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Relationship between hepatic foamy macrophages and performance of cattle raised extensively on *Brachiaria* spp. pastures

[Relação entre os macrófagos espumosos hepáticos e performance de bovinos criados extensivamente em pasto de *Brachiaria* spp.]

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Abstract: The aim was to evaluate the relationship between the area occupied by foamy macrophages and hot carcass weight as a measure of performance in cattle raised extensively on *Brachiaria* spp. pastures. The carcasses of 100 Nellore cattle, aged between 20 and 36 months, were weighed and distributed into two groups: Group 1 (247.15 to 275.39 kg) and Group 2 (312.72 to 343.48 kg). The livers of the cattle were weighed, and samples from the right lobe were collected for histopathological analysis. The areas of the hepatic parenchyma containing foamy macrophages were measured using the ImageJ® software. Statistical analysis of the parameters (liver weight, hot carcass weight, and compromised liver tissue area) was performed quantitatively, calculating the mean, standard deviation, and coefficient of variation. These data were analyzed for normality and homogeneity of variances using the Kolmogorov-Smirnov and Bartlett tests. As the variables were homogeneous and had a normal distribution, they were evaluated by a parametric analysis of variance test. The correlation of the variables was performed using Spearman's test. The significance level adopted was 5 %, and all descriptive analyses were performed using Microsoft Excel program, while the statistical tests were done with the R program. Cattle grazing on *Brachiaria* spp. exhibited hepatic lesions characterized by degeneration (5 %), necrosis (7 %), and the presence (94 %) of a mild inflammatory infiltrate and small areas of hepatic tissue containing foamy macrophages (23 %). The compromised area of the hepatic parenchyma containing foamy macrophages did not influence the hot carcass weight of the cattle.

Keywords: Bovine carcass; progressive weight loss; stereology.

Resumo: O objetivo foi verificar a relação da área ocupada por macrófagos espumosos com o peso de carcaça quente na performance de bovinos criados extensivamente em pasto de *Brachiaria* spp. As carcaças dos 100 bovinos nelore, com idade entre 20 e 36 meses, foram pesadas e distribuídas em dois grupos: Grupo 1 (247,15 a 275,39 kg) e Grupo 2 (312,72 a 343,48 kg). Os fígados dos bovinos foram pesados e amostras do lobo direito coletadas para análise histopatológica. As áreas do parênquima hepático contendo macrófagos espumosos hepáticos foram mensuradas utilizando-se o programa ImageJ®. A análise estatística dos parâmetros (pesos dos fígados, pesos da carcaça quentes e área comprometida do tecido hepático) foi realizada de forma quantitativa, calculando a média, desvio padrão e coeficiente de variação. Esses dados foram analisados quanto

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à normalidade e homogeneidade das variâncias, por meio dos testes de Kolmogorov-Smirnov e Bartlett. Como as variáveis foram homogêneas e tiveram uma distribuição normal, foram avaliadas pelo teste paramétrico de análise de variâncias. A correlação das variáveis foi realizada pelo teste de Spearman. O grau de significância adotado foi de 5 % e todas as análises descritivas foram realizadas pelo programa Microsoft EXCEL e os testes estatísticos pelo programa R. Os bovinos sob pastejo de *Brachiaria* spp. apresentaram lesões hepáticas caracterizadas por degeneração (5 %), necrose (7 %) e presença (94 %) de infiltrado inflamatório de intensidade leve e pequena área do tecido hepático contendo macrófagos espumosos (23 %). A área comprometida do parênquima hepático contendo macrófagos espumosos não influenciou no peso da carcaça quente dos bovinos.

Palavras-chave: Carcaça bovina; estereologia; perda progressiva de peso.

1. Introduction

Improvements in pasture quality and increased production capacity lead to greater livestock efficiency [1, 2]. In 2016, approximately 50 % of Brazil's total planted or natural pastures (100 million hectares) were considered degraded [2]. In 2017, the same percentage was found in 173 municipalities in the Brazilian Cerrado [3], which reduces national livestock productivity [2]. By 2023, the Cerrado already had 67.18 % of its pasture areas with severe or moderate degradation [4].

Brachiaria spp. grasses have gradually replaced natural pastures; however, they have been reported as a hepatotoxic plants in numerous studies [5–8]. Its toxicity has caused liver disease in ruminants in Brazil and Mexico [5, 9–15], including fibrotic lesions in the liver [12, 16–18], which accounted for 1.09 % of the reasons for rejection of this organ at slaughterhouses [16]. Studies have reported that the occurrence of this condition was underestimated, leading to economic losses such as delayed development, low weight gain, and reduced milk production [11, 14, 19, 20].

Starting in the 1970s, *Brachiaria decumbens* (*Urochloa decumbens*) became the most common grass in Brazilian pastures [21], accompanied by reports of liver changes [5,22,23]. Accumulated macrophages with foamy cytoplasm were observed in organs such as the liver, spleen, and hepatic and mesenteric lymph nodes [21, 24, 25]. Their presence was also reported in myocardial cells [26] and in the iliac artery [27], and has also been reported in other ruminants [28–30].

There are reports of the presence of these cells in cattle ranging from 30 days [31] to 150 days after the animals began grazing on *Brachiaria* spp. [21]. An increase in the number of this type of macrophage in animals grazing on *Brachiaria* spp. has been correlated with lower live weight [5,32,33]. This is thought to result from the severity of the histopathological liver changes caused by these cells [32]. Histopathological lesions often do not result in clinical signs or macroscopic changes, but they affect organ function, leading to poor weight gain [32, 33]. Weight losses of approximately 2.52 %, 28.01 %, and 39.28 % have been reported for cattle with hepatogenic photosensitization in the subclinical, moderate chronic, and severe chronic forms, respectively [34].

Although there is a negative correlation between the number of foamy macrophages (FMs) and lower live weight in cattle, this same relationship has not been established when considering the area occupied by these cells, which can vary in size [32, 33]. Areas of the hepatic parenchyma may be replaced by clusters of FMs, thereby interfering with normal liver metabolism [32]. Since FMs vary in number and size, measuring the area they occupy may represent a more efficient and accurate measure of the extent of the alteration [35], which can be assessed using ImageJ® software, providing a more objective analysis compared to the subjectivity of traditional methods [36]. The aim of this study was to investigate the relationship between the area occupied by FMs and hot carcass weight, one of the parameters used to evaluate cattle performance.

2. Material and methods

Liver samples were obtained from cattle aged 20 to 36 months, as determined by dental chronology [37], from a federally inspected slaughterhouse located in the city of Goiânia, Goiás, Brazil. The animals were intact male Nellore cattle, raised extensively on *Brachiaria* spp. pastures and originating from a farm located in the municipality of Montividiu do Norte, Goiás, Brazil.

To evaluate performance and hepatic changes, the hot carcass and liver weights of 100 animals selected from a batch of 200 animals sent for humane slaughter were recorded. Hot carcass weight was obtained by summing the weights of the half-carcasses. As a classification criterion, the lower (group 1) and upper (group 2) quartiles of the batch's weight distribution were used as cutoff points. Thus, liver samples were collected from the 50 cattle with the lowest carcass weights (247.15 to 275.39 kg) and from the 50 with the highest carcass weights (312.72 to 343.48 kg).

It was decided to focus on the right lobe and standardize all samples because Fioravanti [32], when studying apparently healthy Nellore cattle aged between 2.5 and 4 years and raised extensively on *Brachiaria* spp. pastures, demonstrated that there was no statistical difference ($p>0.05$) in the distribution pattern of FMs and in inflammatory changes (in terms of intensity and extent) between the right and left lobes of the liver. Nevertheless, he observed greater amounts of degeneration and necrosis in the right lobe.

The study was approved by the Animal Use Ethics Committee of the Federal University of Goiás (CEUA/UFG) under number 094/2015, in accordance with current legislation and ethical principles.

2.1 Liver samples

A sample was collected from the same region of the right lobe of each liver using a punch-like instrument with the following dimensions: 23 mm inner diameter × 100 mm length (Figure 1). The samples were then placed in a container with 10 % buffered formalin at a ratio of 1 part tissue to 10 parts fixative for subsequent processing [38].

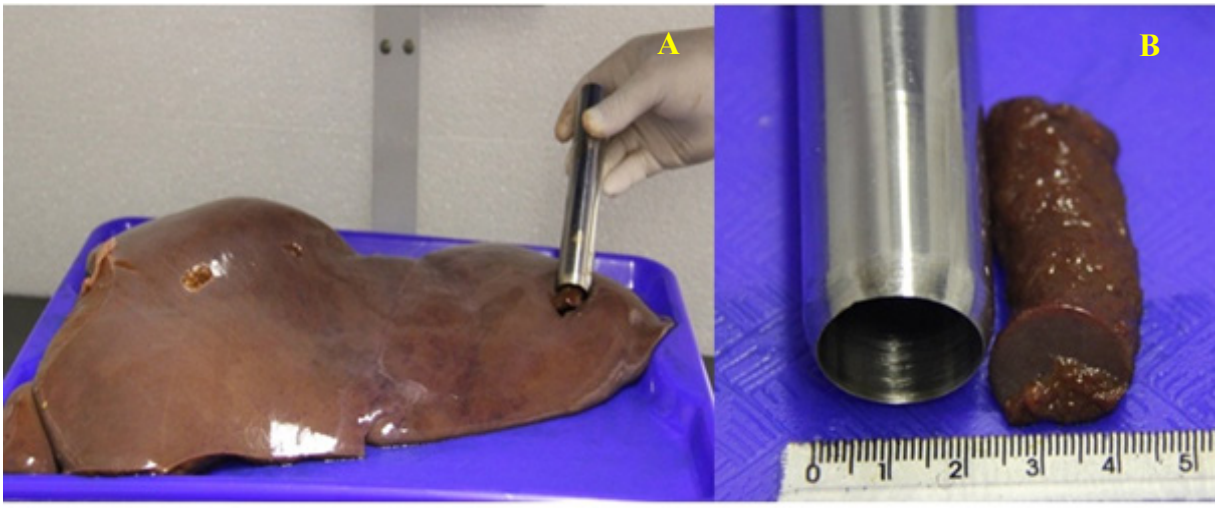

Figura 1. Liver at the sample collection. A – Sample collection from the right lobe. B – Dimensions of the sampling instrument.

2.2 Histopathological analyses

The samples were kept in containers containing 10 % buffered formalin, processed according to the routine method, and then stained with hematoxylin and eosin (HE) [39]. The criteria for analysis were described based on the definition of a functional hepatic acinus proposed by Rappaport (1973) [40], in which the lobule is divided into three zones: zone 1 or centroacinar; zone 2 or mediozonal; and zone 3 or periacinar.

The changes were described based on the following criteria, which have already been used for liver tissue: focal lesion (a single, small lesion); multifocal (lesions in at least three fields and randomly distributed); diffuse (lesions throughout the organ) [32]. The lesions were also classified according to the Rappaport zone. The intensity of inflammatory infiltrate, degeneration, and necrosis was described as: mild (few cells distributed sparsely or around the bile ducts); moderate (occupying part of the portal space); severe (occupying the entire portal space). Degeneration was further classified as microvacuolar and macrovacuolar.

The number of FMs on the slides was counted, both as isolated cells and in clusters. The final number of FMs was obtained by summing the average number of cells in each cluster with the FMs found in isolation. The average number of cells found was estimated at five cells per cluster:

$$Nº\ of\ FMs = (Nº\ of\ clusters\ of\ FMs * 5) + Nº\ of\ isolated\ FMs$$

The area occupied by FMs in the hepatic parenchyma was delineated in each field of the slide and then measured. All slides in which FMs were observed were evaluated, using ten randomly selected fields per slide, which were photographed under a 10x objective [41]. Delineation began with the mandatory criterion of FM presence in the first field.

This procedure was performed using the ImageJ® software, which allowed for greater accuracy in image interpretation [42, 43]. For this purpose, the slides were photographed using a Leica D750 optical microscope coupled with an ICC50E digital imaging module, and their micrometer scales were added to the images (100 µm).

Subsequently, the photomicrographs were calibrated and analyzed using ImageJ® software (version 1.60, Wayne Rasband, National Institutes of Health, USA) across ten fields; the region occupied by FMs was delineated manually, and the percentage was calculated by subtracting the area occupied by FMs from the total image area (Figure 2). The choice to quantify the percentage of area, rather than relying on isolated cell counting, is based on the need to mitigate the bias caused by variations in the size and volume of the damaged cells. Furthermore, the effectiveness of proportional area analysis in liver tissues [44] and its established applicability in the field of veterinary medicine [45] provide the methodological rigor necessary for the precise characterization of tissue damage in cattle.

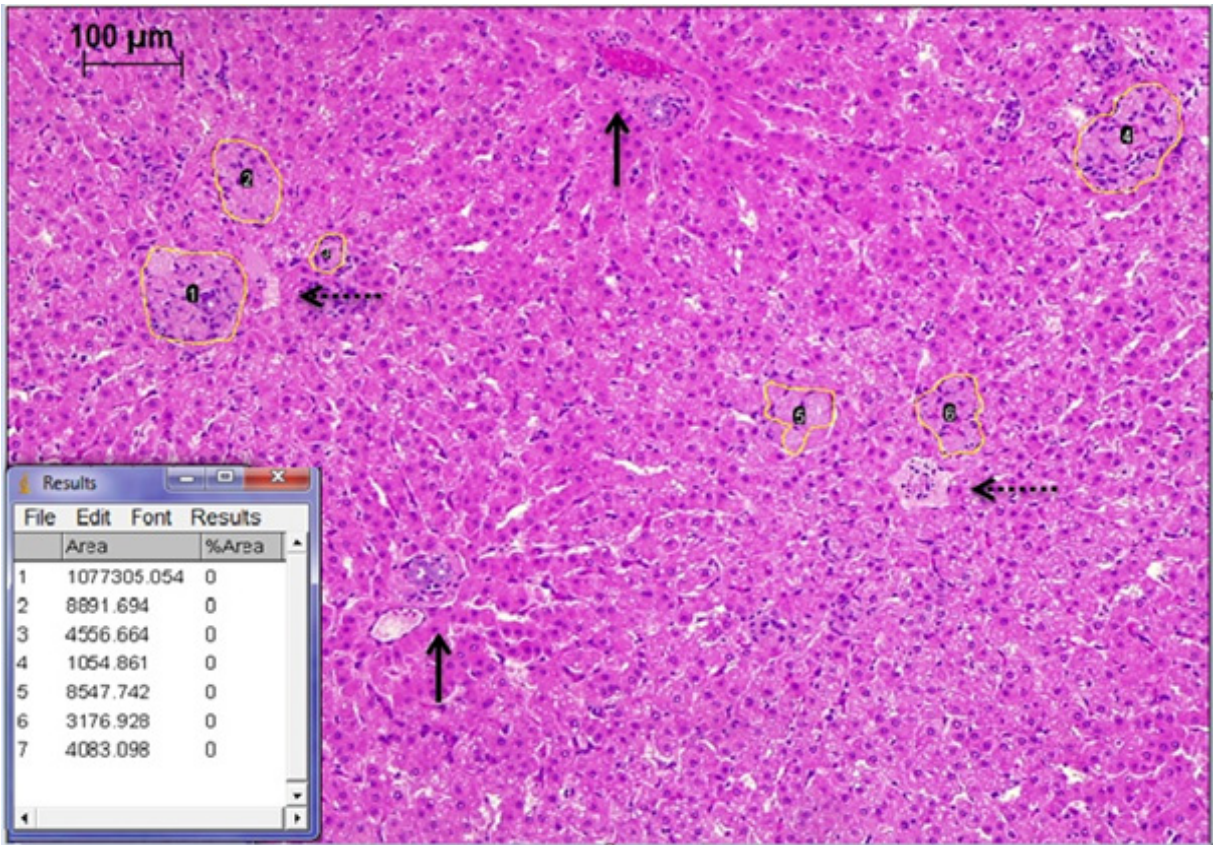

Figure 2. Manual delineation of the area occupied by FMs in the photomicrograph of a HE-stained liver specimen slide. Total area of the field indicated within the rectangle. Area occupied by FM indicated by the numbered boundaries. Vertical solid arrows indicate portal spaces. Horizontal dotted arrows indicate terminal hepatic veins.

2.3 Statistical analyses

Statistical analysis of the parameters (hot carcass weight, liver weight, and area of compromised hepatic parenchyma) was initially performed quantitatively, calculating the mean, standard deviation, and coefficient of variation. Subsequently, these data were assessed for normality and homogeneity of variances using the Kolmogorov-Smirnov and Bartlett tests. Since the variables were homogeneous and had a normal distribution, they were analyzed using the parametric analysis of variance (ANOVA) test.

The analysis of histopathological changes was performed by studying frequencies and was evaluated using the nonparametric chi-square test. Correlation of the variables was also performed using Spearman's correlation. The significance level adopted was 5 %, and all descriptive analyses (presence of necrosis, degeneration, inflammatory infiltrate, and FMs) were performed using Microsoft Excel, while the R program was used for statistical tests.

3. Results and discussion

3.1 Weight of the carcass and liver

The mean, standard deviation, coefficient of variation, and correlation of carcass and liver weights in cattle are shown in Table 1.

Table 1. Mean values ($\bar{X}$), standard deviation (S), coefficient of variation (CV), and correlation (r) for the carcass and liver weights of Nellore cattle with lower (Group 1) and higher (Group 2) weights slaughtered in the municipality of Goiânia.

		$\bar{X}$	S	CV	P	r
Carcass weight (Kg)	Group1 (n=50)	261.27 a	14.12	5.40	**<0.05**	**0.72**
	Group 2 (n=50)	328.10 b	15.38	4.69		
Liver weight (Kg)	Group 1 (n=50)	5.11 a	0.44	8.69	**<0.05**	
	Group 2 (n=50)	5.85 b	0.41	7.09		

Means followed by different letters in the same column and for the same variable are statistically different from one another ($p < 0.05$).

The mean carcass weight in Group 2 was 25.58 % higher ($p < 0.05$) than those for Group 1. This difference contributed to the mean liver weight of Group 2 animals being 14.48 % higher ($p<0.05$) than that of Group 1. This difference occurred because, according to Vaz et al. [46], there is a strong positive correlation between internal organ weight and empty body weight. Similar results regarding the relationship between empty body weight and liver weight were reported by Jorge and Fontes [47] ($r = 0.64$), explaining that heavier animals have greater metabolic capacity than lighter ones [42]. In the present study, the positive correlation between these variables was significant and strong ($r = 0.72$). The liver has high metabolic rates because it actively participates in nutrient metabolism, and both the liver and the gastrointestinal tract are responsive to changes in food intake. The weight and metabolic activity of visceral organs are frequently associated with weight gain efficiency [48].

3.2 Histopathological evaluation

The histopathological changes observed (Table 2) in the liver tissue of the cattle in this study were: microvacuolar degeneration (5 %), necrosis (7 %), cholangiohepatitis (94 %), and the presence of FMs (23 %).

Table 2. Frequency of changes found in the liver tissue of Nellore cattle slaughtered in the municipality of Goiânia.

Liver tissue alterations	**Frequency**		
	Group 1 (n=50)	**Group 2** (n=50)	**Total** (N=100)
Microvacuolar degeneration	2 (4 %)	3 (6 %)	5 (5 %)
Necrosis	5 (10 %)	2 (4 %)	7 (7 %)
Cholangiohepatitis	47 (94 %)	47 (94 %)	94 (94 %)
Presence of foamy macrophages (FMs)	13 (26 %)	10 (20 %)	23 (23 %)
Presence FMs+ cholangiohepatitis	13 (26 %)	8 (16 %)	21 (21 %)
Presence FMs + microvacuolar degeneration	1 (2 %)	1 (2 %)	5 (5 %)
Presence FMs + necrosis	3 (6 %)	0 (0 %)	3 (3 %)
Microvacuolar degeneration + necrosis	0 (0 %)	0 (0 %)	0 (0 %)
Cholangiohepatitis + microvacuolar degeneration	2 (4 %)	3 (6 %)	5 (5 %)
Cholangiohepatitis + necrosis	5 (10 %)	1 (2 %)	6 (6 %)
Presence FMs + cholangiohepatitis + microvacuolar degeneration	1 (2 %)	1 (2 %)	5 (5 %)
Presence FMs + cholangiohepatitis + necrosis	3 (6 %)	0 (0 %)	3 (3 %)
Presence FMs + microvacuolar degeneration + necrosis	0 (0 %)	0 (0 %)	0 (0 %)
Colangiohepatite + microvacuolar degeneration + necrosis	0 (0 %)	0 (0 %)	0 (0 %)
Presence FMs + microvacuolar degeneration + necrosis + cholangiohepatitis	0 (0 %)	0 (0 %)	0 (0 %)

The changes observed in each experimental group (degeneration, necrosis, inflammatory infiltrate, and the presence of FMs) were mild in intensity and showed no significant differences ($p > 0.05$) (Table 3).

Table 3. Frequency, distribution, and location of histopathological changes observed in liver tissue samples from Nellore cattle with lower (G1 - Group 1) and higher (G2 - Group 2) body weights slaughtered in the municipality of Goiânia.

Alterations	Groups			Distribution (%)			Localization (%)				Cluster formation	
		Presence (%)	P	Focal	Multifocal	Diffuse	Zone 1	Zone 2	Zone 3	Portal space	Presence (%)	P
Degeneration	G1 (n=50)	2 (4 %)	1	0	0	100	0	50	50	0		
	G2 (n=50)	3 (6 %)		0	33.33	66.67	0	50	50	0		
Necrosis	G1 (n=50)	5 (10 %)	0.433	80	20	0	27.27	45.45	27.27	20		
	G2 (n=50)	2 (4 %)		100	0	0	0	100	0	0		
Inflammatory infiltrate	G1 (n=50)	47 (94 %)	1	27.66	72.34	0	4.22	19.72	12.68	63.38		
	G2 (n=50)	47 (94 %)		29.79	70.21	0	10.67	25.34	6.67	57.33		
Foamy macrophages	G1 (n=50)	13 (26 %)	0.634	38.46	53.85	7.69	9.09	31.82	54.55	4.54	69.23	1
	G2 (n=50)	10 (20 %)		60	40	0	0	0	90	10	80.00	

Not significant at $p > 0.05$.

The distribution of degeneration in Group 1 was exclusively diffuse (100 %), while in Group 2 it was diffuse (66.67 %) and multifocal (33.33 %). In both groups, this change was of the microvacuolar type, and the lesions were identified in zones 2 and 3. The distribution of necrosis in Group 1 was predominantly focal (80 %) and multifocal (20 %), whereas in Group 2 it was exclusively focal (100 %). The foci were located primarily in zone 2.

In outbreaks of hepatogenic photosensitization caused by *Brachiaria* spp., necrosis has been reported by some authors [25, 30, 49–54], while others [22, 56, 57], in addition to describing the lesion, quantified its presence in approximately 50 % of cases. In the present study, the mean frequencies of degeneration and necrosis across both groups were low (5 % and 7 %, respectively), consistent with Alessi et al. [57], Fioravanti [32], and Moreira et al. [33], who also noted the absence or rare occurrence of necrosis. However, they noted the presence of degeneration in most animals, mainly in zone 3, and judged both changes to be nonspecific in cattle with liver changes kept on *Brachiaria decumbens* pasture.

The presence of inflammatory infiltrates and FMs warrants closer attention, given that these changes have been linked by some authors [10, 11, 13, 17, 18, 32, 33, 53, 58] to hepatic abnormalities, including hepatogenic photosensitization, in animals grazed on *Brachiaria* spp. pastures. Additionally, elevated serum gamma-glutamyl transferase (GGT) activity and cholangiohepatitis (presence of inflammatory infiltrate in the bile ducts and liver parenchyma [59]) have been used to characterize the subclinical form of hepatogenic photosensitization [14, 21 ,54, 58].

Inflammatory infiltrates were present with a multifocal distribution in both groups (over 70 %), predominantly in the portal space (over 91 %) and in zone 2 (between 29 % and 40 %). Inflammatory infiltrate was described by Dobereiner et al. [60] in 80 % of cattle and in all sheep evaluated during outbreaks of hepatogenic photosensitization in the state of Mato Grosso. Similarly, it was described in 43 % to 66 % of cattle groups with clinical signs of photosensitization studied by Alessi et al. [57]. These inflammatory changes were predominantly located in or near the portal space and had a multifocal distribution in cattle [21, 22, 25, 32, 33, 61, 62], buffalo [63, 64], sheep [14, 28, 48, 55, 56, 65–71], goats [50, 52], and horses [51] grazing on *Brachiaria* spp.

Considered a finding suggestive of sporodesmin toxicosis, the presence of cholangiohepatitis was associated with hepatic FMs in the form of clusters located predominantly in zone 3 [32,33]. Cruz et al. [65], however, associated this inflammatory change with plants containing steroidal saponins, and noted that this and other changes, such as lymphocyte and macrophage infiltration, were induced by the experimental administration of saponins obtained from the extract of *Brachiaria decumbens*. This was later confirmed by Riet-Correa et al. [64], who suggested the presence of FMs as a consequence of ingesting the lithogenic steroidal saponins of *Brachiaria* spp.

The first reports of hepatic FMs in cattle coincide with the introduction of *Brachiaria* spp. as the primary forage in Brazil [11, 13, 18, 21, 53]. As demonstrated in the present study, these cells were frequently observed in various animal species raised on this type of grass [11, 13, 16–18, 21, 22, 24, 25, 28, 30, 49, 53, 55, 56, 61, 62, 64, 68–70, 72].

Analysis of the FMs revealed a multifocal distribution (53.85 %) in Group 1 and a focal distribution (60 %) in Group 2. In both groups, the presence of FMs in the form of clusters was identified (over 69 %) in zone 3 (over 90 %). The predominant localization in zone 3 and the presence of clusters have also been described by numerous authors [21, 22, 24, 25, 32, 33, 61]. Several hypotheses have been proposed to explain the higher prevalence of FMs in zone 3. According to Bogliolo and Brasileiro Filho [73], this is related to the fact that this region is responsible for biotransformation. Assumaidaee and Mustapha [6] suggest that saponins, upon biotransformation, generate free radicals that may trigger the presence of FM. According to Fioravanti [32], superoxide radicals, products of the auto-oxidation of sporidesmin, would cause lipid peroxidation and the emergence of FMs, and the higher presence in zone 3 would result from the involvement of endothelial cells and monocytes, which are necessary for the formation of these cells and may even appear in the form of giant cells. The lesions observed in the liver parenchyma did not affect hot carcass weight (Table 4).

Table 4. Correlation coefficients between hot carcass weight and histopathological changes in the liver of Nellore cattle slaughtered in the municipality of Goiânia.

Variable	r	P
Hot carcass weight x FMs presence	-0.017	0.868
Hot carcass weight x presence of inflammatory infiltrate	0.008	0.937
Hot carcass weight x presence of degeneration	-0.013	0.900
Hot carcass weight x presence of necrosis	-0.094	0.350

FMs: foamy macrophages. Not significant at $p > 0.05$.

Fioravanti [32] demonstrated a significant negative correlation between live weight and the number of hepatic FMs in cattle of both sexes, a finding later confirmed by Moreira et al. [33] when working with two groups of male cattle raised on different forage species (*Andropogon gayanus* and *Brachiaria* spp.). On the other hand, Fioravanti [32] did not observe the same correlation

between the number of hepatic FMs and either hot carcass weight or carcass yield. The lesions caused by these cells in the liver also did not alter the hot carcass weight of buffalo [64], nor did they affect performance in sheep [74].

A statistical difference was observed between the cattle groups for mean hot carcass weights, unlike the findings for the mean percentage of the area compromised by FMs in the liver parenchyma (Table 5).

Table 5. Average weight of hot carcasses, frequency, total number, and area affected by FMs in the liver parenchyma of Nellore cattle with lower (Group 1) and higher (Group 2) weights slaughtered in the municipality of Goiânia.

Area affected by FMs in the liver parenchyma					
Group	Mean weight (Kg)	Presence of FMs (%)	Total number of FMs per group	Mean compromised area (%)	P
Group1 (n=50)	261.27 a	13 (26 %)	2,750	0.4478 a	0.563
Group2 (n=50)	328.10 b	10 (20 %)	518	0.0534 a	

FMs: foamy macrophages. Means followed by different letters in the same column and for the same variable are statistically different from one another ($p > 0.05$).

Porto et al. [70] hypothesized that weight loss in animals grazing on *Brachiaria* spp. was due to some alteration in hepatic metabolism. Tissue injury caused by toxic agents increases cytokine production by endothelial cells, monocytes, and Kupffer cells, triggering the cascade of reactions involved in the liver regeneration process [75]. Sporidesmine and saponin were identified as toxic substances to cattle [76]. Hepatic functional reserve and regenerative capacity may have contributed to maintaining normal metabolism and the consequent maintenance of hot carcass weight, since, according to Jesus et al. [75], the regenerative process represents a mechanism of organ protection against the loss of functional liver tissue.

In one study, FMs were detected in 42.4 % of liver samples [53], which were collected from animals slaughtered between 1976 and 2008. Fioravanti [32] found FMs in 67.57 % of bovine livers. Souza et al. [22], Caicedo et al. [62], and Faccin et al. [17] found prevalence rates between 70 % and 80 %, while Gomar [25] and Moreira et al. [33] reported rates above 90 %. It was suspected in the present study that the small percentage of animals with FMs (23 %), combined with the low proportion of affected area on the slide (less than 0.5 %), explains the lack of difference between the groups regarding liver involvement, as reflected in the correlation analysis.

Fioravanti [32], upon quantifying the FMs, observed 14,574 cells in the slides evaluated from the right lobe. Moreira et al. [33], in turn, observed 20,099 cells in the slides evaluated from cattle grazing on *Brachiaria* spp., whereas only half that number was reported for those grazing on *Andropogon*. In the present study, a higher number of FMs was observed in the group 1, totaling only 2,750 cells. Similarly, the highest number of cells found in this study (2,750 cells) represents only 18.86 % of Fioravanti's [32] total and 13.68 % of Moreira et al.'s [33] total, which may explain the absence of a significant correlation between the number of foamy macrophages and hot carcass weight.

Both the liver and the small intestine play a role in modulating food intake [48]. Fioravanti [32] reported the replacement of areas of the hepatic parenchyma by clusters of FMs, a finding also observed in the present study. Zitnan et al. [77] and Montanholi et al. [78] observed that a lower number of cells in high-metabolism structures affected body weight and/or feed efficiency.

The greatest replacement of hepatocytes by FMs was observed in the group with the lowest hot carcass weight; however, the difference in the areas affected among the groups was not statistically significant.

As the slaughter weight increased in Nellore cattle with two permanent incisors (a category identical to that of the present study), Vaz et al. [79] observed that carcass yield decreased. This decrease in yield could explain the lack of correlation between hot carcass weight and the area occupied by FMs, and conversely, the existence of a correlation between the latter and live weight, since the yield formula is $hot\ carcass\ weight * 100 / live\ weight$. In this case, the animals could have had the same hot carcass weights even while gaining weight, thus failing to demonstrate the correlative relationship expected in the hypothesis of the present study.

It was also shown that the animals' age ranged from 20 to 36 months, a period considered less susceptible to poisoning; according to Fagliari et al. [80], the weaning phase (between 7 and 12 months, which causes stress) is the most susceptible age. The fact that slaughter and sampling were conducted in May (the beginning of the dry season) may have influenced the frequency of hepatic FMs. According to Brum [19], this was the season with the lowest frequency of *Pithomyces chartarum* fungal spores. The unfavorable environment for this fungus can be explained by the near absence of senescent material in the pasture and the high stocking rate [80].

Similar average hot carcass weights were found in herds of cattle with healthy livers and in herds of cattle with livers condemned due to fibrosis, demonstrating that this type of lesion did not affect the animals' weight gain [17]. The association of the small area of compromised tissue with the low presence of FMs found in this study, together with the rare observation of necrosis and degeneration (considered nonspecific changes), did not interfere with hot carcass weight in cattle. This may be explained by the fact that the changes were mild, even though inflammatory infiltrate was present in almost all animals.

4. Conclusion

Cattle grazing on Brachiaria spp. exhibit liver lesions characterized by degeneration, necrosis, and the presence of mild inflammatory infiltration, with small areas of liver tissue containing foamy macrophages. The size of the area of liver parenchyma containing foamy macrophages was not associated with reduced hot carcass weight.

Conflict of interest statement

The authors declare that there is no conflict of interest.

Data availability statement

Data will be provided upon request to the corresponding author.

Author contributions

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Generative AI use statement

The authors did not use generative artificial intelligence tools or technologies in creating or editing any part of this manuscript.

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