.05 kgf/cm^3 compared with animals of continental and/or mixed breeds. Of all reproduction biotechnologies, artificial insemination can be used for breeding bovines, making it possible to increase the production of meat with better tenderness.

The significant effect of BW at the beginning of termination on the shear force reflected negatively on meat softness, which is related to the fact that heavier calves receiving more energetic diets at the beginning of termination live for a short period. Another hypothesis that can support this result is related to differences in the feeding efficiency of calves; more efficient cattle show lower rates of protein turnover and increased muscle growth rate owing to higher activity of the enzyme calpastatin[14]. Although this enzyme contributes to the improvement of performance, allowing greater weight at the end of termination, its effects *post-mortem* do not favor meat tenderness. This is because, the enzyme decreases the activity of calpain in the muscle, negatively affecting meat tenderness by decreasing protein degradation[15].

The percentage of concentrate had the greatest impact on the shear force and had the greatest interaction with the variables tested. Increasing the proportion of concentrate is the main strategy adopted by producers to increase the energy level of cattle diets. Although corn is largely the main energy ingredient in the diet, Brazil has great productive and diversified potential with regard to agriculture, which enables other sources such as wheat bran, rice bran, sorghum or millet grains, and soybean husk to be used for feeding ruminants. These ingredients can be used as alternatives to corn without reducing the energy level of the diet and with the possibility of reducing production costs when the price of corn grain is high. Although the percentage of concentrate is related to the termination period and diet energy level, it is also directly related to diet fiber content. Concentrate is one of the factors responsible for ensuring higher activity of calpastatin in the muscle, consequently making the meat less tender[6].

Termination period is recognized by its quadratic effect on meat tenderness, depending on the age. Few studies have reported that tenderness increases with increasing finishing time of up to 120 and 130 days[16, 17]. After this period, the efficiency of weight gain decreases along with increasing age, to an extent where the meat quality decreases[18]. Age, in turn, shows an inverse correlation with tenderness, and in the present study, it had the same representation in the variability of shear force as the finishing time. This is because, as age progresses, intra- and intermolecular “cross-links” (intermolecular covalent bonds) are formed in collagen, which improve collagen stability, decreasing collagen thermal solubility and making the flesh more resistant[19].

The interactions observed between initial weight, termination period, and concentrate percentage are of great relevance because they affect shear force variability and meat tenderness in a joint and systematic way. However, this evaluation should be analyzed

very sparingly, considering the economic efficiency of the system. In a meta-analysis of scientific articles published in Brazil, Cattelam et al.[20] correlated the effects of slaughter age, termination period, and diet energy level using a decision tree. They found that more than 145 days of confinement are required to terminate super precocious calves (up to 18 months of age). To reduce this period, concentrate levels of >69% and energy levels of ≥71% TDN would be required. These results show that producing soft meats in Brazil may represent a high-risk strategy from an economic point of view and that such differentiated meats require a growing market.

Meat marbling is highly valued in the industry owing to its relationship with palatability and softness, especially when the latter is evaluated by a panel of evaluators. Meat marbling produces a lubricant effect and decreases tension between the layers of meat connective tissue during chewing. However, its contribution to shear strength is less evident, with a maximum contribution of 5% to softness variability [7]. Marbling fat is closely related to fat thickness in the carcass[21]. When the amount of fat is scarce, the carcass cooling process is more accelerated as muscles are protected from cooling to a lesser extent, which negatively effects several meat quality characteristics[22].

Conclusions

A higher proportion of variability in the tenderness of meat from confined calves can be explained by factors related to the genetic background and the characteristics of production systems. When the initial weight at termination is higher, it is common to reduce the percentage of concentrate in the diet and shorten the period until slaughter. Under these conditions, the probability of obtaining tender meat is lower. In contrast, reducing the age at which calves are slaughtered and increasing the degree of meat marbling can significantly improve the chance of obtaining tender meat.

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Annex

Annex 1. Studies used for data analysis

Study	Number of treatments used	Total number of animals
Restle et al. [23]	4	24
Feijó et al. [24]	4	45
Vaz et al. [25]	2	70
Vaz et al. [26]	4	463
Faturi et al. [27]	4	48
Vaz e Restle [28]	2	36
Vaz et al. [29]	3	24
Costa et al. [30]	4	24
Vaz e Restle [31]	4	157
Arboitte et al. [32]	3	18
Vaz et al. [33]	3	60
Menezes et al. [34]	8	78
Leite et al. [35]	3	12
Brondani et al. [36]	2	16
Canesin et al. [37]	3	24
Climaco et al. [38]	2	40
Vaz et al. [49]	2	12
Ribeiro et al. [40]	3	41
Metz et al. [9]	2	12
Cattelam et al. [41]	1	12
Rubiano et al. [42]	4	86
Silveira et al. [43]	2	22
Missio et al. [44]	4	16
Vaz et al. [45]	1	12
Menezes et al. [46]	3	17
Climaco et al. [47]	4	20
Donicht et al. [48]	4	20
Arboitte et al. [49]	2	18
Pacheco et al. [50]	1	9
Miotto et al. [51]	5	30
Hirai et al. [52]	3	18
Menezes et al. [53]	3	12
Cattelam et al. [54]	3	48
Barcellos et al. [55]	2	20
Aranha et al. [56]	1	18
Total animals	-	1,582

Source: Own elaboration.