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Bovine tuberculosis control and eradication in Brazil: Lessons to learn from the US and Australia

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ABSTRACT

Brazil, Australia, and the United States of America (USA) are the top 3 beef exporting countries in the world. Livestock's Gross Domestic Product (GDP) accounts for 30% of the GDP of the Brazilian agricultural sector, which shares 21.5% of the country's GDP. The livestock production chain generated $148.47 billion USD in 2016, an increase of 27% over 2015 (ABIEC 2016). In 2015, the gross value of Australian cattle and calf production is estimated at $12.7 billion USD and the cattle industry involves 55% of all businesses with agricultural activity in the country (ABS 2017). In turn, the USA beef chain generated $170.62 billion USD and exports $6.34 billion USD in 2016. In terms of GDP, the red meat and poultry slaughter industry is the largest segment of USA agriculture (USDA 2017).

In addition, Brazil, Australia, and the USA have other similarities, such as beef cattle predominantly raised in grass feed systems, structured Veterinary Services (VS), and large territorial dimension, which makes animal health challenges of those countries comparable. However, while the USA and Australia have almost solved major animal health challenges such as Foot and Mouth, brucellosis, and tuberculosis (TB), Brazil still has difficulties with those diseases with good progress towards the Foot and Mouth eradication but slowly in regards to brucellosis and TB eradication.

Australia is one of the few international examples of successfully eradicating bovine tuberculosis (BTB), and the USA has the longest program of BTB eradication and has nearly eradicated the disease from the nation's livestock population (USDA, 2017). Due to the similarities of the three countries, Brazil can learn from the experience of the USA and Australia to achieve better results in its eradication program.

The objectives of this review are: 1) to compare and highlight the similarities and differences between the BTB control and eradication programs of the three major players of the global meat market; 2) to address the challenges for the Brazilian National Program for Control and Eradication of Bovine Brucellosis and Tuberculosis (PNCEBT) to eradicate the BTB from the country; and 3) to provide recommendations for improvement of the PNCEBT.

1. Introduction

Brazil, Australia, and the United States of America (USA) are the top 3 beef exporting countries in the world. Livestock's Gross Domestic Product (GDP) accounts for 30% of the GDP of the Brazilian agricultural sector, which shares 21.5% of the country's GDP CEPEA, 2017). The livestock production chain generated $148.47 billion in 2016, an increase of 27% over 2015 (ABIEC 2016). In 2015, the gross value of Australian cattle and calf production is estimated at $12.7 billion USD and the cattle industry involves 55% of all businesses with agricultural activity in the country (ABS 2017). In turn, the USA beef chain generated $170.62 billion USD and exports $6.34 billion USD in 2016. In terms of GDP, the red meat and poultry slaughter industry is the largest segment of USA agriculture (USDA 2017a,b,c).

In addition, Brazil, Australia, and the USA have other similarities, such as beef cattle predominantly raised in grass feed systems, structured Veterinary Services (VS), and large territorial dimension, which makes animal health challenges of those countries comparable. However, while the USA and Australia have almost solved major animal health challenges such as Foot and Mouth, brucellosis, and tuberculosis (TB), Brazil still has difficulties with those diseases with good progress towards the Foot and Mouth eradication but slowly in regards to brucellosis and TB eradication (OIE, 2017).

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2. Material and methods

A survey was carried out by collecting information and official documents available on the Brazilian, Australian, and USA official animal health websites: World Organization for Animal Health (OIE) website and at the electronic databases (Google Scholar, CAB abstracts, Animal Health and Production Compendium) during the period of January to March 2017. Documents in English and Portuguese were identified using surveillance subject headings and truncations:

2.1. Brazil

Brasil and PNCEBT; PNCEBT and bovine tuberculosis; PNCEBT and tuberculose bovina; PNCEBT and tuberculose bovina and erradicação.

2.2. Australia

Australia and bovine tuberculosis and eradication; Australia and bovine tuberculosis program; Australia and BTEC and bovine tuberculosis eradication.

2.3. United States

United States and bovine tuberculosis and eradication; US and bovine tuberculosis program; USDA and bovine tuberculosis eradication program.

3. Results

3.1. Brazil

The first initiatives to control BTB occurred at state level during the early 1900's (Antunes et al., 2012). At that early stage, it was still controversial as to whether *M. bovis* could be transmitted between animals and humans. The first initiative to address the control of BTB nationwide was made by the Brazilian Buiatrics Association in 1999, which lead to the launching of the PNCEBT by the Ministry of Agriculture, Livestock and Food Supply (MAPA) in 2001 and override by the Normative Instruction N° 6 in 2004. At that time the official data had indicated a nationwide animal prevalence of 1.3%, the regional distribution was not known (Lage et al., 2006). From 2005 to 2014, adopting the Comparative Cervical Test (CCT) as a standard, 14 epidemiological studies were conducted in 13 states. (Galvis et al., 2016; Bahiense et al., 2016; Barbieri et al., 2016; Dias et al., 2016; Gonçalves & Coelho, 2013; Guedes et al., 2016; Lima et al., 2106; Néspoli et al., 2016; Queiroz et al., 2016; Ribeiro et al., 2016; Rocha et al., 2016; Silva et al., 2016; Veloso et al., 2016; Vendrame & Benitez, 2013). The herd prevalence ranged from 0.5% to 11%, while individual animal prevalence was from 0.035% to 1.3%.

Originally PNCEBT had two specific aims; 1) to reduce the incidence and prevalence of Brucellosis and Tuberculosis, and 2) to establish a significant number of disease-free or disease monitored farms (Brazil, 2006). The program was dedicated to cattle and buffalo, and had a strategy based on a set of compulsory and voluntary measures.

The compulsory measures were established to control the movement of animals and accreditation of veterinarians to act in the program. The compulsory testing of animals for reproductive purposes before interstate movement for the participation in exhibitions, fairs, auctions and other animal agglomerations was reinforced. The training and accreditation of Veterinary Practitioners for actuation on the program was a complementary mandatory measure. The voluntary measure established in the program was the accreditation of properties in two categories: “free of TB” and “monitored” with the aims of creating a market of TB free animals and to bolster the food safety of the livestock chain.

The program adopted the diagnostic methods recommended by the OIE. The standard test for BTB detection in the field is the Tuberculin Skin Test (TST), which involves the intradermal injection of bovine tuberculin Purified Protein Derivative (PPD) and the subsequent detection of swelling (delayed hypersensitivity) at the site of injection 72 ± 6 h later (OIE, 2012).

The Caudal Fold Test (CFT), the Simple Cervical Test (SCT), and the Comparative Cervical Test (CCT) are the official tests of detection. The CFT and SCT were adopted as screening tests for beef and dairy cattle, respectively, while the CCT was adopted as a confirmatory test for animals positive at the screening test. All TB tests can be conducted by State or Federal veterinarian offices, or by accredited private veterinarians (MAPA, 2001). However, usually State and Federal veterinarians do not perform tests, they commonly supervise the private accredited veterinarians performing the tests during the herd accreditation process. The program would accept the use of additional direct and indirect diagnostic testing after approval and under conditions to be stablished by the Veterinary authority.

Accredited veterinarians are also responsible for identifying reactive animals, reporting positive and inconclusive results to VS, and report about the distribution and use of PPD monthly. The reactive animals must be marked with the letter “P” on the right side of the face using a branding iron by the accredited private veterinarian who conducted the test. In addition, reactive animals are kept under quarantine and ithin 30 days sacrificed at slaughterhouses or at the test site under the VS supervision. The diagnostic criteria and norms to treat positive animals were the same for cattle and buffalo.

From this inception in 2001–2017, the program had minor alterations (MAPA, 2001, 2004). In 2017, the PNCEBT had a comprehensive review and major alterations. The goal of the program now was eradication. At that time, a risk-based approach was developed by the state BTB status. The risk ranking was set to range from ‘unknown risk’ to ‘negligible risk’ using the criteria in Table 2. Furthermore, the control of animal movement was redefined in order to protect states in the low risk status classification (MAPA, 2017).

The new rules of herd accreditation were simplified from a dual classification of properties as free of BTB or controlled BTB to a unique classification of property free of BTB. The former accreditation process required 3 screenings of the herd with no reactor animals within 3 months, and the new rules require only 2 screenings in a period ranging from 6 to 12 months to achieve the accreditation of BTB free property (Fig. 1). In addition, the supervision of the accreditation process was delegated to the State authority instead of a Federal responsibility as before (MAPA, 2017).

Another major change was the compulsory herd cleaning policy in states ranked from high risk to negligible risk, according to the following rules:

a) Dairy and non-specialized herds – all animals older than 6 weeks will be tested until there is a detection of no positive animals, ranging from 60 to 90 days.
b) Beef herds – all females older than 24 months and breeding males must be tested.
c) The tests must be performed until 90 days after the outbreak detection, and all positive animals will be abated.
d) The herd sanitation will be performed by accredited veterinarians

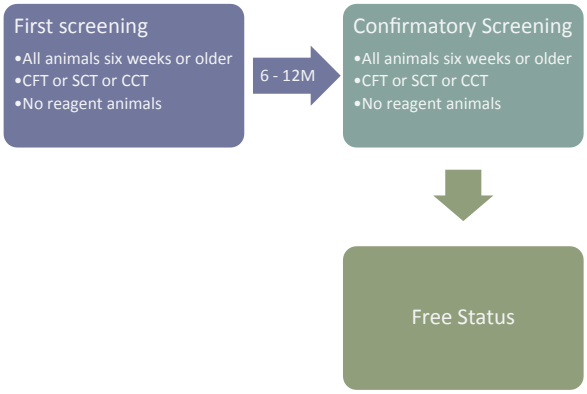

Fig. 1. Herd accreditation process PNCEBT.

under the State Veterinary surveillance.

The new rules for animal movement states that for purposes of interstate movement of cattle and buffalo destined to states classified as very low risk or negligible risk for TB, and it is mandatory to submit negative results of diagnostic tests for TB for any purpose, except immediate slaughter. Animals from states classified as very low risk or negligible risk for TB are exempt from the referred examinations, except for reproduction. All the rules applied equally to cattle and buffalo (MAPA, 2017).

One fundamental feature of the PNCEBT, since it's an early version, is the absence of compensatory measures for farmers. All the costs for the accreditation of the farm from the testing to elimination of reactive animals are under the owner's responsibility with no indemnity or other compensations paid by the governments or the industry.

3.2. United States

The centennial Tuberculosis Eradication Program, which is administered by the USDA Animal and Plant Health Inspection Service (APHIS), State animal health agencies and U.S. livestock producers has practically nearly eradicated BTB from the nation's livestock population (USDA, 2017b).

The program was launched in 1917, moved by (at that date) still controversial scientific evidence that the BTB could be passed between animals and humans and by that time the presumed *M. bovis* prevalence was 5% in all cattle (Olmstead & Rhode, 2004). By 1941, the prevalence was reduced to a rate below 0.5% in every county in the USA, and the country's livestock was officially accredited free of BTB (Naugle, Schoenbaum, Hench, Henderson, & Shere, 2014). The status changed in the year 2000 due to the uncovering of wildlife infection by *M. bovis* (Schmitt et al., 1997) and evidence-based prove of transmission from infected wild white-tailed deer for healthy livestock herds (Schmitt et al., 2002). Currently, the prevalence rate in cattle is lower than 0.001% (USDA, 2017a,b,c).

Initially, the cooperative state-federal TB testing program was voluntary, but after 5 years it evolved into a compulsory system. Despite some protests and attempts by farmers and private veterinarians to resist the tests (Palmer & Waters, 2011), the overwhelming majority of farmers freely participated. From 1917 to 1940, nearly every county was reached by the program, state and local governments, systematically tested and retested cattle and destroyed those that reacted positively (Olmstead & Rhode, 2004).

Since the inception, incentives for farmers' cooperation were considered. Indemnity payments for the farmers was considered the best option, conditioned to testing the entire herd (rather than only suspect animals), removing the reactors for immediate slaughter, and disinfecting the premises thoroughly before restocking. The Federal legislation allowed states flexibility to adjust their eradication policies, schedules, and indemnity values (Naugle et al., 2014).

Originally the focus was on cattle, but later the program included bison (1984) and cervids (1994) as the influence of these species in the epidemiological chain of BTB (Thoen, Steele, & Gilsdorf, 2006) being discovered. Currently, the detection of TB is focused on passive surveillance and is made via slaughter inspection of cattle and bison or diagnostic necropsy (USDA/APHIS, 2005).

Official TB tests can be conducted by State or Federal Veterinarians (CFT test only); or by designated Accredited Veterinarians. The CFT may be conducted by technicians employed and approved by State or Federal governments, under direct supervision of State or Federal animal health veterinarians (USDA-APHIS, 2005).

The CFT and CT are considered primary diagnostic tests (USDA-APHIS, 2005). The primary official screening tests currently used in live animal TB surveillance are the CFT used in cattle or bison herds with unknown TB status. The CT test is required as the initial test in herds affected with bovine tuberculosis. For retesting cattle or bison tuberculin test suspects, CCT test is the official test and can be used only with the prior written consent of cooperating State or Federal animal health officials and can be applied only by a State or Federal regulatory veterinarian trained. The CCT test must not be used as a primary test for animals of unknown status. In addition, the bovine interferon gamma assay may be used in cattle herds when approved by the authorities. Histopathology, diagnostic bacteriology, and Polymerase Chain Reaction (PCR) assay of formalin-fixed tissue are supplemental diagnostic procedures approved for use in the program (USDA/APHIS, 2005).

The identification of reactor animals is made by official veterinarians by branding the letter "T" on the left hip near the tail head, and by tagging with an approved metal ear tag bearing a serial number and inscription "U.S. Reactor" or a similar State reactor tag suitably attached to the left ear (USDA, 2006a,b).

A highlighted feature of the USA program is the Designated Tuberculosis Epidemiologist (DTE) who is a State or Federal Epidemiologist designated in each State by APHIS to make TB decisions concerning the use and interpretation of diagnostic tests and to manage the TB program. The DTE has the responsibility to determine the scope of epidemiologic investigations, determine the status of herds, assist in development of individual herd plans, and coordinate disease surveillance and eradication programs within his or her geographic area of responsibility (USDA-APHIS, 2005).

Based on the infrastructure, the compliance with the national guidelines, and the prevalence of infection a State or zone may be classified in five categories as follows: (1) Accredited-free state or zone; (2) Modified Accredited Advanced state or zone; (3) Modified Accredited state or zone; (4) Accreditation Preparatory state or zone; and (5) Non-Accredited state or zone (USDA, 2017a,b,c). In November of 2017, 48 USA States and Michigan's Upper Peninsula were considered TB Free, and part of Michigan's Lower Peninsula were considered Modified Accredited (Table 3).

The interstate or inter-zone movement requirements for TB are defined according to the state or zone classification and the herd status being more restrictive as lower is the state's status or zone category. To be accredited as free, a herd must pass at least 2 consecutive official TB tests of all eligible animals conducted at 9–15 month intervals, have no evidence of or potential exposure to BTB, and meets the guideline standards (USDA-APHIS, 2005).

Any tuberculosis-affected herd must go through a complete epidemiologic investigation, and all herds in which reactor animals are disclosed shall be quarantined immediately. The first consideration in affected herds is the depopulation of the entire herd. If depopulation cannot be accomplished, the herd must be held under quarantine, until all requirements of an individual herd plan have been completed (USDA/APHIS, 2005).

All cost-benefit analysis are unanimous that the program was an enormous success even with not considering the human health benefits, which would increase benefits far beyond what has been shown. The

reduction or elimination of the TB burden is a perpetual benefit (Thoen et al., 2006), the savings to farmers and meat packers alone exceeded the costs by at least a ratio of ten-to-one (Olmstead & Rhode, 2004). Adopting the Thoen et al. (2006) rationale, the true economic return of the TB program is estimated in between $19 to $90 billion USD in actual values.

3.3. Australia

The Australian National Brucellosis and Tuberculosis Eradication Campaign (BTEC) began in 1970, replacing voluntary State-based TB control programs, and Australia was officially declared free from BTB in December 1997 (Cousins & Roberts, 2001). The last confirmed case of TB in any species in Australia was detected and destroyed in 2002 (AAHC, 2003). By the early 1960's, the *M. bovis* prevalence rate was about 0–1% within dairy animals; however little progress had been achieved in beef herds outside the intensively farmed coastal strips of the southern parts of Australia with the prevalence ranging from 5 to more than 10% (Lehane, 1996).

The BTEC was an initiative of industry, State, and Federal government united with the goal of eradication of *M. bovis* from all cattle and buffalo herds in Australia. Currently, the country does not have wildlife reservoirs for BTB and is recognized as TB free in all animal species (Australia, 1975).

Federal and State Governments and the livestock industry provided financial support to farmers throughout BTEC. Producers, veterinary practitioners, industry and government bodies worked together to develop Standard Definitions and Rules (Cousins & Roberts, 2001). The campaign relied on systematic and repeat skin testing of cattle herds using the CFT, slaughter of reactors, and movement controls (Australia, 1975). This was supplemented with slaughterhouse monitoring and trace back to carcasses with confirmed TB (Animal Health Australia, 2009).

A risk-based approach was adopted and a broad range of strategies were used, such as: a dynamic system of herd and area classification (Table 4 and Fig. 2); risk assessed at the level of the group rather than at the level of the individual; age culling; and restrictions on the movement based on the herd or area risk (AAHC, 2003).

A farm certification program, the Approved Property Programme (APP), was a strategic component to leverage farmer commitment. Individual agreements were established with specific long-term and interim milestones toward the eradication, and the actions were reviewed annually (More, John, Radunz, & Glanville, 2015). Eligibility for BTEC financial support was contingent on agreement to, and compliance with, the APP.

Over a two-year period, four negative whole-herd tests were required for the lifting of movement restrictions (Australia, 1975). A fifth tuberculin test was done 5–8 years later for a herd to become 'certified-free' (Animal Health Australia, 2009). Movement controls meant that stock from infected herds could only move to slaughter or to other infected herds (Radunz, 2006). Controls were imposed until the infection was eradicated (More et al., 2015). Tail tags identified the owner and property of origin of cattle, and enabled them to trace back all cattle that were moved, sold or slaughtered (Australia, 1975). The pathway for herd classification is presented in Fig. 2.

During the course of the eradication campaign, new advances from TB research were incorporated into the program. In 1991, the in-vitro γ−IFN test (BOVIGAM®) was accredited as an official diagnostic test for BTB and subsequently adopted as an ancillary test for TB diagnosis (Radunz, 2006). In 1998, the routine skin testing of cattle herds was replaced by intensive slaughterhouse-based surveillance and following the TB Free Accreditation recognition the BTEC evolved to the Tuberculosis Freedom Assurance Program (TFAP) (AAHC, 2003). TFAP aimed to maintain Australia's freedom from BTB and incorporated both active and passive surveillance procedures for the effective detection of TB in Australia. Currently, the TFAP major components are: the

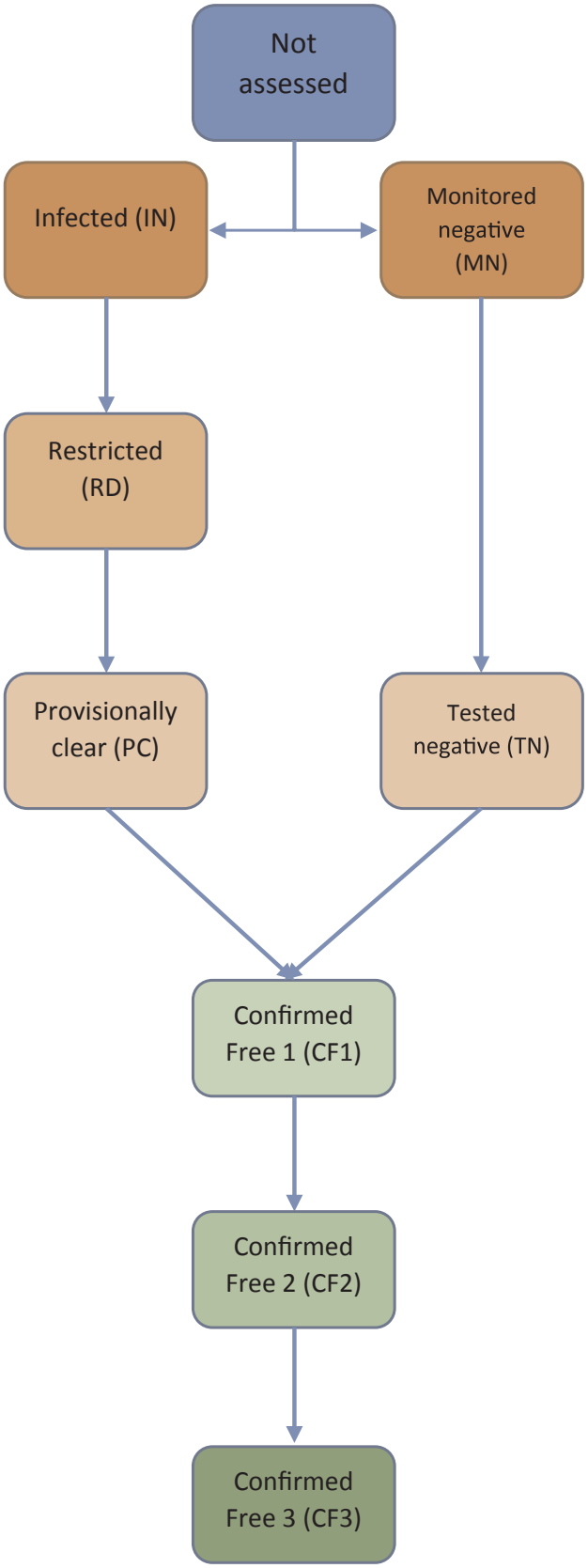

Fig. 2. BTEC pathway for change in herd classification, based on McGuin (1986) and the final (1995) version of the standard definitions and rules.

Table 1
Comparison of Bovine tuberculosis Programs, Brazil, Australia, and US, 2018.

Key points	Brazil	Australia	United States
Year of inception	2001	1970	1917
Rationale for the initiation	Interest group (Buiatrics movement)	Economic (beef export to US)	Public Health (transmission of BTB to humans)
Goal	Control and Eradication	Eradication	Eradication
Status	Voluntary	Compulsory	Compulsory
Major alterations	2017	1997 and 2002	1922, 1934, 1960, and 1965.
Animal Prevalence at inception	1.3%	0–1%, Dairy animals 5–10%, Beef	5%
Routine test	CFT (Beef herds), CST (Milk and non-specialized herds).	CFT	CFT
Confirmatory test	CCT	CCT, Bovigan, Microbiological, and Molecular	CCT, Microbiological, and Molecular
Conduction of tests	Accredited veterinarians and State or Federal Veterinarians (screening and confirmatory tests)	Accredited Veterinarians (screening test) State or Federal Veterinarians (confirmatory tests)	Accredited Veterinarians (screening test) State or Federal Veterinarians (confirmatory tests)
Movement controls, quarantine, and traceback	Yes, No, No	Yes, Yes, Yes	Yes, Yes, Yes
Surveillance	General surveillance	General and targeted surveillance	General and targeted surveillance
OIE Classification	Disease present in bovines, no report wildlife	Free, last occurrence 2002	Disease limited to one or more zones, bovines and wildlife
Wildlife	Not addressed	Addressed	Addressed

National Granuloma Submission Programme (NGSP), Network of Accredited Tuberculosis Reference Laboratories to test the granulomas, and the NGSP database which contains information from TB surveillance. Additionally, targeted herd testing, up-to-date plans of emergency response, strict importation requirements, and state/territory legislation in compliance with the National Program are adopted (Animal Health Australia, 2009, 2012).

4. Discussion

In 2017, a second version of the PNCEBT was launched, with important changes, such as stating BTB eradication as the objective of the program, risk-zoning, and a developing protocol of actions based on the zoning (MAPA, 2017). The PNCEBT is a new program, and there are no measurable results of the program yet. However, it is possible to conduct a comprehensive review and make some suggestions based on past experiences in Brazil, Australia, and the USA to improve the program. In Table 1 we present major differences between the 3 countries programs.

The rationale for the initiation of a disease eradication program is important because acceptance of the program by the society is fundamental for the eradication process to be successful (Cousins & Roberts, 2001; Olmstead & Rhode, 2004). In the USA, the trigger for the BTB eradication program there was the concern of the risk of transmission of BTB to humans. Public health appeal was the major driver to get State and Federal commitment, which leads to near eradication of the disease (Naugle et al. 2014). In Australia, the economic appeal was the determinant trigger for the BTEC, since the occurrence of BTB would jeopardize the beef exportation to the USA, and the program had great support of the farmers, industry, and governments resulting in the eradication of the disease in 27 years (Lehane, 1996). In Brazil, the eradication program was motivated by the National Association of Buiatrics in early 2000s, focused on animal health and willingness to standardize the TST nationwide (Lage et al., 2006), but the movement had no appeal to public health and low impact in the major stockholders such as farmers, industry, or state governments. The impact of the Buiatrics' movement was initially restricted to academia followed by the MAPA, resulting in the first version of the PNCEBT (MAPA, 2001). The program, focused only on animal health and with low appeal to the society resulted in little progress toward BTB eradication during its first 17 years. In Brazil, traditionally the major emphasis in control or eradication of diseases in cattle were in response to trade concerns (Lyra & Silva, 2004). To take advantage of a favorable period to implant tough actions is an interesting lesson to learn from Australia which launched the BTEC just after the eradication of the bovine pleuropneumonia when the society mood was very positive (More et al., 2015), as Brazil seeks to be declared free from Foot and Mouth Disease by OIE in 2018, the momentum is excellent to gather society support and strengthen the actions toward BTB eradication as well.

To the authors' knowledge, there are no successful historical examples of a BTB eradication program based only on voluntary measures or aiming to reduce the incidence and prevalence instead of eradicate the disease. Australia and the USA programs, since their launching, had eradication as a clearly defined outcome (Collins, 2006). Five years after launching, the program turned compulsory forcing latecomer states and farmers to adhere in the USA (Naugle et al., 2014). The Australian BTEC, launched with strong support in society was based in tough compulsory measures toward BTB eradication (Australia, 1975). Until 2016, the PNCEBT was essentially a voluntary program grounded on a two-step process: first BTB control and second BTB eradication (MAPA 2001, 2004). There were no effective mandatory measures towards eradication. As such, no significant reduction of BTB during the first phase of the program was observed. In fact, epidemiological studies showed an increase of the prevalence of the disease in some regions

Table 2
Brazil, PNCEBT, risk-rating table for bovine tuberculosis.

Focus Prevalence	Class	Level			
		Initial	Quality of actions executed		
			Low	Medium	High
Less than 2	A	0	1	2	3
More than 2 less than 3	B	0	1	2	3
More than 3 less than 6	C	0	1	2	3
More than 6	D	0	1	2	3
Unknown	E	0	0	0	0

Where.
E0 – Unknown risk.
D0, D1, D2 e D3 – High Risk.
C0, C1, C2 e C3 – Middle Risk.
B0, B1, B2 – Low Risk.
B3, A0, A1 e A2 – Very Low Risk.
A3 – Negligible Risk.

Table 3
United States, Bovine tuberculosis accreditation categories and State status – Nov. 2017.

Category	Prevalence of TB	States (number as of 12/31/2016)
Accredited Free State or zone	Zero for cattle and bison	48 U.S. States, Michigan's Upper Peninsula and part of Lower Peninsula
Modified Accredited Advanced State or zone	Less than 0.01 percent of total cattle and bison herds	–
Modified Accredited State or zone	Less than 0.1 percent of cattle and bison herds	11 counties in the northern part of Michigan's Lower Peninsula and parts of 2 other counties
Accredited Preparatory State or zone	Less than 0.5 percent of the total number of cattle and bison herds	–
Non-Accredited State or zone	Either unknown or 0.5 percent or more of the total number of cattle and bison herds	–

Table 4
BTEC area classification during the eradication phase. Adapted from Lehane (1996) and More et al. (2015).

Area Classification	How classified
Free	TB believed eradicated. Impending free for at least five years. Approved abattoir monitoring system and granuloma submission programme in place. No herds classified as IN, RD or PC at the time of declaration. Previously infected herds subject to an approved monitoring regime.
Impending Free	Previously a Provisionally Free area. All herds had have to been assessed. No known IN or RD herds at the time of declaration. Capacity to eradicate any breakdown within 24 months of detection.
Provisionally Free	All herds had have to been assessed Apparent disease prevalence less than 0.1 per cent Less than 5 per cent IN herds All IN herds placed in quarantine and active eradication measures instituted.
Eradication	As for Control, plus active disease control.
Control	Quarantine of IN herds. An approved monitoring system in place.
Residual	An area not included in any of the classifications above (only applicable early in the campaign).

CF1 Confirmed free 1, IN Infected, PC Provisionally clear, RD Restricted.

of Brazil (ROXO, 2004). The new PNCEBT, continues to have the original objectives, to reduce the prevalence and incidence of BTB, but now with the goal of eradication of BTB (MAPA, 2017). The new changes include depopulation and/or testing and elimination of all reactive animals according to the State's disease status. Even though the whole program continues to be a “voluntary program”, the new mandatory recommendations (in practice) turn it into a compulsory program. Thus, these new changes towards the eradication of *M. bovis* infection represents significant progress in the new PNCEBT.

The prevalence at the start of a disease eradication process is a fundamental factor that influences the results of the program (Collins, 2006; Naugle et al., 2014; Olmstead & Rhode, 2004). In a logistic model, the chance that a susceptible, but uninfected animal, will become infected by *M. bovis*, raises as the fraction of animals that are infected increases. The transmission can only be controlled by reducing the diffusion of the agent or increasing the number of resistant animals (Thoen et al., 2006). Since increasing the number of resistant animals by vaccine is not an available option, the reduction of *M. bovis* diffusion by elimination of infected animals or segregation of those infected from healthy animals are the two available approaches to the dilemma. Keeping separated herds (infected and uninfected) at the same farm is not currently practical in Brazil, the elimination by culling of the reactor animals is the only feasible option. In consequence, the higher the prevalence rate of *M. bovis*, the harsher the necessary actions will be to eradicate BTB from a region or country. At the inception of the eradication programs, Brazil had the lowest presumed *M. bovis* prevalence of 1.3% (ROXO, 2004, pp. 1–5), whereas the USA's presumed rate was about 5% in all cattle (National Research Council. 1994), and Australia's rate ranged from 1% in dairy to more than 10% in beef animals. Australia was the only country with established epidemiological studies about the prevalence before the National Program, which allowed the adoption of risk-based surveillance actions from the beginning of the campaign (Tweddle & Livingstone, 1994). The low animal aggregation within Brazilian herds seems to be the main feature that influences the current animal prevalence median of 0.3%. On the other hand, the herd prevalence median of 2.3% from the 13 states may be due to inefficient measures to control the diffusion of the *M. bovis* between herds. Even considering that the epidemiological studies about the prevalence of bovine tuberculosis do not took into account the low sensitivity of the CCT, overall, the animal and herd prevalence rates in Brazil remains low (Galvis et al., 2016; Bahiense et al., 2016; Barbieri et al., 2016; Dias et al., 2016; Gonçalves & Coelho, 2013; Guedes et al., 2016; Lima et al., 2106; Néspoli et al., 2016; Queiroz et al., 2016; Ribeiro et al., 2016; Rocha et al., 2016; Silva et al., 2016; Veloso et al., 2016; Vendrame & Benitez, 2013). The figures still favor the adoption of firm actions aiming at BTB eradication, without major protests from farmers association and the risk of shortage of milk and beef. Measures used in the USA and Australia that should be adopted by PNCEBT are the compulsory individual animal identification, testing before any movement of animals from non-accredited herd, and traceability system.

Indemnity funding is a common feature in the USA and Australian programs and believed to be a fundamental factor in the success in both programs (Palmer & Waters, 2011; Thoen et al., 2006). Payments were conditioned to testing the entire herd and adhesion to the rules of the program in both countries (National Research Council. 1994; Tweddle & Livingstone, 1994). In the USA, historical results indicate strong, statistical significant negative effects of lower indemnities on both the share of reactors found and tests completed. On the other hand, in states where indemnities were greater the program made more rapid progress. In Australia, the financial support measures have evolved over time, in addition to indemnity, other measures were implemented (Lehane, 1996; More et al., 2015). These measures included: compensation for destocking, subsidies to hold cattle for the TB test, a restocking freight rebate, low interest loans for infrastructure necessary for eradication, and an interest subsidy. All measures offered in a package of herd certification (More et al., 2015). In contrast, PNCEBT leaves all the costs of testing and eliminating reactor animals to the farmers. There is no legal prevision of indemnity or other incentives to “cleaning” the herd (MAPA, 2017), which represents a major difference from the USA and Australian programs. The experience in the USA, Australia, and Ireland (Olmstead & Rhode, 2004; More et al., 2015; Ohagan et al., 2016) showed indemnity as the major problem in convincing farmers to test the herd. In Australia, the active participation of industry funding the program from the indemnity to advertising was fundamental for the success of the eradication process. In the USA, the indemnity for the

farmers was supported by State and Federal governments. In Brazil, the absence of indemnity or financial support for the farmers certainly will not favor PNCEBT's adherence by farmers. For a major beef exporter, where the government taxes and the industry makes a profit from the sale of healthy animals, it is not unreasonable to request the government and industry to contribute financially to the costs of the eradication effort.

The stakeholders' commitment to the eradication programs were the most highlighted experiences both in the USA and Australia programs (More et al., 2015; National Research Council. 1994; Olmstead & Rhode, 2004; Palmer & Waters, 2011). State governments, policy makers, industry, farmers and their associations are essential to the creation and successful implementation of a disease eradication process. The PNCEBT seems to be only a Federal-State cooperation program, besides participation with representatives in meetings, there are no effective actions by the industry, at least not presented in the rules of the program (MAPA, 2017). The industry sector should be called to bolster the eradication movement through the adoption of different prices for animals and milk from free zones or free properties and supporting research and indemnity.

Farmers associations have influence not only on farmers, but also on local authorities and the communities in general (More et al., 2015; National Research Council. 1994; Ohagan et al., 2016; Olmstead & Rhode, 2004). Without the commitment of the farmers and theirs associations it's very unlikely, that success in a disease eradication program can be achieved. Besides indemnities, other incentives to foster farmers' cooperation should be used in Brazil. Examples of these should include: subsidies, facilitated credit to animal replacement, full indemnity for false positive animals, slaughter and restocking freight rebate, and access to professional support for farm improvement.

Brazil, the USA, and Australia essentially follow the OIE guidelines for the diagnosis of BTB adopting skin tests as a screening test for live animals. Brazilian PNCEBT adopted the CFT and SCT as screening tests (MAPA, 2004, 2017). CFT is restricted to beef animals and any responses to the test are classified as reactors, and the SCT is accepted for use in dairy and mixed herds, as well as, the reaction that the animal can be classified as negative, inconclusive, or positive. Inconclusive, positive, and reactor animals can be submitted to CCT in order to confirm the slaughter decision. The Australian and USA programs adopted the CFT as the screening test for all cattle, buffaloes, and bison. In the USA, all responses to CFT are classified as suspects, unless the professional judgment of the testing veterinarian determine the animal as a reactor (USDA/APHIS, 2005). For a slaughter decision, cattle or bison tuberculin test suspects may be retested using the CCT test (USDA/APHIS, 2005). In contrast, the Australian BTEC had the most aggressive strategy, and the decision to eliminate the reactor animal was based only in CFT (Australia, 1975). The adoption of different screening tests for beef and dairy herds may be confusing. A unique screening test for all kind of farms would facilitate the understanding of the PNCEBT and avoid possible adoption of no indicated test. Faced with the amount of animals to be tested and the technical challenges of the SCT, the CFT seems to be the most indicated primary screening test for the Brazilian conditions as it does not require pre-measure of skin thickness or clipping hair from the injection site.

In the USA and Australia, accredited veterinarians are allowed to perform only CFT screening tests; the confirmatory tests are restricted to official government veterinarians (USDA/APHIS, 2012, AAHC, 2003). That strategy boosted the USA and Australian program since government veterinarians impose more authority and independence to condemn reagent animals than accredited private veterinarians. In Brazil, accredited veterinarians are allowed to perform screening and confirmatory tests. In this regard, Brazil faces difficult challenges. First, there is not a sufficient number of trained veterinarians to perform the tests, especially in the Northern and Northeast regions (Schneider, Barišić, Batalha, & Quinet, 2016). Second, even in regions with a sufficient number of veterinarians, the offer of training for accreditation is reduced. Third, in inner cities or regions where livestock have no economic relevance, the prices paid for the tests do not attract private accredited veterinarians. Forth, there is considerable amounts of frauds and misreporting related to BTB in the program (CFMV system, data not published). Considering difficulties hiring official veterinarians in Brazil, measures to increase the supply of accredited veterinarians, leverage the commitment of private accredited veterinarians, and better oversight of their actions are recommended by Carneiro & Kaneene, 2017. As all States of Brazil are provided with at least one Veterinary School, the training for accreditation offered at Veterinary Colleges would not only provide fresh accredited professionals, but also represent an opportunity for training of active practitioners. The payment for the tests by State or Federal governments, could be a solution to provide and offer accredited veterinarians in inner cities or regions where livestock don't have economical relevance. Finally, to leverage the commitment of honest professionals, to prevent fraud, and assure the quality of the tests, a Monitoring tuberculin testing plan as presented in the USA program would be a worthwhile experience to be copied.

During the compulsory test and slaughter phase, both BTEC and US BTB eradication programs adopted the testing of all cattle and bison (USA) or buffaloes (AUS) 6 months of age and older in each country (Australia, 1975; Olmstead & Rhode, 2004). Under the PNCEBT, cattle and buffaloes aged 6 weeks or older can be tested. During the herd accreditation process, dairy and unspecialized herds should test all cattle and buffaloes 6 weeks of age and older as well as beef herds should test all females 24 months of age and older and bulls in reproductive age (based on current epidemiological knowledge and the cost-effectiveness (MAPA, 2017). Since the PNCEBT requires at least 2 screening tests in a maximum period of 1 year, the requirement of the minimum age to perform the exams could be extended to 6 months without the risk of not testing all animals in the herd and also reducing the cost to farmers.

Confirmatory post-mortem tests, such as culture or molecular diagnosis, are not recommended by the PNCEBT rules (MAPA, 2017). In inner cities and less developed regions, slaughter is usually not under government inspection. As such, surveillance by slaughter inspection may have little impact in BTB eradication in Brazil. However, based on the USA (USDA, 2016) and Australia's (Radunz, 2006) experience and considering the BTB prevalence and existent infrastructure in certain states, confirmatory post-mortem tests (such as culture or molecular diagnosis) should be considered. Regular sampling of lesions considered typical of TB, in the slaughterhouses under official inspection and laboratory diagnosis, will provide a foundation for evidence based advocacy to strengthen the program.

A risk-based surveillance plan was adopted in BTEC (AAHC, 2003) and the USA program (USDA/APHIS, 2015) which should be considered by PNCEBT. Australia, as a free country, relies in surveillance at slaughterhouses and targeted herd testing to detect possible outbreaks. In the USA, slaughter inspection is the foundation of adult cattle and bison in national TB surveillance, and each slaughter establishment should submit suspicious granulomatous lesion(s) from at least one animal in every 2000 adult cattle or bison slaughtered at the facility for laboratory evaluation for TB. In addition to the interstate movement testing, requirements of other measures of surveillance should be adopted in the PNCEBT, such as: the slaughterhouse inspection and sampling, change of ownership testing, and annual herd testing.

The successful herd accreditation process in the USA and Australia was not achieved by the PNCEBT, this failure might be attributed to the lack of appeal for the farmers, logistical difficulties, and also by the prior requirement of at least three negative tests in one year for the herd. The new rules of certification requiring only 2 whole-herd tests in an interval from 6 to 12 months and delegating the supervision of the process to state authorities (MAPA, 2017), makes the process more feasible, but still lacks the appeal for farmers to comply. The authors would suggest the offer of an accreditation program with a package of

obligations and benefits as the BTEC model.

The risk-based strategy that allowed tailored actions according to state or zone classification was a fundamental tool for eradication of BTB in Australia and the USA (AAHC, 2003;USDA a; United States, 2017). The Brazilian decision to adopt that strategy represents significant progress at PNCEBT, and if the risk classification would allow the adoption of zone and state ranking instead of only state classification, it would be even better. In Brazil, considering the variety of ecosystems and the disparities in development between regions, the risk ranking by geographic criteria seems reasonable and should be acceptable in this program as it was adopted in the successful program for the eradication of the Foot and Mouth Disease. A recommended feature for the PNCEBT is the establishment of the Designated Tuberculosis Epidemiologist (DTE) positions, allowing more agility in epidemiology-based decisions tailored by the state or region keeping the compliance with program's principles.

5. Conclusions/recommendations

Due to the challenges facing the BTB eradication in Brazil and considering the particularities in the Brazilian structure and legislation of the animal health services, we would suggest to consider the following recommendations to improve the PNCEBT.

- Take advantage of the momentum
  - o Brazil should take advantage of the receptivity to livestock disease eradication efforts resulting from the successful Foot and Mouth Disease eradication campaign, and enforce the actions toward the BTB eradication.
- Leverage commitment
  - o Measures to get stockholder engagement should be stimulated, in particular those dedicated to farmers, veterinarians and industry, such as:
    - Farmers
      - Financial compensation (indemnity and subsidies)
      - Technical support
    - Veterinarians
      - Amplify the offer of training
      - Funding for testing in designed areas
      - Monitoring of the results
    - Industry
      - Assessment of the cost-benefits of BTB eradication for industry
      - Evidence based advocacy
- Use of epidemiological tools
  - o Assessment of risk by geographic zoning
  - o Assessing local and regional burdens and the cost-benefit and cost-effectiveness of intervention strategies
  - o Designated Tuberculosis Epidemiologists
  - o Surveillance
  - o Traceability system

We acknowledge that perhaps these recommendations are not the only way forward in Brazil, but hope that they will serve as catalysts for the authorities to bring about realistic and sustainable changes that are overdue.

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