Liver condemnation due to bovine and buffalo fasciolosis in Antioquia province, Colombia

Decomiso de hígado por fasciolosis bovina y bufalina en Antioquia, Colombia

Confisco de fígado por fasciolose bovina e bubalina na Antioquia, Colômbia

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Abstract

Background: *Fasciola hepatica* affects cattle and buffaloes causing decreased production and liver condemnation at slaughter. **Objective:** To determine liver condemnation frequency, temporal distribution, and associated factors, as well as the spatial distribution and economic impact of *F. hepatica* infection based on *postmortem* inspection of cattle and buffaloes processed between 2010 and 2019 at one of the main slaughterhouses in Colombia. **Methods:** An observational, descriptive, and cross-sectional study was carried out, with a convenience non-probability sampling. Temporal distribution of liver condemnation frequency was analyzed. Pearson χ^2 test was used to determine association between the dependent variable (i.e., presence/absence of adult parasites of *F. hepatica*) and frequency rates between months and years. Monthly rainfall data was compared with the accumulated monthly frequency. Association between the dependent variable and production type (i.e., industrial-type bovine cattle —intended for milk production, and commercial-type bovine cattle —intended for meat production), weight, and sex (odds ratios, OR and confidence intervals, 95% CI) was explored. Descriptive maps of the municipalities presenting at least one positive case of *F. hepatica* in 2019 and weighted prevalences, both for bovines and buffaloes, were designed. Only losses due to liver condemnation between 2010 and 2019 were considered in the economic impact analysis. **Results:** A total of 1,947,233 animals were processed during the study period, resulting in 3.1% overall frequency of fasciolosis. Industrial-type cattle presented 7.4% higher risk of developing *F. hepatica* compared to commercial-type cattle (OR=0.074; 95% CI:0.07–0.08). Likewise, male cattle presented 3.88 times more risk compared to females (OR=3.88; 95% CI:3.49–4.33). Economic losses due to liver condemnation were estimated at US$1,129,660 for the study period.

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Conclusion: This is the first report of *Fasciola hepatica* in buffaloes in Colombia. Liver condemnations in Colombia occur throughout the year, although its frequency increases during the rainy season. The economic losses, estimated by liver condemnation due to fasciolosis, are high; however, it is necessary to explore such losses considering other productive indicators and larger animal populations. This work demonstrates the importance of systematizing the information generated in slaughterhouses.

Keywords: *buffaloes; calves; cattle; Colombia; condemnation; distomatosis; Fasciola hepatica; fasciolosis; infection frequency; parasitosis; slaughterhouse.*

Resumen

Antecedentes: La *Fasciola hepática* afecta bovinos y bufalinos causando disminución en la producción y decomiso del hígado en planta de beneficio. **Objetivo:** Determinar la frecuencia de decomisos de hígado, distribución temporal y factores asociados, así como la distribución espacial y el impacto económico de la infección por *F. hepatica*, a partir de hallazgos de inspección *post mortem* en bovinos y búfalos procesados entre 2010 y 2019 en una de las mayores plantas de beneficio de Colombia. **Métodos:** Se realizó un estudio observacional, descriptivo y de corte transversal, con un muestreo no probabilístico a conveniencia. Se analizó la distribución temporal de la frecuencia de decomisos de hígado. Se utilizó la prueba χ^2 de Pearson para determinar la asociación entre la variable dependiente (i.e., presencia/ausencia de parásitos adultos de *F. hepatica*) y las tasas de frecuencia entre meses y años, y se compararon los datos mensuales de precipitación pluvial con la frecuencia acumulada mensual. Se exploró la asociación entre la variable dependiente y el tipo de producción (i.e., bovinos de tipo industrial —destinados a la producción de leche-, y bovinos de tipo comercial —destinados a la producción de carne), peso y sexo (odds ratios, OR e intervalos de confianza, IC95%). Se diseñaron mapas descriptivos de los municipios que presentaron al menos un caso positivo de *F. hepatica* en 2019 y de las prevalencias ponderadas para bovinos y bufalinos. Para el análisis de impacto económico se contemplaron únicamente las pérdidas por decomiso de hígado entre 2010 y 2019. **Resultados:** Se procesó un total de 1,947,233 animales en el periodo de estudio, resultando una frecuencia global de fasciolosis del 3,1%. El ganado bovino de tipo industrial presentó 7,4% mayor riesgo de desarrollar *F. hepatica* en comparación con el de tipo comercial (OR=0,074; IC95%:0,07–0,08). Asimismo, el ganado macho presentó 3,88 veces más riesgo en comparación con las hembras (OR=3,88; IC95%:3,49–4,33). Las pérdidas económicas por decomiso de hígado se estimaron en US$1.129.660 para el período de estudio. **Conclusión:** Este es el primer reporte de *F. hepatica* en búfalos realizado en Colombia. Los decomisos ocurren durante todo el año, aunque su frecuencia aumenta durante la temporada de lluvias. En el país se incurre en importantes pérdidas económicas por decomiso de hígados debido a fasciolosis; sin embargo, es necesario explorar dichas pérdidas considerando otros indicadores productivos y en mayores poblaciones. Este trabajo demuestra la importancia de sistematizar la información generada por las plantas de beneficio animal.

Palabras clave: *bovinos; búfalos; Colombia; decomiso; distomatosis; Fasciola hepatica; fasciolosis; frecuencia de infección; parasitosis; planta de beneficio; terneros.*

Resumo

Antecedentes: *Fasciola hepatica* afeta bovinos e bubalinos, causando diminuição da produção e confisco do fígado no abatedouro. **Objetivo:** Determinar a frequência de confisco do fígado, distribuição temporal e fatores associados, bem como a distribuição espacial e o impacto econômico da infecção por *F. hepatica*, com base nos achados da inspeção *post mortem* em bovinos e búfalos processados entre 2010 e 2019 em um dos principais frigoríficos da Colômbia. **Métodos:** Realizou-se um estudo observacional, descritivo e transversal, com amostragem não probabilística de conveniência. A distribuição temporal da frequência de confisco do fígado foi analisada, o teste Pearson χ^2 foi usado para determinar a associação entre a variável dependente (e.g., presença/ausência de parasitas adultos de *F. hepatica*) e as taxas de frequência entre meses e anos, e os dados mensais de precipitação foram comparados com a frequência mensal acumulada. A associação entre a variável dependente e o tipo de produção (i.e., bovinos de tipo industrial — destinados à produção de leite, bovinos de tipo comercial —destinados à produção de carne), peso e sexo (odds ratio, OR e intervalos de confiança, IC95%) foi explorada. Foram elaborados mapas descritivos dos municípios que apresentaram pelo menos um caso positivo de *F. hepatica* em 2019 e das prevalências ponderadas, tanto para bovinos quanto para bubalinos. Para a análise do impacto econômico, foram consideradas apenas as perdas por confisco de fígado entre 2010 e 2019. **Resultados:** Um total de 1.947.233 animais foram processados durante o período do estudo, com uma frequência geral de fasciolose de 3,1%. Bovinos do tipo industrial apresentaram risco 7,4% maior de desenvolver *F. hepatica* em relação aos bovinos do tipo comercial (OR=0,074; IC95%: 0,07–0,08). Da mesma forma, bovinos machos apresentaram 3,88 vezes mais risco em relação às fêmeas (OR=3,88; IC95%: 3,49–4,33). As perdas econômicas decorrentes do confisco do fígado foram estimadas em US$ 1.129.660 para o período do estudo. **Conclusão:** *Fasciola hepatica* é relatada pela primeira vez no país em búfalos. A frequência de apreensões na Colômbia ocorre durante todo o ano, embora aumente na estação chuvosa. As perdas econômicas, estimadas apenas pelo confisco de fígados por fasciolose, são importantes. Porém, é necessário explorar tais perdas considerando outros indicadores produtivos e em populações animais maiores. Este trabalho demonstra a importância de sistematizar as informações geradas pelas plantas de beneficiamento animal.

Palavras-chave: *bezerros; bovinos; búfalos; Colômbia; confisco; distomatosis; Fasciola hepatica; fasciolose; frequência de infecção; parasitose; planta de processamento.*

Introduction

Fasciolosis is caused by *Fasciola hepatica*, which affects the liver of mammals such as bovines and buffaloes causing a decrease in production and liver condemnation. Global economic losses are estimated at 3 billion USD (Mehmood *et al.*, 2017). Fasciolosis is a reemerging zoonotic disease of food transmission (water and plants; Monteiro *et al.*, 2013), common in humid areas of temperate regions (Bekele *et al.*, 2010) and is in the list of neglected tropical diseases (PAHO, 2023).

Fasciolosis has an epidemiological classification and exclusive transmission patterns; however, it is the vector-borne parasitic disease with the largest known latitudinal, longitudinal, and altitudinal distribution, which is why it is cosmopolitan (Mas-Coma *et al.*, 2009). Mas-Coma *et al.* (2005) estimated 600 million infected animals worldwide. It is a zoonotic disease. The Pan American Health Organization (PAHO)-World Health Organization (WHO, 2023) calculates that half of the 2.4 million people infected worldwide are concentrated in Ecuador, Bolivia, and Peru, which are neighboring countries of Colombia. In addition, there are 180 million more at risk of infection (Mas-Coma *et al.*, 2009; Malandrini, 2016); nevertheless, these data are likely underestimated due to low awareness on the subject (Bennema *et al.*, 2014). This parasitism in cattle is of a chronic subclinical course associated with liver damage and blood loss caused by parasites in the bile ducts (Mazzeri *et al.*, 2017). It leads to decreased production, weight loss, fertility problems, and treatment-related over-costs, which increases the economic impact for farmers (Kaplan, 2001). In Colombia, losses of COP$ 12.483 million have been reported (Benavides, 1996), being the only data available on general economic losses for the country.

The parasite becomes evident during *postmortem* inspection of the liver, often leading to liver condemnation in Colombian slaughterhouses, abiding by Resolution 240 of the Colombian Ministry of Health and Social Protection (2013). However, the information derived from condemnation is rarely used for epidemiological analyzes to support prevention and control programs for both human and animal fasciolosis. This is a neglected disease by the livestock sector, and the country-level data are outdated. Therefore, we aimed to assess the liver condemnation frequency, temporal distribution, and associated factors, as well as the spatial distribution and economic impact of *F. hepatica* infection based on *postmortem* inspection of cattle and buffaloes processed between 2010 and 2019 at a large slaughterhouse in Colombia.

Materials and Methods

Ethical considerations

The study was approved by the Ethics Committee for Animal Experimentation (CEEA) of Universidad de Antioquia through an expedited endorsement (Act 126, August 6, 2019).

Study design

An observational, descriptive, and cross-sectional study was conducted with a convenience non-probability sampling based on consolidated information of liver condemnations due to fasciolosis from 2010 to 2019. The study was carried out at the facilities of one of the largest cattle and buffalo slaughterhouses in Colombia (Sociedad Central Ganadera S.A.) located in Medellín (Antioquia province). This slaughterhouse processes about 800 bovines per day arriving from all over the country; however, more than 80% come from Antioquia.

All animals are subjected to rigorous *postmortem* veterinary inspection to determine if the meat and edible meat products are appropriate for human consumption; if not, all condemnations are registered. The inspectors were veterinarians who carried out a standardized inspection protocol and were informed and trained on liver inspection and rigorous collection of data. For the study purpose, any animal with at least one adult form of *F. hepatica* on inspection of the bile ducts was taken as a case.

Daily information on date, total number of animals processed, condemnations, and individual condemnation causes from February

1st, 2010, to December 31st, 2018, were analyzed. Information from January 1st to December 31st, 2019, was available from the GESPLAN v. 29.0, 2019 software (LMSoftware S.A.S., Medellín, Colombia), which allowed the same and other variables that were not available in the records of previous years, i.e., production type (i.e., industrial-type bovine cattle —intended for milk production-, commercial-type bovine cattle —intended for meat production), species, weight, sex, and origin (municipality and province). Information on liver condemnation for reasons other than fasciolosis (i.e., telangiectasia, cirrhosis, abscesses, adhesions, congestion, lithiasis, and steatosis) was excluded from the study. All the information was collected in an Excel® sheet (Microsoft Corp., Redmond, WA, USA).

Statistical analysis

Descriptive statistics were calculated for all variables of interest. Pearson's χ^2 test was used to determine association between the dependent variable (i.e., presence/absence of adult parasites of *F. hepatica*) and the frequency rates between months and years, considering a significance level of $p<0.05$. In addition, monthly rainfall data in Antioquia from Weather Spark (2020; https://weatherspark.com/countries/CO/02) were compared with the monthly accumulated frequency of fasciolosis. In addition, association between the dependent variable and the explanatory variables (i.e., type of production, weight, and sex) was explored, considering information on adult bovine cattle (animals >2 years old), bovine calves (animals ≤2 years old), and buffaloes. The results are presented as *odds ratios* (OR) with their corresponding confidence intervals (95% CI). In all cases, recategorization of weight was defined according to the median, as these data did not present a normal distribution, according to the Shapiro-Wilk test results. All the analyses were carried out using the Stata v. 16.0, 2020 software (Stata Corp, College Station, Texas, USA).

Spatial analysis

The proportion of total positive cases with respect to the total number of cases did not have a localized spatial representation. Given the absence of information at the national level and considering the sample size, the value observed in this proportion was assumed empirically as a working hypothesis (maximum expected proportion of positive cases of fasciolosis) in any Colombian municipality. The stabilized proportions were weighted with the Bayesian averaging (Eberhart and Russell, 1966; Morera and Soto, 1999; Jaramillo *et al.*, 2010) for each municipality.

The comparison of the ratio of positive cases among municipalities was made to generate a weighted prevalence map using the ArcGis software, v. 10.8.1, 2020 (Environmental Systems Research Institute, California, USA). The preparation of the dataset was based on 1) the Official geographic coordinates of the municipalities offered by the Colombian Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM) through their open data platform. The coordinates refer to the centroid of the municipality (not the municipal seat). However, the location of the municipal seat was included in the resulting map as a geographical reference; 2) Geolocation properties, for which an attribute table was created to include locality (province and municipality names), coordinates, and values mapped using the Magna Sirgas 2000 official Colombian reference system; 3) Establishment of nodes and edges. The concentration nodes of *F. hepatica* were established from the geographic coordinates of the weighted municipal prevalences. In both, the map of access roads was included, which are constituted by the edges that connect said nodes; and 4) A general map of the weighted prevalence of *F. hepatica* cases by municipality and a localized map of the weighted proportions of most relevant positive cases (De Smith *et al.*, 2007).

Economic impact estimation

Meat outlet prices for 2019 and the Consumer Price Index (CPI) were used to calculate the yearly value per kg of liver from 2010 to 2018. The yearly inflation rate from the Statistical Yearbook, Antioquia government (DANE, 2019) was used. Then, the price per kg of liver per year was

multiplied by the total kilograms seized during the corresponding year. Type of production was considered for year 2019 since this information was available; therefore, the average weight of 60 pieces was used considering it a representative sample of each production type (industrial and commercial).

Each average weight (6 kg for commercial-type cattle, and 10 kg for industrial-type cattle) was multiplied by the number of livers confiscated according to production type per day, and by the commercial price per kg of liver in 2019.

Results

A total of 1,947,233 animals were processed in this slaughterhouse between 2010 and 2019. Liver confiscations due to findings compatible with *F. hepatica* amounted to 60,784 cases (3.1%) including industrial and commercial-type cattle, calves, and buffaloes. The maximum frequency of confiscations occurred during 2013 (5.9%) and the minimum in 2019 (1.3%). Figure 1 presents central tendency measures of the yearly distribution. According to Figure 2, liver condemnations occurred every month, with decreasing frequency during the last years of the study period.

The frequency of liver condemnation decreased in correspondence with processing of industrial-type cattle (Figure 3). The average participation of this type of cattle in the total processing was 13% between 2010 and 2016, decreasing to 3% between 2017 and 2019 ($p<0.05$).

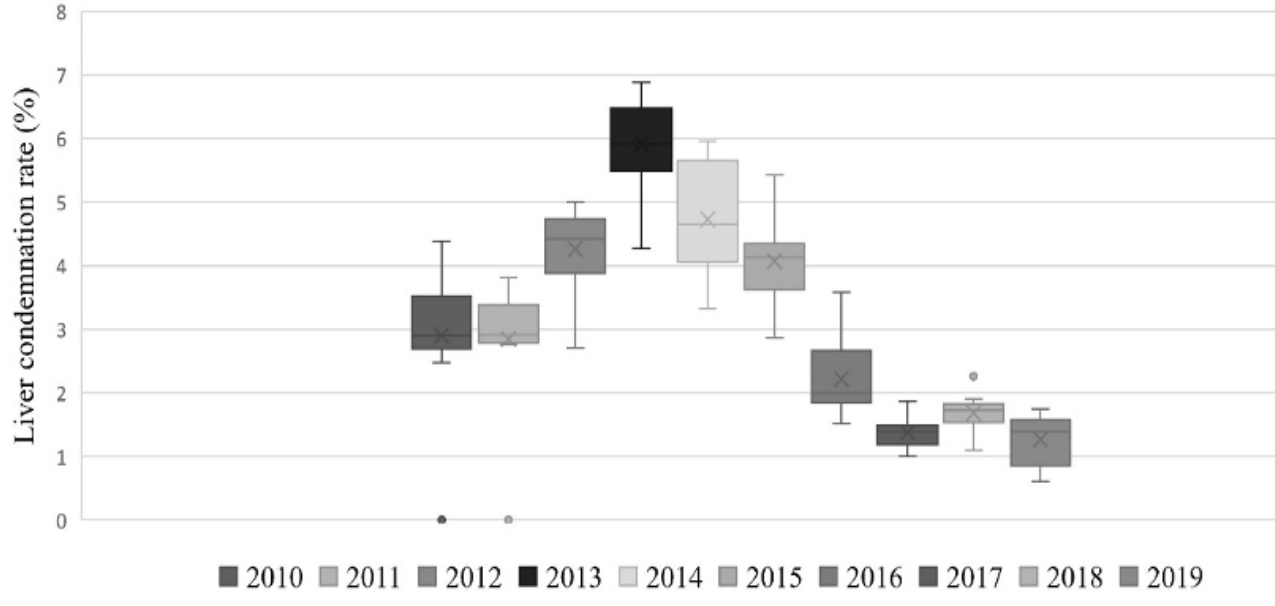

Figure 1. Frequency distribution of liver condemnations due to *Fasciola hepatica* in animals processed from 2010 to 2019.

Figure 2. Distribution of liver condemnations due to *Fasciola hepatica* in animals processed (solid orange line) from 2010 to 2019. The gray bars correspond to the total number of animals processed per month.

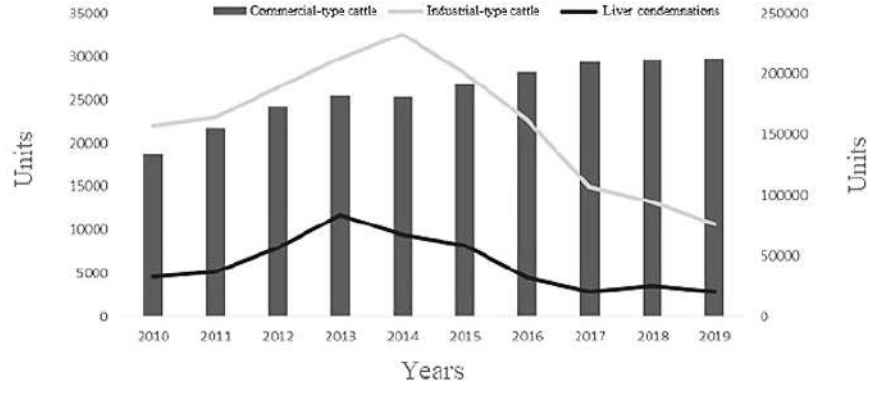

Figure 3. Relationship between liver condemnations due to *Fasciola hepatica* and bovine cattle processed.

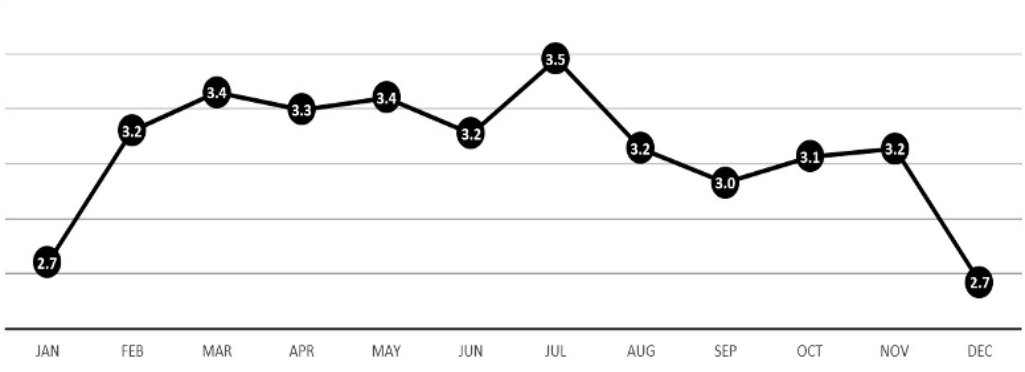

Figure 4. Monthly distribution of liver condemnations due to *Fasciola hepatica* from 2010 to 2019.

Regarding monthly condemnations during 2010-2019, the highest number occurred in July, and the lowest in December (Figure 4). Significant difference was observed in the frequency of liver condemnations through the monthly periods but keeping the same pattern in each year of observation.

Regarding associated factors, industrial-type cattle had 7.4% higher risk of developing *F. hepatica* compared to commercial-type cattle. Likewise, male cattle of both types had 3.88 times higher risk of developing *F. hepatica* compared to females. Both associations were statistically significant (Table 1). Results for calves and buffaloes are shown in Tables 2 and 3, respectively, highlighting the finding of a *F. hepatica*-positive male buffalo.

In 2019, the slaughterhouse received animals from 217 municipalities in 18 Colombian provinces, collecting a total of 223,344 reports as study cases for spatial analysis. Of this, 112 municipalities (52%) from eight provinces had at least one positive case of fasciolosis. From all the sites, 95 municipalities were in Antioquia province, and the rest in Boyacá, Caldas, Chocó, Córdoba, Risaralda, Santander, and Sucre provinces. The highest frequencies of liver condemnations due to *F. hepatica* at the municipality level correspond to San Pedro de los Milagros (47.6%), Santa Rosa de Osos (36%), Donmatías (27%), Entrerríos (24.2%), Urrao (18.6%), San Vicente (15.6%), Medellin

Table 1. Factors associated with liver condemnations due to *Fasciola hepatica* in adult bovine cattle from 2010 to 2019 (n=220,421).

Variable	Category	Number of negatives	Number of positives	Total	Distribution (%)	OR (95%CI)	P-value
Type of production[1]	Industrial	8,574	1,368	9,942	4.5	0.074 (0.067–0.081)	0.000*
	Commercial	209,291	1,188	210,479	95.5		
Weight[2] (kg)	≤436	7,544	882	71,426	32,4	0.99 (0.915–1.085)	0.938
	>436	147,321	1,674	148,995	67.6		
Sex	Male	158,990	568	159,558	72.4	3.88 (3.490–4.333)	0.000*
	Female	58,875	1,988	60,863	27.6		

OR: Odds Ratio; CI: Confidence Interval.
[1]Industrial: intended for milk production; Commercial: intended for meat production.
[2]Estimated median for the data=436 ± 67.47 (IQR: 395–472 kg).

Table 2. Factors associated with liver condemnations due to *Fasciola hepatica* in calves from 2010 to 2019 (n=1,795).

Variable	Category	Number of negatives	Number of positives	Total	Distribution (%)	OR (95%CI)	P-value
Weight[1] (kg)	≤239	516	89	605	33.7	1.20 (0.919–1.580)	0.177
	>239	985	205	1,190	66.3		
Sex	Male	705	141	846	47.1	0.96 (0.752–1.241)	0.790
	Female	796	153	949	52.9		

[1]Estimated median for the data=239 ± 68.67 (IQR: 203–266 kg).

Table 3. Factors associated with liver condemnations due to *Fasciola hepatica* in calves from 2010 to 2019 (n=1,795).

Variable	Category	Number of negatives	Number of positives	Total	Distribution (%)
Weight[1] (kg)	≤472	567	0	567	50.27
	>472	560	1	561	49.73
Sex	Male	326	1	327	28.98
	Female	801	0	801	71.02

*Estimated median for the data=472 ± 69.12 (IQR: 434–510 kg).

(15%), and Yarumal (14.2%). Figure 5 shows a frequency map of liver condemnations due to *F. hepatica*. Figure 6 presents the results for the most relevant municipalities (frequency of liver condemnations >3,781).

Economic losses for liver condemnations due to *F. hepatica* in 2010-2019 were 1,129,660 USD (based on the dollar price for year 2020). In Table 4 the liver weight (kg) used for the calculations was determined as follows: from 2010 to 2018, an average of 6 kg was used (Marín and Martínez, 1977) and for 2019, the liver weight of 60 animals per each production type was averaged, resulting in 6 kg for commercial-type cattle and 10 kg for industrial-type cattle. The price per kg of liver used for the calculation was 3.88 USD (retail price in 2020). Inflation was applied to this value to establish the liver price per year. Data from calves and buffaloes were incorporated into the information of industrial-type cattle.

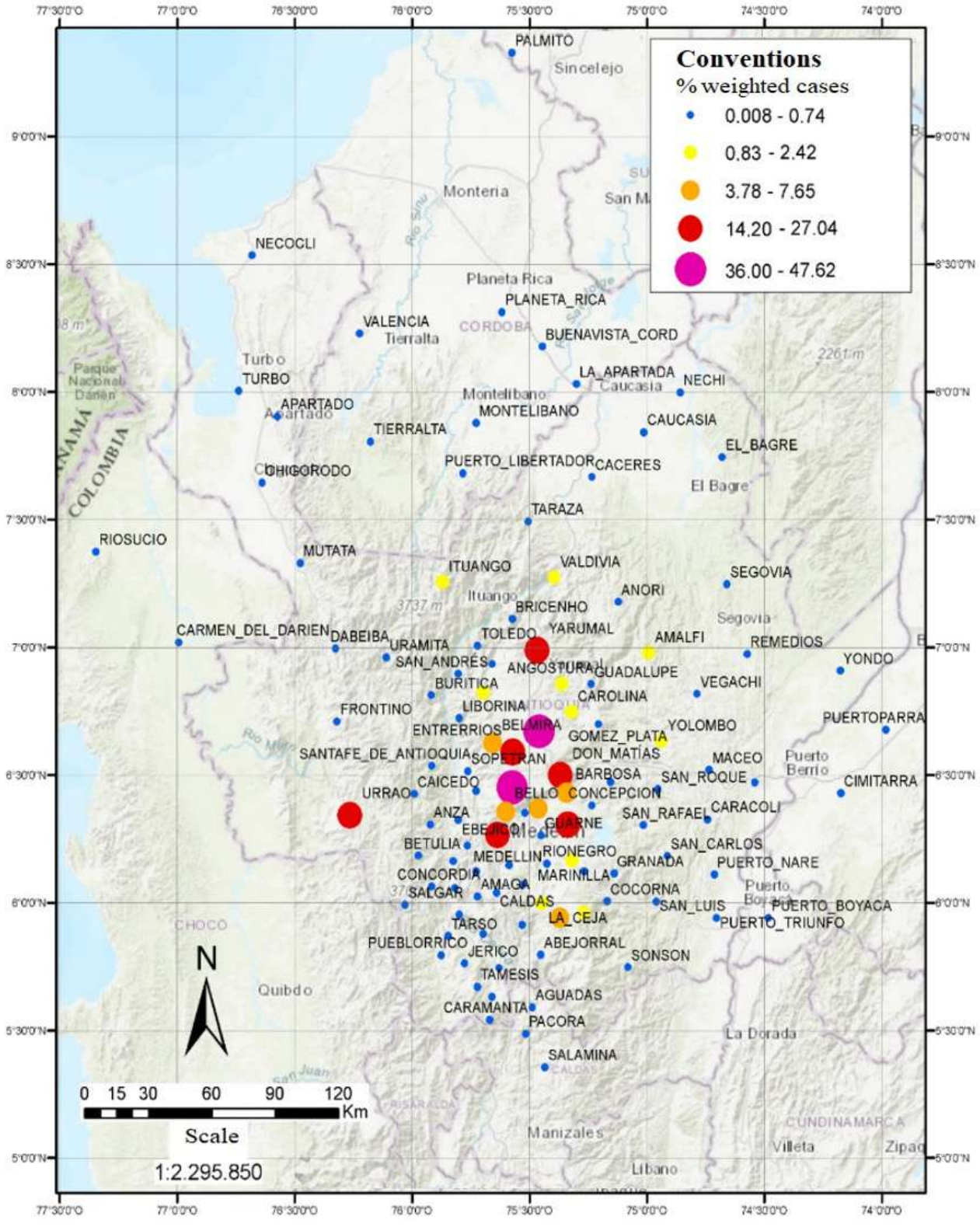

Figure 5. Weighted cases of liver condemnation frequency due to *Fasciola hepatica* during 2019.

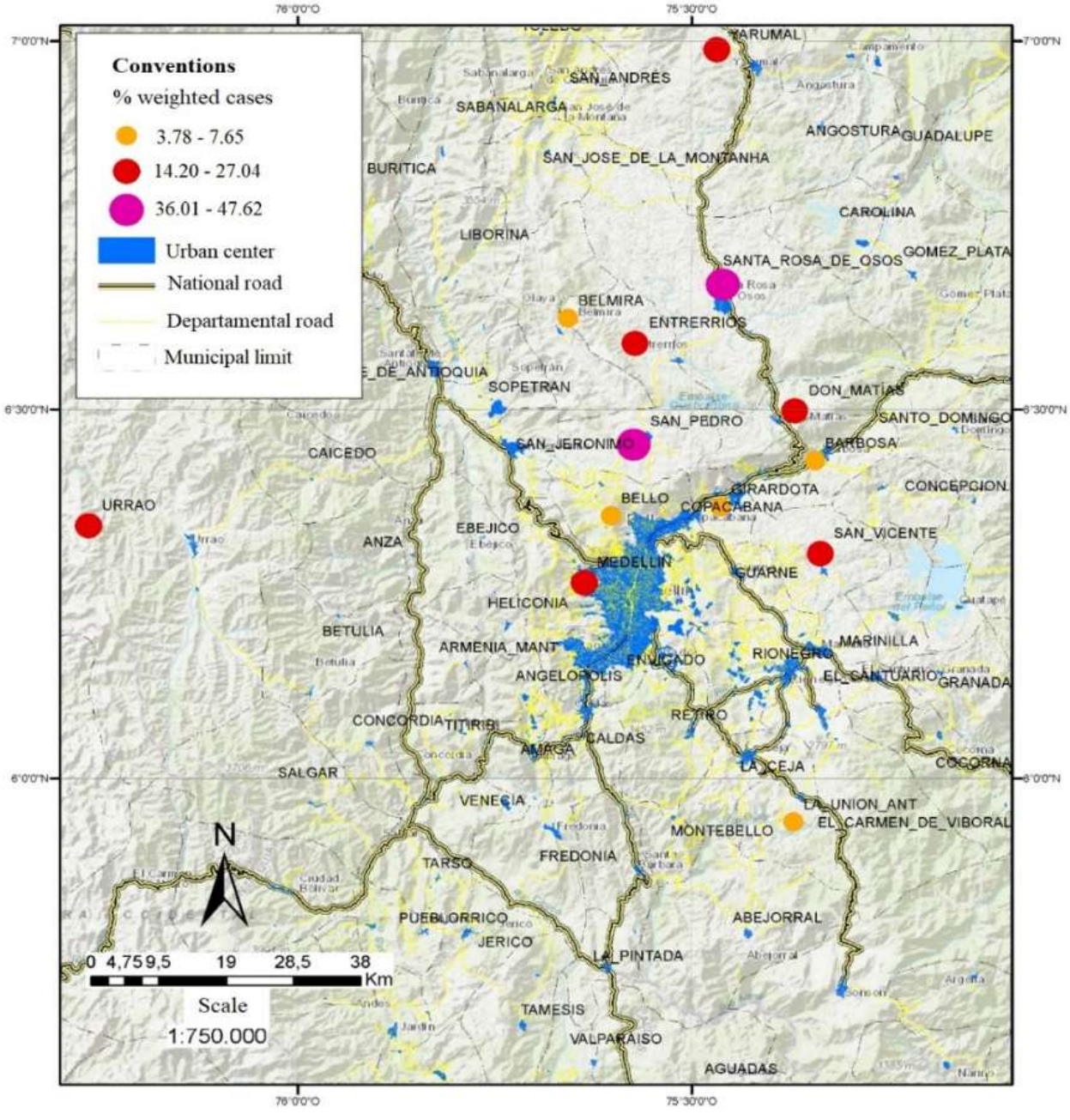

Figure 6. Weighted cases of liver condemnations frequency due to *Fasciola hepatica* during 2019 in the most relevant municipalities.

Table 4. Annual economic losses of liver condemnations due to *Fasciola hepatica* during 2019.

Year	Adjusted animals processed/year	Livers with *F. hepatica*	Price per-kg of liver (USD)	Inflation (%)	Economic losses (USD)
2010	145,488	4,605	2.66	3.17	73,589.56
2011	167,588	5,163	2.75	3.73	85,119.03
2012	186,161	7,957	2.85	2.44	136,082.18
2013	197,185	11,684	2.92	1.94	204,703.37
2014	199,789	9,421	2.98	3.66	168,254.54
2015	200,873	8,198	3.09	6.77	151,761.25
2016	206,463	4,500	3.29	5.75	88,943.91
2017	209,746	2,883	3.48	4.09	60,260.84
2018	210,596	3,522	3.63	3.18	76,630.47
2019	223,344	1,494*	3.74	3.80	33,540.40
		1,357**	3.74		50,774.57
Total	1,947,233	60,784			1,129,660

*Commercial-type cattle cattle. **Industrial-type cattle cattle.

Discussion

This study aimed to determine the frequency of liver condemnations due to *F. hepatica*, including their temporal and spatial distribution, associated factors, and economic impact. This analysis was conducted on *postmortem* inspection findings from cattle and buffaloes slaughtered during 10 years at one of the main slaughterhouses in Colombia. This study is the first published report in the country of a spatial analysis using slaughterhouse information.

The sample size and the follow-up in this study can be considered big compared to other studies worldwide. The study by Kithuka *et al.* (2002) in Kenya offers a similar evaluation spanning over a decade with a considerable number of processed animals, reporting 8% prevalence of fasciolosis and economic losses of 2.6 million USD due to liver condemnations. That figure is higher than the one calculated in the present report. Although it is difficult to compare infection prevalence between countries or regions given the ecological, epidemiological, and management features, higher prevalence is evident in their report compared to the present study. In Ecuador, prevalence between 7 and 14.7% has been reported (Cali, 2012; Arteaga, 2013; Medina-Torres, 2014; Moscoso-Andrade, 2014; Buestán, 2017) and between 3.5 and 47.6% in Guatemala, Peru, and Bolivia (Góngora and Santa Cruz, 2006; Villatoro, 2008; Ticona *et al.*, 2010). Several studies have been carried out in Colombian slaughterhouses and the most comparable reported 12.8% prevalence (3,081/24,082) in Pasto, Nariño province (Cedeño *et al.*, 2012).

According to the monthly analysis, July had the highest frequency of condemnations. Regarding the life cycle of the parasite, a higher infection rate could potentially occur two months before -that is, in May- coinciding with the historically highest rainfalls recorded in the province (DANE, 2019). In turn, parasitism decreases in December since it is the dry season, which restricts the presence of the vector, in agreement with previous reports (Hernández-Guzmán *et al.*, 2021). It should be noted that the frequency reported herein may be underestimated since the animals may be infected in a migration stage of the parasites (prehepatic) with hepatic absence of the adult parasite.

Our results reveal a dynamic frequency pattern of liver condemnations both annually and monthly, demonstrating a significant decrease in recent years, which may have several causes. One

of them is slaughter decrease (10%) of industrial-type cattle, which is at greater risk of infection due to its geographical location (favoring the presence of the vector) and production conditions (Becerra, 2001; Valencia-López *et al.*, 2012; Correa *et al.*, 2016; Chaparro *et al.*, 2016). Additional factors contributing to this trend could be related to a positive influence of the national programs on training and implementation of good livestock practices promoted in the country during recent years.

Accordingly, the OR results concurs with expectations of industrial-type cattle having higher risk of developing *F. hepatica* compared to commercial-type cattle. On the other hand, since more males than females are processed at this slaughterhouse, it is understandable why the OR showed that male cattle in both production types are at higher risk of developing *F. hepatica* compared to females.

Interestingly, no associated factors were identified for calves. However, the high casuistry of condemnations in animals up to 200 kg live weight is remarkable. This may be due to a developing immune system that could make them more susceptible to diseases.

Associated factors were not explored for slaughtered buffaloes since only one individual was positive. This is the first case reported in Colombia for this species, but not the first exploration of the subject. Prada *et al.* (2006), Balvin *et al.* (2017), and Ramírez-Londoño *et al.* (2020) evaluated 150 buffaloes in a farm at the Magdalena Medio region, 153 in three slaughterhouses in Antioquia, and 226 in a slaughterhouse in Santander province; all of them resulted negative to *F. hepatica*. Several positive cases have been reported in Venezuela (Montiel *et al.*, 2001) and Argentina (Malandrini, 2016).

Regarding spatial distribution, the Northern dairy area of Antioquia province had the highest frequency of fasciolosis. This agrees with findings from prior studies (Gómez *et al.*, 2006; López *et al.*, 2008; Escobar *et al.*, 2011; Uruburu *et al.*, 2013; Chaparro *et al.*, 2016; Correa *et al.*, 2016). Urrao and Yarumal municipalities presented important frequency (18.6 and 14.2%, respectively) despite not having the typical climatic conditions commonly associated with the parasite´s vector suggesting adaptation of both vector and parasite to different ecological zones.

The economic analysis indicated cumulative losses of 1,129,652 USD due to liver condemnations during the study period (2010-2019). The only information available in Colombia was reported by Benavides (1996), who adjusted unsourced data for 1980 for the entire country without specifying fasciolosis (e.g., treatment, condemnation rate, mortality, coinfections). Considering it is the only information available for the country, after adjusting to the current cost and inflation to date, theoretical estimated losses at the national level would be 15,882,628 USD per year. Annual average loss in the present study was 113,000 USD, representing 0.7% of the total calculated losses reported for the country, which is significant considering we evaluated data from only one slaughterhouse, and it represents only losses due to liver condemnation. Similarly, losses of 18,941 USD were calculated for liver condemnations due to fasciolosis in a slaughterhouse in Ecuador (Buestán, 2017) Similarly, losses of 210 million USD per year due to variations in carcass weight were reported in Brazil (Molento *et al.*, 2018), much higher than data reported in Colombia. Three slaughterhouses in Costa Rica reported 67,438 USD losses due to liver condemnations in 2014 (Rojas and Cartín, 2016). Total economic losses due to fasciolosis imply that liver condemnations constitute only 16% of the overall losses, highlighting an 84% underestimation. Furthermore, this calculation does not consider other potential sources of losses, such as those associated with treatments, mortality, decreases in reproductive indicators, coinfections, and others. When this 84% adjustment is incorporated into condemnation losses, the cumulative economic losses are estimated to approach 7,060,329 USD for the period between 2010 and 2019.

It should be noted that, although live weights of industrial and commercial-type cattle did not differ by more than 20 to 30 kg, an important difference in liver weight was found for cattle in each type of production. This disparity can be attributed to the fact that industrial-type cattle are processed at a higher age, after going through greater metabolic demand. In addition, in this system animals receive concentrated feed and more medications compared with commercial-type cattle.

The economic impact results should be considered with prudence given the source of comparison (Benavides, 1996). In addition, it is noteworthy that information on milk prices at the national and provincial levels is available, while information on sale prices per kg of liver and other meat by-products is not. The Colombian Federation of Livestock Farmers (FEDEGAN, by its name in Spanish) only has price records of live weight at slaughter and the sale value varies considerably depending on the meat cut. For this reason, the average value per kg of liver was taken from butcher shops, which makes it difficult to analyze the economic impact of condemnations at the slaughterhouse. Comparing the data on economic losses in this study with those carried out in Ecuador, Brazil, and Costa Rica would require using similar standards for all of them, such as, for example, losses per slaughtered animal instead of losses per slaughterhouse.

This study shows the usefulness of using slaughterhouse records to monitor the epidemiological status not only of fasciolosis, but of any disease, as well as for estimating economic losses associated with condemnations (Kithuka *et al.*, 2002; Bekele *et al.*, 2010; Khanjari *et al.*, 2010; Borji *et al.*, 2012; Cali, 2012; Ezatpour *et al.*, 2014; 2015; Sayadi *et al.*, 2015; Mohamadzadeh *et al.*, 2016; Buestán, 2017; Festus *et al.*, 2017; Shamsi *et al.*, 2020; Soosaraei *et al.*, 2020). Despite its value, slaughterhouse records are rarely used for epidemiological analysis in Colombia. In fact, we found no articles or reports using information from slaughterhouses in spatial epidemiology at the national level.

Some countries have incorporated the concept of syndromic surveillance into slaughterhouse inspection as a complementary approach to other animal health surveillance systems (Alton *et al.*, 2010; 2012; Katz *et al.*, 2011; Triple S Project, 2011). Syndromic surveillance is defined as real-time collection, analysis, interpretation, and dissemination of health-related data to facilitate early detection of potential human or veterinary public health threats that require prompt and effective public health interventions (Triple S Project, 2011; Dupuy *et al.*, 2014). In contrast to classical epidemiological surveillance, where the objectives are first defined and then the relevant data is collected, syndromic surveillance entails using available data collected for other purposes to monitor and address public health concerns without impacting the way it is collected.

Given that Fasciola is a vector-borne disease, any conditions that could affect the vector can decrease or increase the infection. Among these, climatic conditions play a significant role, yet there is currently no system that constantly analyzes the climatic changes in each production site to determine the impact that they have on vector-parasite-host dynamics.

Another unexplored aspect in Colombia is the economic losses associated with fasciolosis coinfection of bovines with paramphistomosis (López *et al.*, 2008) and *Mycobacterium bovis* (Claridge *et al.*, 2012; Munyeme *et al.*, 2012; Howell *et al.*, 2019), including the interference-related losses of *F. hepatica* in the intradermal tuberculin skin test (Belloi *et al.*, 1995).

To conclude, this study offers an evaluation of fasciolosis frequency in Colombian cattle and buffaloes. Occurrence of liver condemnations throughout the year shows a higher frequency during the rainy season. Patterns of presentation and predisposing factors, along with economic implications, provide valuable insights. Addressing current limitations and data disparities could enhance the accuracy of economic evaluations. Although economic losses estimated by liver condemnations due to *F. hepatica* are significant it is necessary to

explore such losses considering other productive indicators and larger animal populations. The present study also reports for the first time the presence of *F. hepatica* in buffalo liver in Colombia. Finally, it is evident that the control measures taken during primary production are not enough to prevent calves from acquiring the infection early in life, which can affect their growth and productivity. This work also demonstrates the importance of systematizing the information generated by animal slaughterhouses.

Declarations

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Conflicts of interest

The authors declare they have no conflicts of interest regarding the work presented in this report.

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Author contributions

MQ and LCB had the idea of the article and lead the study conception and design. The literature search and data analysis, as well as the critical revision of the manuscript was performed by all the authors (i.e., MQ, MU, ELE, JBM, NMC, LCB). The first draft of the manuscript was written by MQ, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Use of artificial intelligence (AI)

No AI or AI-assisted technologies were used during the preparation of this work.

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