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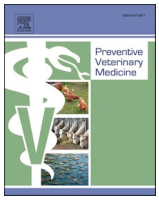

Bovine cysticercosis epidemiology and the economic impact of the triceps brachii incision in a South African export abattoir

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ABSTRACT

Taenia saginata is a zoonotic tapeworm of humans with bovines as its intermediate host (bovine cysticercosis). Traditional meat inspection is the main measure to identify the larval stage in carcasses and prevent human infection, but has a notoriously low sensitivity, especially in low prevalence settings. The legislation in multiple African countries mandates an incision in both triceps brachii muscles to detect the parasite as part of the normal post-mortem inspection, but this has an economic cost and is not universally mandated in other countries. The primary aim of this study was to investigate the epidemiology of bovine cysticercosis at an export abattoir in South Africa and determine the validity and cost of the triceps incision. Risk factors were investigated, and the effect of additional heart incisions on the current inspection. Four incisions were made into the heart in addition to the normal post-mortem inspection in 3353 carcasses. The proportion of positive animals with and without the cardiac and triceps incisions were compared using McNemar's chi-square tests, while risk factors were assessed using binary logistic regression. The economic impact of the triceps incision was estimated using a stochastic economic cost model. Thirty-three positive carcasses were identified for an apparent prevalence of 0.98 % (95 % CI, 0.69–1.36 %), while the true prevalence was estimated at 6.6 % (95 %CI, 4.3–8.8 %). All cysts were confirmed as *T. saginata* on histopathology with 70 % (95 %CI, 53–83 %) located in the heart. The additional cardiac incisions resulted in the detection of significantly more cases compared to the normal inspection method prevalence of 0.72 % (95 %CI, 0.47–1.05 %; $P < 0.001$). The apparent prevalence of *T. saginata* when omitting the triceps incision was not significantly lower compared to the prevalence when included in the inspection ($P = 0.480$). External feedlots (OR= 4.17, 95 %CI: 2.04–8.54, $P < 0.001$) and older animals (OR=3.90, 95 %CI: 1.17–13.03, $P = 0.027$) were associated with a positive detection. The current median annual financial cost to the food business operator from the triceps incision was estimated at $30387 (95 %CI: $0-$130696), with the proportion of deboned meat exported identified as the most important factor affecting cost (Spearman's rho=0.853). The identification of risk factors could aid in the development of a more effective risk-based inspection system. The current inspection should be modified to increase exposure of the heart and remove the triceps incisions. The latter should especially be considered given the minimal contribution to cysticercosis detection, the unsupported requirement for its inclusion specifically in Africa, and its economic impact, especially as beef exports increase.

1. Introduction

Taenia saginata is a zoonotic tapeworm of humans, and infestation causes bovine cysticercosis in its intermediate host. The parasite is the cause of taeniasis in millions of people worldwide (Okello and Thomas, 2017), although exact prevalence estimates are not available. It is especially widespread in low- and middle-income countries where raw or undercooked beef is widely consumed (Murrell et al., 2005; Henderson-Frost and Gilman, 2018). Both *T. saginata* taeniasis in humans and bovine cysticercosis remain largely neglected conditions, most likely due to the absence of clinical signs in cattle, limited information on its true economic impact, and the fact that human taeniasis

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has a low health burden (Dermauw et al., 2018). Humans are definitive hosts and become infected when ingesting viable metacestodes in raw or undercooked beef. Tapeworm eggs shed in faeces are extremely resilient and can withstand a wide range of environmental conditions (Bucur et al., 2019). Although its health effects on human hosts are usually minimal, the economic impact on cattle farmers and the beef industry can be substantial (Dorny and Praet, 2007; Jansen et al., 2018b; Laranjo-González et al., 2018; Goodhead et al., 2021). A carcass diagnosed with *T. saginata* has a reduced monetary value of between 20 % and 45 %, with costs incurred from freezing, downgrading, and rejection (Dorny and Praet, 2007; Verwoerd and Prozesky, 2012; Laranjo-González et al., 2016). This has a notable impact on commercial beef producers and the livelihood of farming households with limited income sources (Goodhead et al., 2021).

Traditional meat inspection remains the primary method of identifying the parasite in South Africa and elsewhere. Lightly infested carcasses undergo mandatory freezing treatment to inactivate metacestodes, while heavily infested carcasses are rejected for human consumption (Department of Agriculture, 2004). Meat inspection is unsuccessful in detecting the majority of infestations, with the sensitivity in lightly infested animals estimated at 15 % (WHO and FAO, 2020). Immunodiagnostic tests are 3–10 times more sensitive than meat inspection for the detection of *T. saginata*, with antibody detection techniques able to detect both current and previous infestations, while antigen detection techniques only detect viable cysticerci (Geysen et al., 2007; Jansen et al., 2018a). However, antigen-detecting ELISA has a lower sensitivity in animals that harbour lower numbers of cysts compared to animals with higher numbers of cysts (Dorny et al., 2010). Immunodiagnostic tests have therefore been suggested as a herd screening test, rather than a diagnostic test for individual animals (Murrell et al., 2005).

The heart is an important location for metacestodes, and an increase in exposure of the myocardium during inspection has been generally shown to improve the detection of cysts (Scandrett et al., 2009; Eichenberger et al., 2011; Kiermeier et al., 2019). Other predilection sites include the muscles of the head (Pugh and Chambers, 1989; Scandrett et al., 2009) and tongue (Jorga et al., 2020). Studies investigating the shoulder clod as a predilection site for bovine cysticercosis have produced mixed results. Although high numbers of *T. saginata* metacestodes have been reported in the shoulder clod following experimental infestation (Kyvsgaard et al., 1990; Scandrett et al., 2009), low relative cyst densities in this location compared to other sites suggested that the shoulder is a much less important site than the heart and muscles of the head. Similarly, a study in Tanzania reported that the triceps muscle had a lower cyst density than the heart, tongue, and masseter muscles (Maeda et al., 1996). However, other research reported that the shoulder was an important site for cysts with both experimentally (Lopes et al., 2011) and naturally (Abunna et al., 2008) infested cattle, although cyst densities were not calculated.

The South African Red Meat Regulations (Department of Agriculture, 2004) mandates the making of a deep transverse incision into the distal part of the triceps brachii as a component of the standard inspection technique. A similar requirement exists in other African countries, including Namibia (Mbiri et al., 2020), Zimbabwe (Sungirai et al., 2014), Ethiopia (Jorga et al., 2020) and Kenya (National Council for Law Reporting, 2012). This has a negative economic impact on the carcass value due to reduced use of the shoulder clod or bolar blade, while potentially contributing to bacterial contamination (EFSA, 2013). The triceps brachii muscle is not incised as part of the standard inspection method in Canada (Scandrett, 2007), Australia (Kiermeier et al., 2019), the EU (Eichenberger et al., 2011), the UK (Marshall et al., 2016), Brazil (Soares et al., 2011), Mexico (Cueto González et al., 2015) or the USA (USDA, 2016). Claims of its necessity specifically in Africa have been made, with walking long distances and a subsequent increase in blood supply to the shoulder as an apparent justification (Gracey et al., 1999).

The aims of this study were to investigate the epidemiology of cysticercosis in an export beef abattoir in South Africa, to identify the most common locations of metacestodes, to explore the justification for the incision into the triceps brachii and determine its contribution to inspection sensitivity. A range of potential risk factors for *T. saginata* in cattle were investigated, and the potential economic impact of the triceps incision was estimated.

2. Materials and methods

2.1. Study design

The study protocol was reviewed and approved by the University of Edinburgh R(D)SVS Veterinary Ethical Review Committee (VERC reference number 90.20), the University of Pretoria, Faculty of Veterinary Science Research Ethics Committee (REC 113–20), and the Department of Agriculture, Land Reform and Rural Development (DALRRD) (12/11/1/1/8). The study was carried out in bovine animals slaughtered at a high throughput export-approved abattoir in South Africa between 6 November 2020 and 3 December 2020. All animals were delivered from local bovine feedlots. The majority of animals slaughtered at the abattoir were sourced from two feedlots owned by the same food business operator that owns the abattoir. At these feedlots, weaner calves were purchased from a wide variety of farmers in South Africa, Namibia and Botswana, and calves were stationed at the feedlots for approximately 120 days. Water was sourced from nearby rivers, and feed was produced at the on-site feed mill. Most cattle that were presented for slaughter were less than 24 months of age, although some animals were older. Cattle from four other feedlots were also included in the study population, with six feedlot sources in total.

The total sample population of 3353 carcasses was obtained by using the approach of estimating a proportion based on exact binomial probabilities (Fosgate, 2005), with an assumed proportion of 0.005, an error limit of 0.0025 and a 95 % confidence level. Sampling of carcasses took place during normal slaughtering hours within the study period, with 17 sampling days in total, and approximately 200 cattle sampled per day.

All carcasses were weighed directly after exsanguination, and the weight, sex, and feedlot of origin were recorded in the abattoir database. The approximate age of each animal was determined by evaluating the number of permanent incisors, issuing the animal with a corresponding grade, and recording this on the database as part of the national bovine classification system. After evisceration and electrical stimulation, each carcass was split into two sides, and each carcass side received an adhesive sticker on the foreleg with a unique serial number. All organs were similarly marked and correlated to the carcass of origin, ensuring complete traceability.

Post-mortem meat inspection for cysticercosis was conducted on all carcasses in accordance with the Red Meat Regulations as published under the South African Meat Safety Act (No. 40 of 2000). Inspection was done by trained and registered meat inspection personnel stationed at multiple points along the slaughter line. These inspection points were each attended to by a different registered inspector that worked on a rotational basis and can be summarized as follows:

1. Head: The inspector made two incisions in both the external masseter muscles and one incision into the pterygoid muscle on each side of the head. The removed tongue was observed and palpated.
2. Red offal: The trachea, lungs, heart, and liver were inspected, and the heart opened to expose both ventricles.
3. Carcass: Two registered inspectors were responsible for the inspection of the bovine sides; one attended to the forequarter, while the other attended to the hindquarter. During inspection of the forequarter, one incision was made into each triceps brachii muscle, and the diaphragm on each side received two incisions. All organs and surfaces were visually inspected. Furthermore, four additional incisions were performed on all carcasses forming part of the study into

the interventricular septum of the heart. All cysts identified in the heart were classified according to whether they were discovered during normal inspection or identified after the additional incisions were made.

Carcass serial numbers and cyst organ locations were recorded during the slaughter process, while data pertaining to the sex, weight, age, and feedlot of origin of the animals were collected from the abattoir database after each sampling day.

All suspect cysts discovered during inspection were collected in 10 % buffered formalin and sent for histopathological examination by a registered veterinary pathology specialist after the conclusion of data collection. The veterinary pathologist was asked to confirm the lesions as *T. saginata*.

2.2. Data analysis

2.2.1. Cysticercosis detection

The apparent prevalence of cysticercosis with and without the additional heart incisions was estimated with a 95 % confidence interval. The proportion of positive animals obtained with and without the additional incisions were compared using McNemar's chi-square tests.

An estimate of the true prevalence of cysticercosis in the sample population was calculated using a standard formula (Thrusfield, 2018), the WHO estimate of sensitivity for traditional meat inspection of 15 % (WHO and FAO, 2020), a specificity of 100 %, and the test prevalence from the normal post-mortem inspection without the additional incisions.

McNemar's chi-square test was used to compare the number of cases detected with the additional incisions with the corresponding number of detections excluding those identified by the triceps incision. The same test was used to compare the number of positive cases using the normal inspection method with this number excluding those cases identified in the triceps brachii.

Statistical analyses for the estimation of proportions were performed using the OpenEpi opensource online statistical software (Dean et al., 2013). In all cases where proportions were estimated, the Mid-P method was used to calculate confidence intervals. McNemar's chi square analyses were performed using Epitools Epidemiological calculators (Sergeant, 2018).

2.2.2. Risk factor analysis

The association between a positive cysticercosis diagnosis and the sex, live weight, and age of cattle were estimated using binary logistic regression. Age was categorized as "Young", for animals containing no permanent incisors, and "Old", for animals containing at least one permanent incisor. Weight was categorised as "Light", weighing < 429.20 kg, and "Heavy", weighing > 429.20 kg using the median of the sample population. Potential risk factors were first screened using univariate models and variables with $P < 0.2$ were selected for a multivariable regression model. Associations were reported as odds ratios (OR) with their corresponding 95 % confidence intervals (CI). Analyses were performed using commercial software (IBM SPSS Statistics Version 27, International Business Machines Corp., Armonk, NY, USA).

2.2.3. Economic data collection

Actual abattoir data for the year 2021 were collected from the internal database for the purpose of determining the live animal weights (W_L), dressing percentage (DP), carcass weights (W_c), total meat produced (W_M), the number of animals slaughtered (N_s), the prices obtained for the exported bolar blade (V_{BE}) and the trimmings sold in the local market (V_T), the proportion of meat produced that was deboned (P_D), and the proportion of deboned meat that was exported (P_E). A cutting yield test was conducted in the deboning hall at the study abattoir in which twenty bolar blade primal cuts from twenty different sides were used. The total weights were measured, as well as the weight of the section of bolar blade that had to be cut off and used for trimmings as a result of the inspection cut into the triceps muscle. The section lost to trimmings (P_{BLT}) for each sample was calculated as a proportion of the total weight of the bolar blade for that sample, and the median and standard deviation calculated across all samples. The weight of the bolar blade as a percentage of carcass weight (P_B) was also collected from this block test. A further 1650 carcasses slaughtered within the same calendar year were sampled from the abattoir database for the purpose of calculating the standard deviations for the live animal weights, dressing percentage, and carcass weights. The average packaging cost/kg (V_K) for export was determined as R0.80/kg from actual data. The Rand/Dollar exchange rate for 2021 was obtained from an internet site (Xe, 2023).

2.2.4. Economic cost model

Collected data were used to develop a stochastic model to calculate the potential cost of the incision into the triceps brachii at the study abattoir (Table 1).

Calculations:

a) Weight of bolar blade deboned for export/year (W_{BDE}) = N_s *W_L* (DP/100)*P_B*P_D*P_E
b) Weight of bolar blade lost to trimmings/year (W_{BLT}) = W_{BDE} * P_{BLT}
c) Potential value of the downgraded bolar blade if it were not subject to triceps incision and available for export/year (V_{PE}) = W_{BLT} * V_{BE}
d) Value of the bolar blade sold as trimmings due to the triceps incision (V_{CT}) = W_{BLT} * V_T
e) The total cost of packaging of the downgraded bolar blade per year if it were to be used for export (V_{KT}) = W_{BLT} * V_K.
f) The actual weight of bolar blade that is exported as a primal cut (W_{ABE}) = W_{BDE} – W_{BLT}.
g) The cost of packaging of the actual exported bolar blade (V_{KAB}) = W_{ABE} * V_K.
h) Yearly loss in USD due to the incision into the triceps muscle (V_X) = V_{PE} – V_{CT} – V_{KT}.

The model was implemented in Microsoft Excel (Microsoft Office 2016, Redmond, Washington, USA) using a macro written in visual basic and run with 10000 iterations. Sensitivity analysis was performed by calculating Spearman's rank correlation coefficients between each stochastic element of the model and yearly loss. Additionally, the model was adapted to calculate the potential loss in USD for each proportion of deboned meat that is exported ranging from 1 % to 100 %. This model was run for 1000 iterations for each proportion. Output was reported as the median (2.5th and 97.5th percentiles) yearly loss in USD.

Statistical significance was assessed at $p < 0.05$ for all formal comparisons stated above.

3. Results

3.1. Cysticercosis prevalence/detection

Thirty-three cysticercosis positive carcasses were detected inclusive of the additional heart incisions for an apparent prevalence of 0.98 % (95 % CI, 0.69–1.36 %). This was significantly higher than the normal post-mortem inspection technique without the additional heart incisions that only detected 24 carcasses (0.72 %; 95 % CI, 0.47–1.05 %, $P < 0.001$). Only one cyst was detected per carcass in all carcasses except for one carcass in which four cysts were detected. The true prevalence of bovine cysticercosis in the sample population was estimated to be 6.6 % (95 % CI, 4.3–8.8 %). The organ with the highest number of identified cysts was the heart, followed by the masseter muscles and the triceps (Table 2). All suspect cysts were confirmed as *T. saginata* on histopathology.

Inspection including additional heart incisions, but without the triceps incision, detected 31 positive carcasses (0.92 %; 95 % CI, 0.64–1.29 %), which was not significantly different to the prevalence when

Table 1
Stochastic cost model parameters used to estimate the economic impact of the incision into the triceps brachii at a bovine export abattoir in South Africa. All variables were modelled using normal distributions.

Parameter	Description	Mean	SD	Source
N_s	Number of animals slaughtered in 2021	380086	5674.75	Abattoir database
W_L	Average live weight (kg) at bleeding for the period per animal	433.19	47.57	Abattoir database
W_c	Average cold carcass weight per animal (kg) after chilling	273.28	32.74	Abattoir database
DP	Dressing %	63.05	2.63	Abattoir database
W_M	Total cold meat slaughtered (kg) for the period	103871783.3	1441133.68	Abattoir database
P_B	Bolar blade proportion of total carcass weight	0.03077	0.0102	Deboning block test
P_D	Proportion of meat deboned in 2021	0.3421	0.0408	Abattoir database
P_E	Proportion of deboned meat exported in 2021	0.2823	0.234488	Abattoir database
P_{BLT}	Approximate proportion of bolar blade weight lost to trimmings	0.13657	0.0238	Deboning block test
V_{BE}	Average price of bolar blade for export (R/kg)	75.26	1.01	Abattoir database
V_T	Average price of trimmings (R/kg)	61.51	1.74	Abattoir database
	Average Rand/USD Exchange Rate 2021	14.79	2	Xe (2023)

Table 2
Location of *T. saginata* cysts in bovine carcasses diagnosed at meat inspection at an export beef abattoir in South Africa in both the normal post-mortem inspection method, with specific heart locations indicated for those carcasses where cysts were identified in the heart. Inspection was conducted in 3353 carcasses, with four additional incisions into the heart conducted after normal inspection.

Location of cyst	Total number of carcasses	Proportion (%) (95 % CI)	Number of carcasses using only normal inspection	Proportion (%) (95 % CI)
Heart	23	70 (53–83)	14	58 (38–77)
Interventricular septum	10	30 (17–47)	1	4 (0–19)
Left ventricular free wall	8	24 (12–41)	8	33 (17–54)
Right ventricular free wall	5	15 (6–30)	5	21 (8–40)
Masseter	8	24 (12–41)	8	33 (17–54)
Triceps	2	6 (1–19)	2	8 (1–25)
TOTAL	**33**		**24**	

including the triceps incision (0.98 %; 95 % CI, 0.69–1.36 %) (P = 0.480). There was also no significant difference in the detection of cysts using the normal post-mortem inspection (0.72 %; 95 % CI, 0.47–1.05 %) compared to this inspection method with the triceps incision omitted (0.66 %; 95 % CI, 0.42–0.98 %) (P = 0.480) (Table 3).

3.2. Risk factors

In the univariate analysis (Table 4), cattle from outside feedlots had higher odds of having cysticercosis detected compared to cattle from internal feedlots (OR= 4.17, 95 % CI: 2.04–8.54, P < 0.001). Older animals were also positively associated with cyst detection compared to younger animals (OR= 3.90, 95 % CI: 1.17–13.03, P = 0.027). In the multivariable logistic regression analysis, cattle from outside feedlots (OR= 4.73, 95 % CI: 2.20–9.79, P < 0.001) and older animals (OR=5.70, 95 % CI: 1.32–17.24, P = 0.006) remained significantly associated with a positive cysticercosis detection (Table 5).

Table 3
Comparison of various post-mortem meat inspection methods on the detection of *T. saginata* cysts in bovine carcasses at an export beef abattoir in South Africa. Inspection was conducted in 3353 carcasses, with four additional incisions into the heart conducted after normal inspection.

Post-mortem meat inspection method	Number of carcasses	Prevalence	95 % Confidence Interval
Normal	24	0.72	0.47–1.05
Normal excluding triceps incision	22	0.66	0.42–0.98
Normal with additional heart incisions	33	0.98	0.69–1.36
Normal excluding triceps incision with additional heart incisions	31	0.92	0.64–1.29

Table 4
Outcome of univariable model of risk factors for bovine cysticercosis among 3353 bovines slaughters at a high throughput bovine abattoir in South Africa.

Variable	Level	Number of detections	Total	Odds ratio (95 % CI)	P value
Feedlot of origin	Outside	12	412	4.17 (2.04, 8.54)	<0.001
	FBO	21	2941		
Sex	Male	26	2351	1.59 (0.69, 3.67)	0.278
	Female	7	1002		
Weight	Heavy cattle (>429.20 kg)	18	1675	1.20 (0.60, 2.40)	0.597
	Light cattle (<429.20 kg)	15	1678		
Age	Old	3	86	3.90 (1.17, 13.03)	0.027
	Young	30	3267		

CI = confidence interval. FBO = food business operator.

3.3. Stochastic cost model

The median estimated 2021 annual financial loss to the food business operator attributed to the triceps incision was calculated as $30 387 (95 % CI: $0–130 696). The most important parameter affecting the cost incurred due the triceps incision was the percentage of deboned meat exported (Spearman's rho=0.853), followed by the weight of the bolar blade as a proportion of the carcass weight (Spearman's rho=0.329; Fig. 1). The potential annual loss to the food business operator in USD ranged from a median of $1 188 (95 % CI: $390–2 471) if only one percent of deboned meat is exported, to $123 401 (95 % CI: $32 563–252 753) if all deboned meat is used for exports (Fig. 2).

Table 5
Outcome of multivariable model of risk factors for bovine cysticercosis among 3353 bovines slaughters at a high throughput bovine abattoir in South Africa.

Variable	Level	Parameter estimate ($\hat{\beta}$)	Odds ratio (95 % CI)	P value
Feedlot of origin	Outside	1.5536	4.73 (2.20, 9.79)	<0.001
	FBO	Referent		
Age	Old	1.7399	5.70 (1.32, 17.24)	0.006
	Young	Referent		

CI = confidence interval. FBO = food business operator.

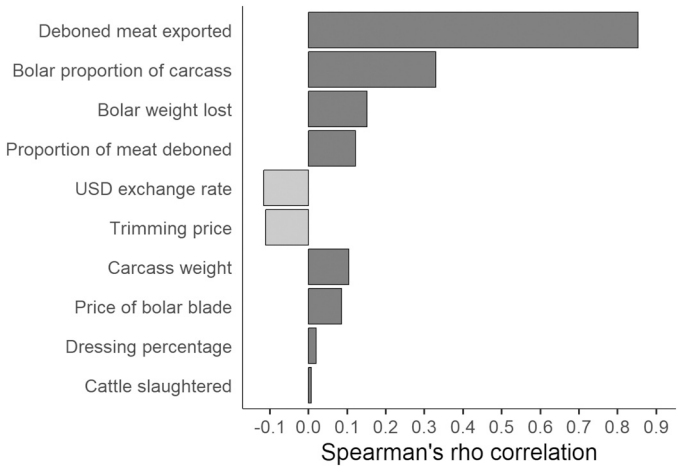

Fig. 1. Tornado plot of Spearman's rank correlation coefficient values for various input parameters illustrating those most affecting the cost from the triceps brachii incision at an export beef abattoir in South Africa.

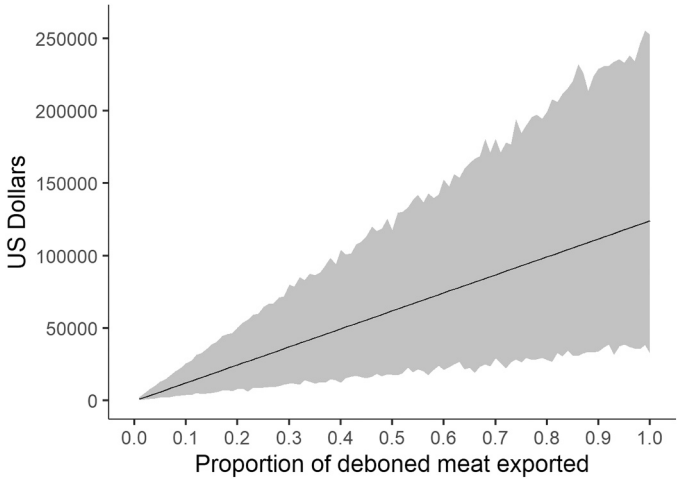

Fig. 2. Relationship between the proportion of deboned meat used for export and the cost incurred by the food business operator due to the triceps brachii incision at a beef export abattoir in South Africa.

4. Discussion

This study at a bovine export abattoir in South Africa aimed to investigate epidemiological factors pertaining to bovine cysticercosis and its detection through meat inspection. It also specifically evaluated the validity of the mandatory inclusion of incisions into the triceps brachii muscles and estimated the economic cost of this practice to the food business operator.

The recorded prevalence contributes to the epidemiological data regarding cysticercosis in sub-Saharan Africa, which is currently limited (Dermauw et al., 2018). The estimated true prevalence also highlights the potential number of positive carcasses not identified at the abattoir in this population of feedlot animals, even when including the additional incisions into the heart. Previous serological studies in rural South African cattle recorded seroprevalences of 15 % and 22.8 % (Tsotetsi-Khambule et al., 2017), indicating that the prevalence in the general population could be even higher. Meat inspection, which currently serves as the primary detection and control measure to regulate bovine cysticercosis in South Africa, is not sufficient on its own to prevent human exposure and potential circulation of the parasite.

The results highlight the importance of incising the heart as part of the mandated standard inspection method. There is currently a widespread practice of omitting the two mandatory longitudinal incisions into the interventricular septum of the heart, which was also identified in this study. This might cause a meaningful number of positive cysticercosis carcasses to pass meat inspection undetected, especially in low prevalence settings. Further investigation into the feasibility of amending existing legislation to mandate additional incisions into the heart during meat inspection is warranted. This proposed modification is a practical and simple solution to enhance the sensitivity of meat inspection to detect bovine cysticercosis without increasing the cost of inspection, and with potential implications for improving food safety. The heart is not a valuable commodity and is often consumed as a component of processed meat, and so the change will have minimal negative financial consequences to the food business operator.

The omission of the triceps brachii incision did not significantly lower the detected bovine cysticercosis prevalence and suggests that its removal from the current inspection procedure would not lead to a significantly reduced sensitivity of meat inspection. Should additional cardiac incisions be made, incisions into the triceps muscles will also not significantly improve detection. The currently mandated practice could also increase and spread high-priority bacterial meat-borne hazards (EFSA, 2013) due to the increased contact between the inspector, the inspection equipment, and the carcass.

The historical insistence and continued requirement of the incision into the triceps brachii specifically in Africa, does not appear to be rooted in reputable evidence. Previous justification making broad reference to long-distance journeys undertaken by cattle on the African continent (Gracey et al., 1999) is indicative of an incomplete understanding of the farming systems in the region today, as well as the predilection sites. The beef industry comprises both formal and informal sectors, extensive and feedlot systems, and traveling distances undertaken by cattle will vary greatly depending on the ownership, region, breed, source of nutrition, and availability of transport and infrastructure. If future investigations provide evidence that cattle in rural environments, particularly those undertaking prolonged journeys, exhibit a higher prevalence of metacestodes in the triceps brachii, it would be prudent to consider implementing a two-tiered approach within a risk-based inspection system. If triceps brachii incisions are limited to animals classified as high-risk for *T. saginata* infection, this approach could enhance inspection effectiveness and result in cost savings for the FBO. While the risk exists for the FBO to advocate for increased line speeds and reduced inspection personnel following the elimination of the triceps brachii incision, this should not be the case, as meat inspectors will continue to conduct visual inspections and carcass trimming as required.

Cattle originating from external feedlots were more likely to be cysticercosis positive, which could either point to higher rates of infection during the feeding period or be related to the difference in sourcing of weaner calves. The internal feedlot implements a HACCP-based system where farms from which weaner calves are sourced and that are associated with a consistently high cysticercosis prevalence at slaughter are excluded from future purchases. The programme also includes obligatory deworming of all feedlot staff every three months. The vertical integration of the internal feedlot and abattoir further supports the traceability of carcasses to primary suppliers. The results could reflect the success of this programme when compared to external feedlots where similar measures might not have been implemented. Older animals were also associated with a higher risk of cysticercosis detection, which is in accordance with other research (Calvo-Artavia et al., 2013) and is likely related to a longer productive life that increases the odds of infestation (Comin et al., 2021). It is noteworthy that the study population consisted exclusively of feedlot cattle where the variation in age was relatively small. Despite some studies in other farming systems that suggested that female animals are more likely to be cysticercosis positive (Calvo-Artavia et al., 2013), this study did not identify sex as a significant risk factor, which was in accordance with another South African

study in feedlot cattle (Verwoerd, 2018). The data provide evidence for the value in classifying suppliers into risk categories, with the future potential of adapting the intensity and approach of meat inspection accordingly should novel legislation be introduced. This is especially relevant as traditional meat inspection methods are increasingly replaced with integrated food safety assurance systems that are more effective in protecting human health (EFSA, 2013; Collins et al., 2015).

The results highlighted the potential financial losses for a single beef producer as a result of the triceps brachii incision, should the proportion of exports increase. In South Africa alone, the value of exported beef has increased eightfold from R309 000 000 (approximately $16 800 000) in 2011 to R2 530 000 000 (approximately $138 000 000) in 2020 (DALRRD, 2021). Furthermore, the value of the South African Rand weakened from approximately 7.50 to the US dollar to around 16.50 to the US dollar during the same period (SARB, 2023), representing a depreciation of approximately 120 %, and thus increasing the competitiveness of South African beef in international markets. The growth in exports can furthermore support the expansion of the industry even if there is a decrease in local beef consumption (USDA, 2020). The reduced proportion of the bolar blade available for export therefore not only leads to direct financial losses for the producer of African beef, but also furnishes their direct international competitors with an unfair advantage.

The use of a non-probability sampling method is a limitation and potential source of bias. The estimation of true prevalence also assumed a perfect specificity and only incorporated a single reported value for the sensitivity of meat inspection. Uncertainty in sensitivity and specificity estimates could have been included in a stochastic evaluation rather than the deterministic approach reported. The reported prevalences also do not account for the clustered sampling design per day. The variance inflation factor was relatively small (1.58) and had limited influence on confidence intervals due to the small estimated prevalences. The cost of meat inspection was also excluded from the analysis. It should lastly be noted that the sample population consisted exclusively of feedlot cattle and findings are unlikely to represent the informal sector. Notwithstanding these limitations, the findings should be valuable to the broader South African beef industry and industries in other African countries with export abattoirs.

5. Conclusions

The heart is the most important organ in the bovine carcass for the detection of *Taenia saginata* cysts, and this should be reflected in the guidance from official veterinary controls and the formulation and implementation of legislation. Additional cardiac incisions will, especially in low prevalence settings, significantly improve the detection of the parasite. Risk-based inspection techniques should consider age and origin as risk factors to achieve a more specific assessment of each animal, thus improving efficacy while minimizing unnecessary contact and carcass damage. Finally, the mandated incision into the triceps brachii muscle in African cattle does not significantly increase the sensitivity of meat inspection for *T. saginata,* does not appear to be rooted in strong evidence, and comes at an economic cost that will escalate further as beef exports increase. The continued insistence of its inclusion today in specifically African cattle is not supported by the evidence and is detrimental to the sustainability and future growth of the local beef industry.

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Declaration of Competing Interest

None.

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