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LA BIOSÉCURITÉ DANS LES ÉLEVAGES BOVINS BELGES : FORCES, FAIBLESSES, FACTEURS DÉTERMINANTS ET IMPACTS

BIOSECURITY IN BELGIAN CATTLE FARMS: STRENGTHS, WEAKNESSES, DETERMINING FACTORS AND IMPACTS

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"*The important thing is to never stop questioning [or learning].*" – Albert Einstein

"*Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less.*" – Marie Curie

Acknowledgments

Like most veterinarians, I have been confronted my whole carrer as a private veterinarian and rural development project coordinator with the reluctance of animal owners to support cost-effective preventive treatments such as vaccines and deworming. I have always wondered what arguments could be used to convince them to engage into preventive measures and behaviours. While stationed in Mauritania during the Ebola crisis in West Africa, I realised that the lack of awareness or the cost were not necessarily the main reasons. Indeed, hand hygiene, which is promoted as the key element of prevention, was not implemented by the humanitarian staff despite the obvious fear of the disease, the high risk and the availability of hand sanitizers at the entrances of all offices.

Understanding the determining factors of health behaviours and identifiying the best ways to promote preventive measures became a personal questioning and I was therefore thankfull to be given the opportunity to perform research on this topic.

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Acronyms

ANSES	French Agency for Food, Environmental and Occupational Health & Safety
ARSIA	Regional Association for Animal Health and Identification
ARSIA	Association Régionale de Santé et d'Identification Animale
AU-IBAR	African Union – Interafrican Bureau for Animal Ressources
BRD	Bovine respiratory diseases
BRSV	Bovine respiratory syncytial virus
BRU	Brucellosis
BS	Biosecurity
BSM	Biosecurity measure
BVD	Bovine Viral Diarrhoea
CBPP	Contagious Bovine Pleuropneumonia
CCPP	Contagious Caprine Pleuropneumonia
CFA	Confirmatory Factor analysis
DEFRA	Department for environment food rural affairs
DGZ	Dierengezondheidszorg Vlaanderen
DNA	Deoxyribonucleic Acid
ECDC	European Centre for Disease Prevention and Control
ECHO	Directorate-General for European Civil Protection and Humanitarian Aid Operations
EFA	Exploratory factor analysis
FAO	Food and Agriculture Organization
FASFC	Federal Agency for the Safety of the Food Chain
FFBO	Food and Feed Business Operators
FMD	Foot and mouth disease
FMV	Faculty of Veterinary Medicine
FPS	Federal Public Service
GMOs	Genetically modified organisms
GGMs	Genetically modified Microorganisms
HACCP	Hazard Analysis - Critical Control Point
HBM	Health Belief Model
IBR	Infectious bovine rhinotracheitis
LMO	Living Modified Organism
NGO	Non governmental organization
OH	One Health
OIE	World Organization for Animal Health
PPEs	Personal Protective Equipments
QFL	Milk quality control
RVP	Rural veterinary practitioners
SEM	Structural equation model
TBP	Theory of Planned Behaviour
TTM	Transtheoretical Model of Behaviour Change
UPV	Professional Union of Veterinarians
US	United States of America
WHO	World Health Organization
YCD	Young calf diarrhoea

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Summary

Background: According to WHO-FAO, biosecurity is "a strategic and integrated approach that encompasses the policy and regulatory frameworks (including instruments and activities) that analyse and manage risks in the sectors of food safety, public health, animal life and health, and plant life and health, including associated environmental risk". Biosecurity is a key element of the European Union Animal Health Strategy since 2007 and is part of the recent European law on animal health in application since April 2021. Biosecurity serves the purpose of the International Health Regulation adopted in 2005 by the World Health Organization which is "to prevent, protect against, control and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks, and which avoid unnecessary interference with international traffic and trade". Biosecurity includes all measures preventing the introduction and/or spread of pathogens. As part of the One Health concept, biosecurity is particularly important as it includes the prevention of the spread to humans, to animals, to plants and to the environment. It is therefore a holistic and integrated approach, which considers also the interactions between different stakeholders and sectors. To increase the farmers' resilience towards infectious diseases and answer the major public health challenges regarding zoonoses and antimicrobial resistance, it is important to improve the biosecurity levels in cattle farms based on cattle holders' needs and priorities.

Methodology: The study is divided into five parts. The first section aimed at identifying **the most important animal and public health** issues to be addressed in Belgium **and related biosecurity measures (BSM).** In order to consider different perspectives this first study was done by triangulating the information from a literature review of previous prioritization exercises, the Belgian laboratory databases and a veterinary survey. The second part consisted in assessing the **actual level of BSM implementation in Belgian cattle farms** and in a better understanding of the different constraints and experiences of cattle farmers towards BSM (Study 2). This was performed by 100 face-to-face interviews and visits in dairy and beef farms in Belgium. Another on-line study was then developed in order to **better understand the factors determining the adoption of BSM** by cattle holders (Study 3). For the third part, a methodology based on herd monitoring allowed analysing the cost-benefit ratio of a vaccination campaign in goats (Study 4); it was applied to the cattle sector by assessing an eventually correlating the level of BSM implementation (extracted from the study 2), herd mortality and reproduction parameters obtained from the regional animal health and identification associations. The aim of both studies was t**o assess the possible economic benefits of BSM**. At last, two on-line surveys were developed to determine the **attitude and behaviours of rural veterinarians towards biosecurity**, as actors and possible guidance counsellors (Study 6), and as a professionals at risk of contracting zoonoses (Study 7).

Results: Six diseases of interest were identified from the first study, based on previous prioritization exercises, rural veterinarians' and laboratory databases. These six diseases gather all the possible transmission pathways of infectious diseases and can therefore not discriminate the most important BSM to be prioritized. Nevertheless, it allows the national authorities to identify the diseases of importance from the cattle farmers' point of view, and to be targeted in their communication towards biosecurity in order to address these priority diseases in the Belgian context. Studies 2 and 3 showed an overall low implementation level of biosecurity in Belgian cattle farms and highlighted a correlation between the perceived importance of BSM and their implementation; it also listed the perceived lack of efficiency, feasibility and utility as the main reasons for their non-implementation. These findings were confirmed by the third study, which identified the perceived benefits of BSM as one of the main determining factors of implementation, as well as health motivation of cattle farmers. Both constructs seem to be correlated to the biosecurity knowledge and can therefore be influenced through continuous training and awareness-raising activities. It also demonstrates the urgent need of evidence-based studies to demonstrate the cost-efficiency of BSM. Such efficiency was illustrated by study 5: a negative correlation was found between the level of biosecurity in a farm and mortality rates. This methodology could be used to promote biosecurity and demonstrate its economic benefits. Studies 6 and 7 highlighted the risk for rural veterinarians to be responsible of a disease spread between farms and to contract an infectious zoonotic disease due to the low implementation of some key BSM. It also confirmed that, as in previous studies, rural veterinarians, are not yet fulfilling completely their role and responsibilities as biosecurity advisers; they should be empowered as key biosecurity informants.

Conclusion: Biosecurity level in cattle farming remains low and faces multiple challenges. In order to improve it, it is necessary for the different stakeholders to agree on shared goals and objectives taking into consideration the animal, public and environmental health as well as the socio-cultural factors and the sector economical context. In order to do so, they will require further studies in terms of BSM cost-efficiency in order to identify the most important and convince the stakeholders of their utility and benefits despite the eventual constraints. Appropriate communication channels should be used with rural veterinarians, as they appear to be the most trustful informants to provide technical guidance to cattle farmers. In order to do so and to effectively shift their role from curative to preventive medicine, they need a proper guidance from the authorities, a proper biosecurity training and communication, as well as an enabling environment.

Résumé

Introduction : La biosécurité est « une approche stratégique et intégrée de l'analyse et de la gestion des risques pesant sur la vie et la santé des personnes, des animaux et des plantes et des risques associés pour l'environnement ». Elle représente un élément clé de la stratégie de l'Union Européenne pour la santé animale de 2007 et de la récente loi européenne sur la santé animale qui a pris effet en avril 2021. La biosécurité permet de servir l'objectif de la législation sanitaire internationale adoptée en 2005 par l'Organisation Mondiale de la Santé visant à « prévenir la propagation internationale des maladies, à s'en protéger, à la maîtriser et à y réagir par une action de santé publique proportionnée et limitée aux risques qu'elle présente pour la santé publique, en évitant de créer des entraves inutiles au trafic et au commerce internationaux ». Elle inclut les mesures prévenant l'introduction d'agents pathogènes et/ou permettant de limiter leur diffusion. Dans le cadre du concept « une seule santé », la biosécurité est particulièrement importante car elle inclut la prévention de la dispersion des agents pathogènes vers les hommes, les animaux, les plantes et l'environnement. Il s'agit d'une approche holistique et intégrée prenant en considération les interactions entre les différents acteurs et secteurs. En vue d'améliorer la résilience des éleveurs bovins vis-à-vis des maladies infectieuses et de répondre aux risques majeurs de santé publique liés aux zoonoses et la résistance antimicrobienne, il est important d'améliorer le niveau de biosécurité dans les élevages bovins en se basant sur les besoins et priorités des éleveurs.

Méthodologie : L'étude peut être divisée en cinq parties. La première partie a pour objectif **l'identification des risques sanitaires les plus importants pour la santé animale et humaine** en Belgique **ainsi que les mesures de biosécurité (BSM) permettant de les limiter**. Cette étude a été réalisée en triangulant les informations issues d'une revue de littérature sur les exercices de priorisation des maladies infectieuses, des données des laboratoires de référence en Belgique et d'un sondage auprès des vétérinaires afin de prendre en compte différentes perspectives. La deuxième partie consistait à évaluer le **niveau actuel de mise en œuvre des BSM dans les élevages bovins en Belgique** et de mieux comprendre les différentes contraintes et expériences des éleveurs vis-à-vis des BSM (Etude 2). Ceci a été réalisé à travers 100 entretiens individuels et visites de terrain dans des fermes laitières et viandeuses en Belgique. Une seconde enquête en ligne a ensuite été réalisée afin de **mieux comprendre les facteurs déterminant l'adoption des BSM par les éleveurs** (Etude 3). Une méthodologie basée sur un suivi longitudinal des troupeaux a été utilisée en vue d'analyser le ratio coût/bénéfice d'une campagne de vaccination des chèvres (Etude 4). Elle a ensuite été appliquée au secteur de l'élevage bovin afin d'identifier une éventuelle corrélation entre le niveau de biosécurité d'un élevage (données de l'étude 2) et les taux de mortalité et de reproduction de ce dernier. L'objectif de ces deux études était de **déterminer les bénéfices économiques possibles des BSM**. Finalement, deux questionnaires en ligne ont servi à **déterminer l'attitude et les comportements des vétérinaires ruraux en ce qui concerne la biosécurité** et ce, en tant qu'acteurs et conseillers techniques en la matière (Etude 6) et en tant que professionnels à risque de contracter une zoonose (Etude 7).

Résultats : Six maladies infectieuses identifiées comme importantes du point de vue des exercices de priorisation antérieurs, des vétérinaires ruraux et des données de laboratoire. Ces six pathologies regroupent tous les modes de transmission possibles des maladies infectieuses et ne permettent donc pas de discriminer les mesures de biosécurité prioritaires. Néanmoins, cela permet d'identifier les maladies les plus importantes aux yeux des éleveurs bovins et de les utiliser dans le cadre de la communication concernant la biosécurité en vue de cibler les priorités des éleveurs dans le contexte belge. Les études 2 et 3 ont mis en évidence un faible niveau de mise en œuvre de la biosécurité (BS) dans les élevages bovins belges ainsi qu'une corrélation entre l'importance perçue d'une BSM et sa mise en œuvre. Les raisons les plus fréquemment exprimées pour justifier la non mise en œuvre d'une BSM sont : une faible perception de l'efficience, la faisabilité et l'utilité de la BSM. Les facteurs déterminants principaux de la mise en œuvre des BSM identifiés étant la perception des bénéfices d'une BSM et le sens de responsabilité des éleveurs vis-à-vis de la santé. Ces deux constructions mentales semblent être corrélées avec le niveau de connaissance en matière de BS et peuvent donc être influencées par des formations continues et des activités de sensibilisation. Des études factuelles démontrant le rapport coût/efficacité positif des BSM sont nécessaires. Cette efficience a été illustrée par l'étude 5 à travers la mise en évidence d'une corrélation négative entre le niveau de BS au sein d'un élevage et son taux de mortalité. Cette méthodologie pourrait être utilisée pour promouvoir la BS et démontrer ses bénéfices économiques. Les études 6 et 7 ont mis en évidence le faible niveau de mise en œuvre de certaines BSM importantes par les vétérinaires ruraux, ce qui les expose au risque d'être responsables de la dissémination d'agents pathogènes entre les élevages et de contracter une maladie zoonotique. Elles ont également montré que, comme d'autres études existantes, les vétérinaires ruraux n'assument pas pleinement leurs rôles et responsabilités de guidance technique en matière de biosécurité et devraient être mieux responsabilisés en tant que source d'information principale en matière de BS.

Conclusion : Le niveau de BS dans les élevages bovins reste faible et représente de nombreux défis. Afin de l'améliorer, il est nécessaire que les différents acteurs identifient des buts et objectifs communs prenant en compte la santé animale, publique et environnementale ainsi que les facteurs socio-culturels et le contexte économique du secteur. Pour ce faire, des études portant sur le rapport coût/efficacité des BSM sont nécessaires afin d'identifier les BSM prioritaires et de convaincre les différents acteurs de leur utilité et bénéfices en dépit des éventuelles contraintes induites par ces BSM. Une voie de communication efficiente doit être utilisée et, dans ce cadre, les éleveurs considèrent les vétérinaires comme la source d'information la plus fiable pour leur fournir des conseils techniques. Pour pouvoir jouer ce rôle efficacement, les vétérinaires ruraux doivent pouvoir accorder une importance croissante à la médecine préventive et bénéficier de conseils et recommandations clairs de la part des autorités, d'une formation adéquate en BS et en communication ainsi que d'un contexte d'intervention favorable.

Resumen

Antecedentes: La bioseguridad es "Un enfoque integrado y estratégico que engloba los marcos regulatorio y político (incluyendo herramientas y actividades) para analizar y gestionar los riesgos relativos a la inocuidad de los alimentos, la salud pública y la vida y la sanidad de los animales y las plantas, incluyendo también los riesgos medioambientales asociados". La bioseguridad es un elemento clave de la estratégia sanitaria de la Unión Europea desde 2007 y de la reciente Ley Europea de Sanidad Animal que ha entrado en vigor en abril de 2021. Sirve el objectivo del Reglamento Sanitario Internacional adoptado en 2005 por la Organización Mundial de Sanidad (OMS) para «prevenir la propagación internacional de enfermedades, proteger contra esa propagación, controlarla y darle una respuesta de salud pública proporcionada y restringida a los riesgos para la salud pú-blica y evitando al mismo tiempo las interferencias innecesarias con el tráfico y el comercio internacionales». La bioseguridad incluye todas las medidas para prevenir la introducción de patógenos y/o reducir su diseminación. Bajo concepto Una Salud, la bioseguridad es particularmente importante ya que incluye prevenir la diseminación a los humanos, a los animales, a los vegetales y al medioambiente. Es un enfoque integral e integrado, que también considera las interacciones entre los diferentes sectores interesados. Para aumentar la resiliencia de los ganaderos a las enfermedades infecciosas y dar respuesta a los grandes retos de salud pública relacionados con las zoonosis y la resistencia antimicrobiana, es importante mejorar los niveles de bioseguridad de las granjas de bovino en base a las necesidades y prioridades de los ganaderos de bovino.

Material y métodos: El estudio se puede dividir en cuatro partes. La primera sección tiene como objetivo la identificación de los **problemas más importantes de sanidad animal** y **de salud pública** a considerar en Bélgica **y las medidas de bioseguridad (BSM) relacionadas**. Este primer estudio se ha realizado triangulando las informaciones de una revisión bibliográfica sobre ejercicios de priorización, de las bases de datos de los laboratorios belgas y de una encuesta a veterinarios para tener en cuenta diferentes perspectivas. La segunda parte consiste en **valorar el nivel actual de aplicación de las BSM en las granjas de bovino de Bélgica** (estudio 2), en ella se realizaron 100 entrevistas personales en visitas a granjas de bovino lechero y de carne. También se realizó un estudio en línea **para conocer mejor los factores que determinan la adopción de medidas de bioseguridad** aplicadas por los ganaderos de vacuno (estudio 3). Para la tercera sección, se ha partido de una metodología para valorar la razón coste-beneficio de una campaña de vacunación en cabras basada en la monitorización del rebaño (estudio 4) y se ha aplicado al sector bovino para evaluar una eventual correlación entre el nivel de aplicación de las BSM (obtenidas en el estudio 2) y la mortalidad y parámetros reproductivos obtenidos de las asociaciones regionales de identificación y sanidad animal. El objetivo de estos dos estudios era evaluar **el posible beneficio económico de las medidas de bioseguridad.** Finalmente, se llevaron a cabo dos encuestas en línea para determinar la **actitud y el comportamiento** de los

veterinarios rurales en relación a la bioseguridad, como actor y como posible asesor (estudio 6) y como profesional a riesgo de contraer zoonosis (estudio 7).

Resultados: En el primer estudio se identificó una lista de 6 enfermedades de interés obtenidas a partir de ejercicios previos de priorización, de los veterinarios rurales y de las bases de datos de laboratorios. Estas seis enfermedades incluyen todos los posibles métodos de transmisión de las enfermedades infecciosas y por tanto no discriminan las BSM a priorizar. Ello debe permitir a las autoridades nacionales identificar las enfermedades de importancia para los granjeros de bovino y tenerlo en cuenta en sus comunicaciones respecto a la bioseguridad, con la finalidad de dirigirlas a las enfermedades prioritarias para los granjeros en el contexto de Bélgica. Los estudios 2 y 3 muestran el poco nivel de aplicación de la bioseguridad en las granjas de bovino de Bélgica y permiten observar una correlación entre la importancia que atribuyen a las BSM y su aplicación, mostrando que si no se aplican se debe principalmente a la percepción de su falta de efectividad, aplicabilidad y utilidad. Estos resultados se han confirmado con el tercer estudio, que identifica los beneficios que se perciben de las BSM como uno de los factores determinantes de su aplicación, así como de la motivación hacia la sanidad por parte de los ganaderos de bovino. Ambos resultados parecen estar correlacionados con el conocimiento sobre la bioseguridad y por tanto pueden ser modificados mediante la formación continuada y actividades para aumentar el conocimiento. También demuestra la necesidad urgente de estudios basados en la evidencia para demostrar el coste-eficiencia de las BSM. Esta eficiencia se ha ilustrado en el estudio 5 en el que se ha encontrado una correlación negativa entre el nivel de bioseguridad (BS) en la granja y la mortalidad. Esta metodología podría ser utilizada para promover la BS y demostrar su beneficio económico. Los estudios 6 y 7 muestran el riesgo para los veterinarios rurales de ser los responsables de la diseminación de enfermedades entre granjas y de contraer enfermedades infecciosas zoonóticas, debido a la poca aplicación de algunas BSM claves. También que, como en estudios previos, los veterinarios rurales no están aplicando plenamente su papel y su responsabilidad como asesores de bioseguridad y deberían empoderarse como consultores clave sobre la bioseguridad.

Conclusión: El nivel de bioseguridad en las granjas de bovino sigue siendo bajo y se enfrenta a múltiples retos. Para mejorarlo, es necesario que los diferentes actores estén de acuerdo en compartir objetivos teniendo en consideración la salud animal, la salud pública y la del medioambiente, así como los factores socio-culturales y el contexto económico del sector. Para ello, se requerirán nuevos estudios en términos de coste-eficiencia de las medidas de bioseguridad para identificar las BSM más importantes a recomendar y convencer a los implicados de su utilidad y benefició, a pesar de las eventuales limitaciones. Se deben usar los canales de comunicación apropiados, en los que los veterinarios rurales deben aparecer como los divulgadores que disfrutan de mayor confianza para orientar a los ganaderos de bovino. Para ello y para cambiar de manera efectiva su papel de curar animales a la medicina preventiva, necesitan una orientación clara de las autoridades, una formación correcta en términos de bioseguridad y comunicación, así como un contexto propicio.

General preamble

"Prevention is better than cure", this quote attributed to Desiderius Erasmus in around 1500 A.D. certainly applies to both human and animal health. Over the years, infectious diseases have caused a huge impact on both animal and public health. Due to the progress in sciences, in particular in epidemiology, many measures to prevent and control these diseases have been identified and promoted. Biosecurity has been defined by the World Health Organisation (WHO) as "a strategic and integrated approach to analysing and managing relevant risks to human, animal and plant life and health and associated risks for the environment" (Infosan, 2010). It is a key element of the European Union Animal Health Strategy (European Comission, 2007). As part of the One Health approach, strengthening biosecurity in the different animal production systems is also important to preserve the public and environmental health.

The proper implementation of biosecurity in an animal production system has been strengthened over the years, especially in more intensive production systems such as pig and poultry industries. Nevertheless, based on several studies, it appears that the level of implementation of biosecurity measures (BSM) in cattle farms remains low. Several studies have listed the BSM to be implemented in the different farming systems in order to reduce the incidence of infectious diseases but different constraints prevent their adoption.

To increase the farmers' resilience towards infectious diseases and answer the major public health challenges regarding zoonoses and antimicrobial resistance, it is important to clearly identify the priority BSM to be implemented. The first step consists in assessing their actual level of implementation then identifying the constraints as well as the determining factors of behaviour changes to be addressed in order to increase the level of BSM adoption by cattle farmers.

As a first step, the prioritisation of cattle diseases was performed in order to identify the main diseases affecting cattle farm in Belgium and the related BSM to be considered as a priority.

The second phase of the PhD consisted in evaluating the BSM implementation level in the different types of cattle farms. A participative approach was implemented in order to gather the farmers' opinion on the efficiency and level of constraints of BSM. The aim of this study was (i) to determine the gap for improvement, (ii) develop a scoring system in order to rank and compare cattle farmers based on the level of BSM implementation, (iii) identify the barriers preventing the adoption of BSM and (iv) assess the farmers' resilience towards infectious disease outbreaks.

The third part consisted in two pilot studies on the cost-effectiveness of BSM. A methodology to assess the cost-effectiveness of a vaccination program by a stochastic model fed by herd monitoring was developed for the goat keepers in Africa and could easily be used in the Belgian context for other disease-specific BSM. A second study assessed if a higher level of biosecurity in a cattle farm was correlated to higher production rates and/or lower mortality rates that could then be converted into economic benefits.

The fourth component of the PhD consisted in studying the factors determining the adoption of BSM by the cattle farmers as well as by the rural veterinarians. Rural veterinarians were targeted as the main actors of biosecurity in the cattle farms as either technical advisers, guidance counsellors or possible vectors of infectious diseases. As rural veterinarians are also a population at risk for contracting zoonoses, complementary studies on their perceptions and attitudes regarding such diseases were also implemented.

This PhD provides an overview of the actual level of biosecurity observed in Belgian cattle farms and the possibilities of improvements considering the main infectious diseases to be targeted, the challenges and the possible benefits. The results can also improve the adoption rate of BSM by adapting the communication messages and support tools based on main factors determining behaviours. It is therefore useful for any cattle farmer and guidance veterinarian as well as for the animal and public health authorities.

Chap. 1 - Introduction

1. Biosecurity: history and principles

1.1 From curative to preventive medicine

If the first practitioners in both medical and animal health were mainly asked to treat diseases, the necessity and benefits of preventing them is not a modern concept, as mentioned by Daniel M. Becker (Becker, 1988) and George Rosen (Rosen, 1975).

Preventive medicine of infectious diseases implies a proper knowledge of their aetiology and epidemiology. Several examples of measures to prevent infectious diseases can be found as early as in 2000 B.C. (Becker, 1988), long before the discovery of microorganisms such as molds and bacteria in 1676 (Porter, 1976). In several religions, the sacred texts such as the Old Testament and the Coran mentions hygienic and nutritional measures to protect from food-borne and infectious diseases. Over time, based on observations, trials and errors, different protective measures against infectious diseases were identified and proven to be effective. We could mention, as key examples, the preventive measures developed in the 14th century in Italy and southern France against the plague (e.g.: sanitary cordon, observation and isolation facilities and disinfection procedures) (Rosen, 1975), the variolation practice reported as early as in 1670 (Riedel, 2005).

The 19th century saw the onset of epidemiology with the studies of John Snow during the cholera outbreak in London in 1845, identifying contaminated water as the source of the disease and the measures to be taken in order to control it (Tulchinsky, 2018), as well as the development of the first vaccines. The discovery of antibiotics in the 20th century allowed a major step towards the control and eradication of some major infectious diseases. Since then, the era of modern medicine led to major improvements and epidemiological knowledge was developed. The incidence of infectious diseases was largely reduced and several diseases have been regionally eradicated. In the 1960s, the medical and public health professionals were convinced that "infectious diseases were gradually going to disappear under the combined influence of hygiene, antibiotics, and vaccines"(Echaubard, Rudge and Lefevre, 2018). The development of the biomedical sciences in the 20th and 21st century led to major successes in terms of disease control and prevention such as the eradication of small pox and of rinderpest, as well as the regional eradication and control of many infectious diseases. Nevertheless, the last decades showed the (re)emergence of infectious diseases with 60% of them being zoonotic and 75% of new humans pathogens originating from animals (Jones *et al.*, 2008). The development of antibioresistant microorganisms is also a new and recent challenge representing a major setback in the fight against infectious diseases.

Several factors such as globalization, the new technologies of agricultural productions and food processing, the increased international movements of goods, animals and persons increase the risks of (re)emergence and spread of infectious diseases. Therefore, preventive medicine remains a key element for both public and animal health, and should include new and innovative measures and strategies.

1.2 Biosecurity: origin, concept and definition

The biosecurity concept is relatively new as its first citation in Pubmed was recorded in 1987. Its general uptake increased slowly with an average of 5 publications including the term "Biosecurity" per year in the 1990s, 127 from 2000 to 2010 and 680 from 2011 to 2020 (**Fig. 1**) (Pubmed, no date).

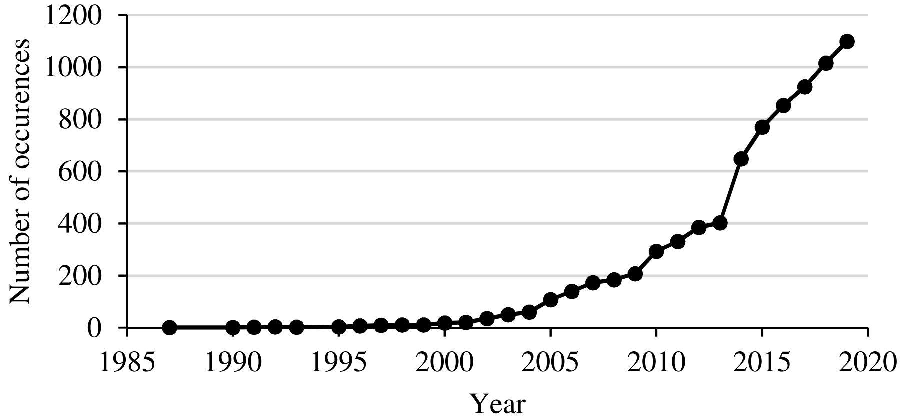

Figure 1 – Evolution of the number of occurrences of the term « Biosecurity" in Pubmed

Although frequently referred to in scientific literature with a similar meaning (Peng, Bilal and Iqbal, 2018), biosecurity is different from biosafety. Biosafety is complementary to biosecurity and refers to "the implementation of laboratory practices and procedures, specific construction features of laboratory facilities, safety equipment, and appropriate occupational health programs when working with potentially infectious microorganisms and other biological hazards"(Bakanidze, Imnadze and Perkins, 2010). It is defined in Belgium as "the safety for human health and the environment, including the protection of biodiversity, during the use of genetically modified organisms (GMOs) or micro-organisms (GMMs), and during the contained use of pathogenic organisms for humans" (https://www.biosafety.be/content/belgian-regulatory-framework-biosafety).

Before its use in animal health and production system, "Biosecurity" was mainly used in defense regarding the control of bioweapons. Biosecurity is still defined on the Belgian biosafety server as dealing with "the prevention of misuse through loss, theft, diversion or intentional release of pathogens, toxins and any other biological materials (https://www.biosafety.be/content/biosecurity). The term biosecurity was then largely used by the agricultural sector and defined by the US association of State Departments of Agriculture as "the vital work of strategy, efforts and planning to protect human, animal and environmental health against biological threats". The primary goal of biosecurity is to protect against the risk posed by diseases and organisms; the primary tools of biosecurity are exclusion, eradication and control, supported by expert system management, practical protocols, and the rapid and efficient securing and sharing of vital information. Biosecurity is therefore the sum of risk management practices in the defence against biological threats" (NASDA, 2001). Since then, the concept of biosecurity has been adopted by several countries and integrated in strategic documents of different sectors. In the animal health and production sector , biosecurity is commonly defined as " a set of management and physical measures designed to reduce the risk of introduction, establishment and spread of animal diseases, infections or infestations to, from and within and animal population" (https://www.oie.int/fileadmin/Home/eng/Health_standards/tahc/2018/en_glossaire.htm). It is referred to in the Animal Health Law (Regulation (EU) 2016/429) where biosecurity is defined as "the sum of management and physical measures designed to reduce the risk of the introduction, development and spread of diseases to, from and within: (a) an animal population, or (b) an establishment, zone, compartment, means of transport or any other facilities, premises or location". Different definitions of the term biosecurity therefore co-exist with an attempt to propose a unified definition as "the strategies to assess and manage the risk of infectious diseases, quarantine pests, invasive alien species, living modified organisms, and biological weapons" (Meyerson, 2002). For the Food and Agricultural Organization (FAO) and the World Health Organization (WHO), biosecurity is a strategic and integrated approach that encompasses the policy and regulatory frameworks (including instruments and activities) that analyse and manage risks in the sectors of food safety, public health, animal life and health, and plant life and health, including associated environmental risk" (Infosan, 2010). Since 2007, biosecurity has been included as a key element of the European Union Animal Health Strategy (European Comission, 2007). Biosecurity is also included in the country preparedness plan of the European Centre for Disease Prevention and Control (ECDC) (Tsolova, 2013) and serving the objective of the International Health Regulation adopted in 2005 (WHO, 2005).

Biosecurity includes all measures preventing the introduction of pathogens (bio-exclusion) and/or reducing the spread of pathogens (bio-containment) (Mai, 2014). As part of the One Health concept, biosecurity is particularly important as it includes the prevention of the spread to humans, to animals, to plants and to the environment. It is therefore a holistic and integrated approach, which considers the interactions between different stakeholders and sectors, as presented in **Figure 2**. A proper biosecurity level therefore minimises the impact of infectious diseases on public, animal and plants health, on the economy, on the environment and on the society in general. The FAO and WHO definition of biosecurity which include these aspects seems therefore more appropriate and should be considered by the other actors and referenced as such in order to emphasize the importance of biosecurity, not only for animal health but also for public and environmental health.

The different kind of hazards targeted by biosecurity relate to different sectors such as the food safety, the human, animal and plant health with a special attention brought to the zoonoses, the biological weapons and the invasive alien species as defined in **Table 1**.

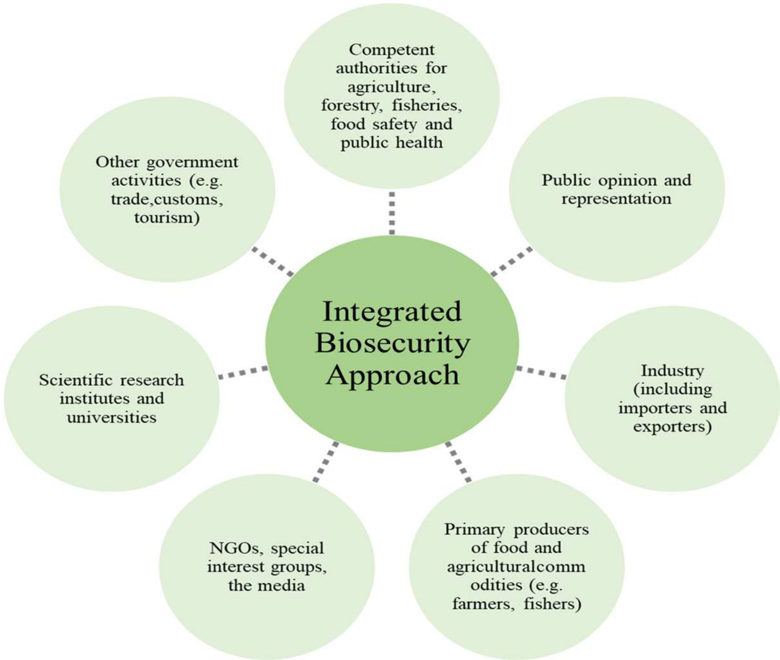

Figure 2 – Sector interests that are important to an integrated approach to biosecurity (Source: FAO, 2007b)

Table 1 – Definitions of the different type of hazards applicable to different biosecurity sectors (Adapted from FAO, 2007b)

Biosecurity sector	**Hazard definition**
Food safety	A biological, chemical or physical agent in, or condition of, food with the potential to cause an adverse health effect
Zoonoses	A biological agent that can be transmitted naturally between wild or domestic animals and humans
Animal health	Any pathogenic agent affecting animals that could produce adverse consequences on the animal, human or environmental health[1]
Plan health (or pest)	Any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products
Plant health Quarantine	A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled
"Biosafety" in relation to plants and animals	A living modified organism (LMO) that possesses a novel combination of genetic material obtained through the use of modern biotechnology that is likely to have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health (Cartagena Protocol on Biosafety).
"Biosafety" in relation with food	A recombinant DNA organism directly effecting or remaining in a food that could have an adverse effect on human health
Invasive alien species	An invasive alien species outside its natural past or present distribution whose introduction and/or spread threatens biodiversity

[1] Adapted definition, the FAO definition of animal health hazard was "Any pathogenic agent that could produce adverse consequences on the importation of a commodity"

1.3 Biosecurity in animal production systems

Biosecurity includes BSM that should be implemented by a large number of stakeholders (**Fig. 2**), in different sectors. Biosecurity in animal production systems includes the measures that can be implemented by the animal producers at the farm level in order to manage the risks of infectious diseases in their premises. It represents the basis of disease control programs towards endemic and exotic diseases. Based on the international and national animal health authorities, some BSM contributing to a disease eradication or control program are mandatory (e.g. in Belgium: winter screening in Belgium to detect potential shedders or carriers and tests at purchase for some diseases) while others should be implemented on a voluntary basis.

In animal productions systems, biosecurity is sometimes divided into two compartments (John F Mee *et al.*, 2012; Dewulf and Van Immerseel, 2018). External biosecurity or Bio-exclusion regrouping the BSM aimed at preventing the introduction of an infectious agent in a farm. Internal biosecurity or Bio-containment consists of the BSM aimed at preventing the spread of infectious agents within farm and to other farms.

Biosecurity in animal productions systems can also be divided into 5 stages or compartments in order to highlight its importance not only in terms of animal health but also its role in protecting public health and the environment (**Fig.3**) (Saegerman, Dal Pozzo and Humblet, 2012). These five compartments are:

1. Bio-exclusion: BSM preventing the introduction of a pathogen in a farm
2. Bio-compartmentation: BSM preventing the spread of a pathogen within the farm
3. Bio-containment: BSM preventing the spread of the pathogen to other farms or premises
4. Bio-prevention: BSM preventing the spread of zoonotic pathogens to humans
5. Bio-preservation: BSM preventing environmental contamination(s)

Biosecurity measures are regrouped into different categories and can be related to one or several biosecurity compartments. As an example, applying a quarantine for newly purchased animals will contribute to Bio-exclusion while a proper carcass disposal system will contribute to Bio-compartmentation, Bio-containment, Bio-prevention and Bio-preservation.

Figure 4 below, from Villarroel *et al.*, 2007, shows an example of a comprehensive flowchart for biosecurity in a large dairy farms. It illustrates the potential critical control points to consider and the complexity of disease control in such premises.

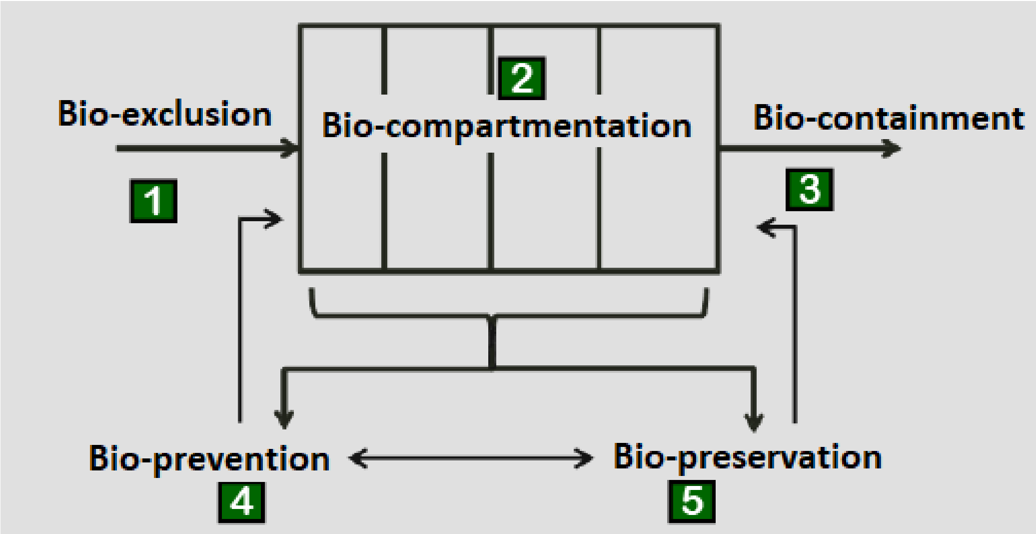

Figure 3 – Biosecurity principles and compartments in animal facilities (Source: Saegerman, Dal Pozzo and Humblet, 2012)

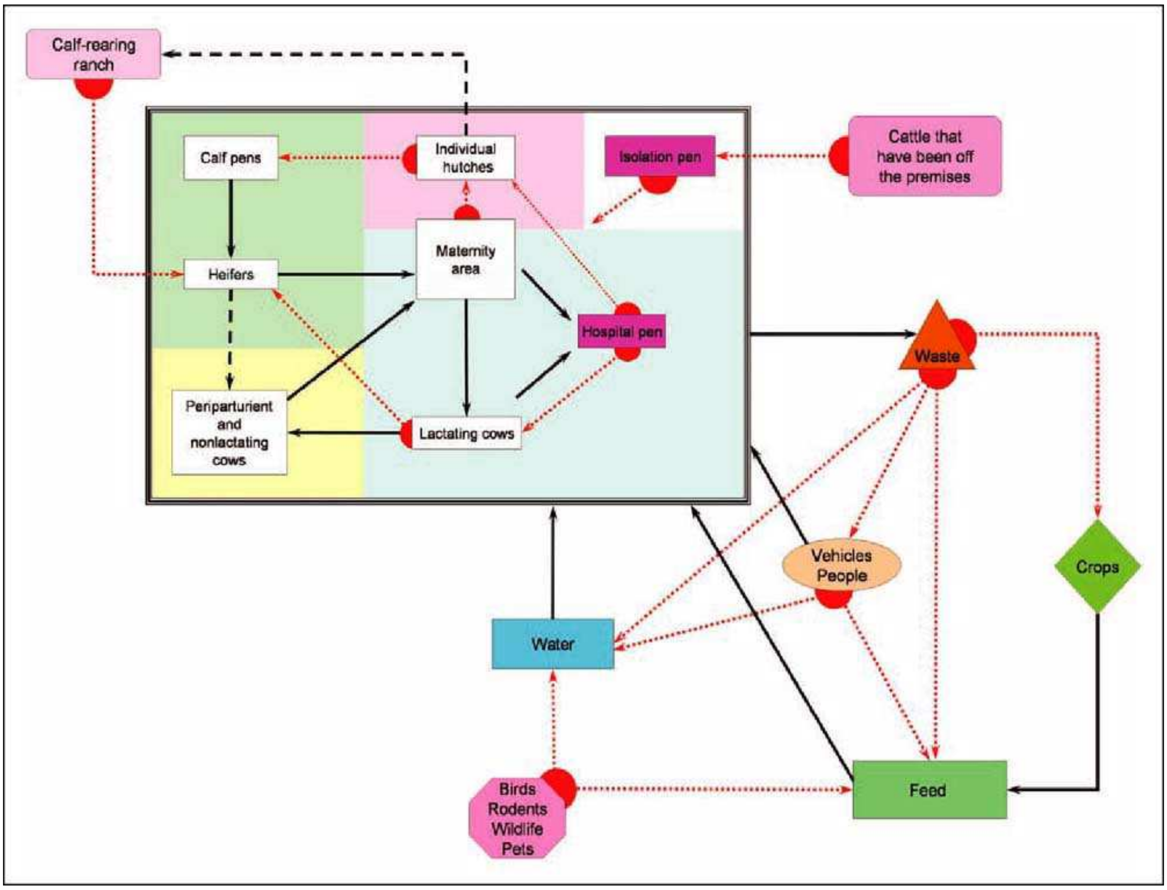

Figure 4 - Biosecurity on large dairy farms. Each arrow pointing toward the farm represents a biosecurity risk. Arrows inside the black box represent biocontainment risks. Black solid arrows represent the typical flow of cattle or products on most dairies, whereas black dashed arrows represent events that may apply only to some dairy farms. Semicircles with red dashed arrows represent hazard and control points for transmission of disease agents (Source: Villarroel et al., 2007)

2. Biosecurity measures in cattle farms

The BSM are identified based on the transmission pathways of infectious diseases and risk factors. Some BSM are disease-specific (e.g. vaccination protocols), but the majority of BSM are generic and contribute to reducing the risks related to several infectious diseases, either by preventing their introduction (e.g. applying a quarantine), blocking the transmission pathways (e.g. isolation of sick animals) or by reducing the overall infection pressure (e.g. general hygiene). An overview of the main transmission pathways of the most important cattle diseases are presented in **Appendix 1** (Sarrazin *et al.*, 2018). The main generic BSM are presented below based on the targeted transmission pathway.

2.1. Prevention of direct contact with pathogen shedders or carriers

Direct contact is considered as the main transmission pathway of pathogens for many infectious diseases (Van Winden, Stevens and McGowan, 2005; DairyCo, 2009; Brennan and Christley, 2012; John F. Mee *et al.*, 2012; Saegerman, Dal Pozzo and Humblet, 2012; Nöremark and Sternberg-Lewerin, 2014). It can be prevented through the implementation of different BSM.

- **Preventing the transmission of a pathogen agent through infected cattle**

The principal BSM consists in keeping a herd closed and avoiding any animal movements (Van Winden, Stevens and McGowan, 2005). This means no purchase of animals and no animal re-entry in the farm (e.g. after a show). If purchases cannot be avoided, their number and their sources should be minimised (French *et al.*, 1999; Bazeley, 2009). In case of purchases or re-entering animals, several BSM can mitigate the risk of introduction of an infectious disease (pre- and post-movement BSM). Testing the animals with highly sensitive tests and applying a proper quarantine (in a separate building, strictly compartmented) should ideally be performed before any animal movements (Davison *et al.*, 2003; Maunsell and Donovan, 2008). In addition, purchasing animals from farms free of infectious diseases, i.e. a farm with an equal or higher sanitary status and health management, or buying cattle which has not been previously bred can also minimise the risk of infectious disease introduction (Sanderson, Dargatz and Garry, 2000; Wells, 2000; Van Winden, Stevens and McGowan, 2005).

During the transportation, BSM should be taken in order to prevent any contamination by infected animals. The vehicle needs to be cleaned and disinfected before loading and animals from different sources should not be transported together (Maunsell and Donovan, 2008; Bazeley, 2009).

Upon arriving at destination, post-movement testing and quarantine can be applied in order to strengthen the biosecurity. Based on the incubation period of the diseases and the authors, the recommended duration of quarantine (pre- or post-movement) varies from 3 (Davison *et al.*, 2003) to 6 weeks (Caldow, 2009) with a commonly advised period of 4 weeks (Bazeley, 2009). For some diseases, a medical treatment can also be administered to animals upon arriving at the farm, in order to eliminate possible carriers (e.g. deworming, vaccinations and foot bathing) (Bazeley, 2009).

Within the farm, animals should be classified and compartmented based on their risks. As many diseases can be transmitted from older to younger animals (Table 2), it is highly recommended to house calves and adult animals in different buildings (Maunsell *et al.*, 2011). Separated areas are also recommended for sick animals and for the maternity and calving area (Maunsell and Donovan, 2008). The isolation pen for sick animals should never be used as a maternity pen and these areas should be properly cleaned and disinfected after use (Anderson, 2009).

Table 2 - Examples of diseases which can spread from older to younger cattle justifying a separate housing (Source: Anderson, 2009)

Disease	Main transmission pathway
Escherichia Coli diarrhoea	Contact with faeces
Salmonellosis	Contact with faeces
Leptospirosis	Contact with urine, uterine discharge and aborted foetus
Johne's disease	Contact with faeces
Enzootic bovine leucosis	Contact with blood from needles, dehorners, tattoo pliers
Bovine viral diarrhoea	Contact with body fluids from an infected animal
Gastrointestinal parasitism	Contact with eggs in faeces
Coccidiosis	Contact with oocysts in faeces

An all-in all-out system should be established and any contacts with animals from others farms should be avoided in pastures by installing double fences separated by at least 3 meters (Crawshaw *et al.*, 2002; Van Winden, Stevens and McGowan, 2005; John F Mee *et al.*, 2012).

Figure 5 – Double fencing to prevent direct contacts between animals from adjacent pastures (Source: www.nadis.org.uk)

Regarding breeding animals, bulls should not be shared and should be regularly tested. In case of artificial insemination or embryo transfers, the origin and status of semen and embryos should also be controlled and from a safe origin (Anderson, 2001; De Clercq *et al.*, 2021).

➢ **Prevention of pathogen introduction through other species**

Other species such as wildlife, including rodents and birds, and domestic carnivores can be carriers of pathogens and infect cattle (e.g. tuberculosis (Allen *et al.*, 2011; Lavelle *et al.*, 2016), foot and mouth disease (Brückner *et al.*, 2002) and BVD virus (Rodríguez-Prieto *et al.*, 2016; Milićević *et al.*, 2018)) transmission from wildlife to cattle). In order to prevent such risks, different BSM should be taken to prevent any contact such as closed housing areas for cattle (including screened openings to prevent entry of birds). Rodent control programs should also be implemented on a regular basis in animal holdings. Animal foodstuffs and waste could attract wildlife and should be stored safely (Anderson, 2001; John F Mee *et al.*, 2012).

Although not fully effective, double fences and/or electrical fences should be placed around the pastures to reduce the risk on contact with wildlife (John F Mee *et al.*, 2012).

Figure 6 - Risk of introduction of pathogens through contact with other species. Left: livestock and wildlife contact in pasture (*with the courtesy of Dr Serge Bellflamme, private vet practitioner,2013*) **and right, domestic cats and poultry in an individual veal box** (*with the courtesy of Dr Maud Dumont, private vet practitioner,2021*)

2.2. Prevention of indirect contaminations by fomites

Based on their resistance in the environment, pathogens can easily be transmitted through fomites. Some specific BSM are therefore needed in order to prevent the introduction and spread of infectious diseases through persons, and inanimate items such as vehicles, equipment, etc. (John F. Mee *et al.*, 2012; Robertson, 2020). The possibilities of indirect contacts among farms are multiple, as illustrated in the Figure 7 below (Brennan, Kemp and Christley, 2008).

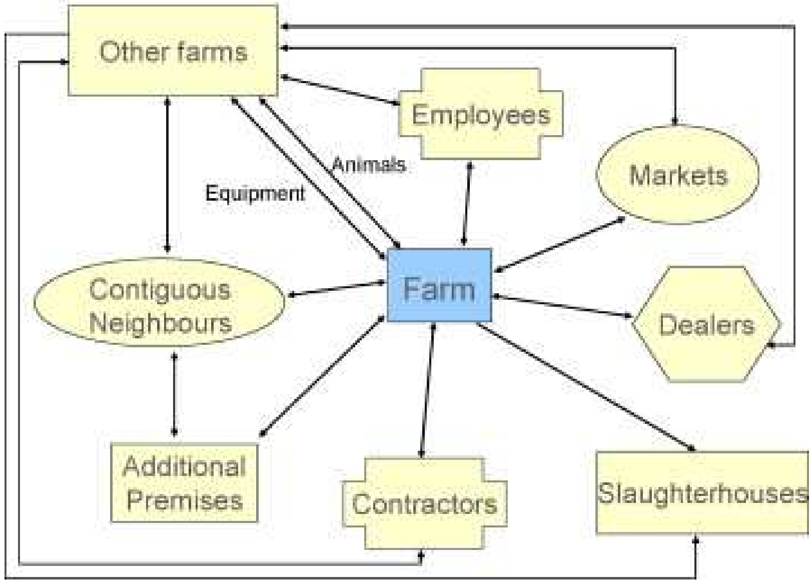

Figure 7 – Schematic representation of potential contact characteristics of cattle farms
(Source: Brennan, Kemp and Christley, 2008)

The access of vehicles and visitors to premises should be controlled, e.g. thanks to a perimeter fence and making appointments for visitors (Villarroel, David A Dargatz, *et al.*, 2007; Maunsell and Donovan, 2008; Anderson, 2009; John F Mee *et al.*, 2012). Any vehicle entering the premises should be cleaned and disinfected (at least the wheels) and clean paths (with prohibited access to vehicle) should be established. Based on the same principles, access of visitors to premises should be controlled. Some specific hygiene measures should be taken, especially for professional visitors, who represent a higher risk as they transit through different farms. Ideally, clean personal protective equipment (PPE) such as boots, coveralls and gloves, should be available for visitors. If not possible, they should wear cleaned and disinfected PPE and walk through a footbath before entering the premises (Tompkin *et al.*, 1999; Maunsell and Donovan, 2008; Moore *et al.*, 2008). Farm workers should not visit other cattle farms, to avoid the risk of introducing an infectious disease (Robertson, 2020). Sharing of materials and equipment between farms should be avoided. If shared, they should be properly cleaned and disinfected before being returned.

Within the farm, specific BSM are needed to prevent contamination through fomites between the different areas (e.g. isolation pen, maternity pen and calves stables) (Villarroel, Dargatz, *et al.*, 2007; Maunsell and Donovan, 2008; Anderson, 2009; John F Mee *et al.*, 2012). Specific equipment should be allocated to the different areas and the workers should always follow a strict hygiene procedure when going from an area to another (hand washing, boot cleaning, walking through a footbath and changing clothes). In addition, the workflow should be organised in order to go from the less contaminated to the most contaminated areas (Maunsell *et al.*, 2011).

2.3. Preventing food and water contaminations

Contamination of feed and water by domestic or wild animals are a possible source of infections as well. Some protective and hygienic measures have been identified and listed in different studies to prevent this risk (Anderson, 2001; Maunsell and Donovan, 2008; John F Mee *et al.*, 2012).

The feed and water troughs should be regularly cleaned and preserved from any biological contamination such as manure or urine. Granular feed should be stored in a locked room to prevent any contamination by wildlife, e.g. rodents and birds. In pasture, access of cattle to natural water points should be prohibited to prevent animals from drinking water potentially contaminated, e.g. by wild animals.

Figure 8 - Possible contamination of feed and water by wild animals in pastures. *(with the courtesy of Dr Serge Belleflamme, private vet practitioner, 2016)*

Feeding equipment and materials should be used specifically for that matter and each compartment should have its own equipment. The use of feeding equipment for manure handling is a common practice that should be avoided (Sanderson, Dargatz and Garry, 2000). The feeding equipment should be regularly cleaned and disinfected. For the calves housed individually, the feeding equipment should be calf-specific, and cleaned and disinfected after use.

Figure 9 – Calf specific buckets cleaned and disinfected after each feeding *(with the courtesy of Dr Olivier Vandemaele, private vet practitioner, 2021)*

2.4. Prevention of airborne contaminations

In order to prevent airborne contaminations, it is highly recommended to separate physically high-risk areas such as the quarantine area, the isolation pen and the maternity pen, and the low risk areas (Anderson, 2001; Van Winden, Stevens and McGowan, 2005; Maunsell and Donovan, 2008; Brennan and Christley, 2012; John F Mee *et al.*, 2012; Robertson, 2020). Calf pens should also be physically separated from adult cattle stables (Maunsell *et al.*, 2011).

The natural ventilation should be designed as to promote the air flow from younger to older animals (Maunsell *et al.*, 2011).

Figure 10 – Temporary fan used in case of high temperature to ensure a proper ventilation in the stables (*with the courtesy of Dr Olivier Vandemaele, private vet practitioner, 2021*)

2.5. Prevention of vector-borne diseases

The importance of vector-borne diseases is increasing as the geographic distribution of vectors is expanding due to, among others, climate change and international traffic. Several vector-borne diseases have emerged recently in Europe, such as bluetongue in 2006 (Moutou and Pastoret, 2015) and Schmallenberg disease in 2011 (Tarlinton *et al.*, 2012). The incidence of several tick-borne diseases such as babesiosis and anaplasmosis are also increasing and represent a clear hazard (Heyman *et al.*, 2010).

Several BSM help reducing the risk of vector-borne diseases: application of acaricides and mosquito repellents on cattle, chemical treatment of the environment to reduce layed eggs or larvae populations as well as the regular disposal of manure, removal of stagnant water, the establishment of some vegetation-free buffer zones around pastures and placing traps and nets around the stables for mosquitos and midges (Maunsell and Donovan, 2008; Robertson, 2020).

2.6. Prevention of contaminations by biological products

Infected animals can shed pathogens through faeces, urine, nasal and ocular discharges, saliva, exhaled breath and sputum, milk, semen, uterine fluids, foetal tissues, blood and tissues from live and dead animals. Any product issued from cattle should be handled properly in order to avoid further contaminations.

- **Milk and colostrum**

Milk and colostrum could be contaminated by different pathogen agents such as *Mycoplasma* spp., *Mycobacterium avium* spp. and *Salmonella* spp. (Maunsell and Donovan, 2008). In case colostrum or milk from another farm is used for calves, its origin should be controlled (e.g. farms from a health status equivalent or higher, animals tested, etc.); if given to calves, waste milk should be pasteurized (Villarroel, Dargatz, *et al.*, 2007; Maunsell and Donovan, 2008; Klein-Jöbstl, Iwersen and Drillich, 2014). In any case, it is recommended to provide milk originating from other cows of the same farm; indeed, the colostrum contains antibodies against the pathogens present in the farm. The milk produced for human consumption should be regularly tested for major zoonotic diseases (e.g. brucellosis and tuberculosis) and a mastitis control program should be in place.

- **Manure**

Manure should be stored away from the animal transit and housing areas and regularly eliminated (Kuster *et al.*, 2015).

To prevent dispersion by the wind, manure should not be spread less than 500 meters from other farms and in case if windy weather. Manure from other farms should not be used (Sibley, 2010). Some manure treatments such as composting can help prevent the risk of some pathogen agents such as *E.coli, Salmonella, Mycobacterium* spp. and *Listeria* to spread and have been advised (Grewal *et al.*, 2006; Villarroel, David A. Dargatz, *et al.*, 2007). Other manure treatment (e.g. lime or calcium cyanide 0,4%) have also be recommended before spreading the manure on the soils in order to prevent some diseases such as Q fever (Rodolakis, 2006; Angelakis and Raoult, 2010).

➢ **Placenta and foetal tissues**

Calving is considered as a high-risk event. Indeed, the reduced immune defences of the pregnant cow will lead to an increased shedding of any pathogen such as *Coxielle brunetii*. Many of them can be found in the foetal tissues and uterine fluids. The cow should be placed in a separate area or maternity pen before birth and the foetal tissues should be removed and properly evacuated from the area after birth. The maternity pens should be cleaned and disinfected after each calving (Anderson, Andrianarivo and Conrad, 2000; Klein-Jöbstl, Iwersen and Drillich, 2014).

Except for suckling calves that remain with the cow, other calves should be separated from the mother within the first 24 hours and placed in individual calf hutches (Klein-Jöbstl, Iwersen and Drillich, 2014).

Figure 11 – Individual calf hutches with no possible direct contact between animals (*with the courtesy of Dr Olivier Vandemaele, private vet practitioner, 2021*)

➢ **Dead animals**

Carcasses should be handled with gloves and PPEs (safety googles, mask and protective clothing). They should be placed on a cemented area, for an easy decontamination after removal, and properly covered to prevent any transmission of pathogens through rodents, cats or dogs. Ideally, this area should allow the rendering truck to pick-up the carcass without entering the premises, as these vehicles represent a major risk of contamination (Villarroel, David A. Dargatz, *et al.*, 2007; Kuster *et al.*, 2015). After handling a carcass, the farmer should properly wash his/her hands, clean its clothes and boots; the area should be cleaned and disinfected after carcass removal as well.

2.7. Reduction of the infection pressure and enhancement of the animal immunity

The infection pressure is defined as the level of contamination of the environment by infectious microorganisms susceptible to infect animals (or humans). To reduce the infection pressure, a good general hygiene of stables is recommended, with the litter kept dry and clean, and stables but also equipment regularly cleaned and disinfected. An optimal natural ventilation and a correct housing density are also necessary, as well as appropriate temperature and relative humidity. Some preventive treatments can also help reducing the infection pressure such a deworming program, the identification and elimination of disease carriers, a regular hoof trimming and foot bathing.

To boost the animal immunity, animal welfare and comfort are important as well as a proper nutrition (Maunsell and Donovan, 2008). Vaccinations increase the herd immunity towards specific diseases. In calves, the administration of a good quality colostrum, ideally originating from the farm, is also essential (Villarroel, David A. Dargatz, *et al.*, 2007; Maunsell and Donovan, 2008). The selection of more rustic and resistant animals should also be considered (Perry and Grace, 2009).

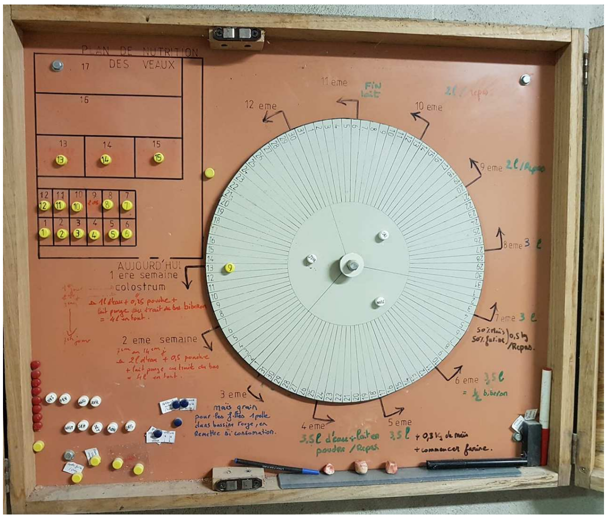

Figure 12 – Example of a veal nutrition protocol in a farm (*with the courtesy of Dr Olivier Vandemaele, private vet practitioner, 2021*)

2.8. Management of animal health

In addition to the BSM detailed above, and to ensure their proper enforcement, a cattle farm should have an effective animal health management program and monitoring system in place (Maunsell and Donovan, 2008). Specific protocols should be written to describe the procedures to follow in different cases of high biosecurity risks such as: entering animals, sick animals (e.g. regular screening, identification, health status, and treatment records), management of calves, dairy management and vaccinations. Farm workers should be regularly trained on biosecurity and animal health.

3. Organisation of disease control programs and technical guidance of farmers in Belgium

3.1. Official structures or moral persons involved in the disease control programs and technical guidance of farmers

The Federal Agency for the Safety of the Food Chain (FASFC) is responsible for the assessment and management of risks that may be harmful to the health of consumers as well as the health of animals and plants. The Agency carries out food safety inspections throughout the food chain.

The FASFC integrates all control services that are competent for the entire food chain. The FASFC is not only competent for controlling food, feed, fertilisers and phytopharmaceuticals, but is also responsible for sanitary (animal diseases) and phytosanitary (plant sector) prevention and control measures. Laying down operational rules on controls, certification, infrastructure standards to be complied with by food chain, Food and Feed Business Operators (FFBO's) are also a part of its mission"[2]. FFBO's are responsible for the auto-control (Regulation (EC) No 178/2002 – 'General Food Law'-, this Food Law was further developed in Belgium into the Royal Decree of 14 November 2003). FASFC agents runs punctual controls (randomised or targeted) on the different holdings to ensure the respect of the legislation in terms of animal production, animal health and food chain safety (including all aspects related to the feed and certain aspects of animal by-products). They have the authority to take urgent measures and punitive measures in case of non-compliance.

By law (Royal Decree, 2010, 2012), each cattle farm is monitored by a guidance veterinarian who is responsible of: (i) controlling the drug register of the farm, (ii) monitoring the global health of the herd based on regular visits (at least once every 4 months) and (iii) investigate any event or anomaly observed on the animals. His missions are: diseases' diagnosis, prevention and treatment as well as technical guidance of the farmer. To do so, the guidance veterinarian can ask for a third party assistance and needs to follow continuous training.

The regional associations for the animal health and identification, ARSIA in Wallonia and DGZ in Flanders, are mandated by the federal authority and assist the farmers in complying with their legal obligations regarding animal health and identification. They are also assisting the veterinarians in diseases' diagnosis and sanitary monitoring of the herds. These two associations are funded by the farmers, their services in animal identification and diagnosis and by the authorities for the execution of their official mission.

Sciensano is a public institution with six field of action including: animal health, food consumption and food safety, health and disease monitoring and health and environment. Sciensano is the National Reference laboratory for all regulated (notifiable) animal diseases.

3.2. Organization of the disease control in Belgian cattle farms

Overall, the disease control programs and/or epidemiosurveillance in Belgium is ensured through two main mechanisms.

- Passive surveillance, which is event-driven and relies on: (i) the mandatory notification of some diseases to the FAFSC by the farmer, the veterinarian and the laboratories, (ii) the regular

[2] https://www.fasfc.be/about-fasfc/mission

epidemiosurveillance visists by the guidance veterinarian of the farm and (iii) the syndromic surveillance.
- Active surveillance of certain diseases as part of the winter screening.

3.2.1. Passive surveillance:

- Mandatory notification: a list of diseases are notifiable in Belgium. In case of suspicion of any of notifiable disease, the veterinarians needs to make the necessary samples for confirmation or invalidation and notify the FASFC for further measures to be taken according to the different control programs in place.
- Regular monitoring of the herd by the guidance veterinarian: each holding under contract needs to be visited at least every 4 months with a complete visual inspection of animals. Any anomaly detected on this occasion will be subject to further investigations by the veterinarian for the diagnosis and the further implementation of disease control actions.
- Syndromic surveillance: the syndromic surveillance in Belgium relies mainly on the mandatory notification of abortions, the data from rendering plants and the different mortality and reproduction rates collected and generated by the two regional animal health and identification associations. Nevertheless, all the data generated by the different systems are not yet fully used and this surveillance could be strengthened (Cardoen *et al.*, 2014).

3.2.2. Active surveillance

- Winter screening and mandatory control programs: annually, and in addition to holdings at risks or already monitored (e.g. contact farm of recent outbreaks of tuberculosis or brucellosis), a number of holdings and animals are randomly selected for screening. In 2020, the diseases of concern were: bluetongue, brucellosis, enzootic bovine leucosis and tuberculosis. In addition, regular testing is done within the framework of the IBR and BVD national control programs, in order to preserve or improve the farm status.
- Voluntary disease control programs: the regional animal health and identification associations propose to their members some additional control programs on a voluntary basis. Cattle diseases targeted in these control programs are: neosporosis, salmonellosis and paratuberculosis.

4. Implementation of biosecurity measures in the cattle farms

4.1. Implementation level and constraints

If some BSM are mandatory, the majority of them are implemented on a voluntary basis. The correct implementation of BSM in cattle farms is a key component of any public and animal health strategy. Several studies were implemented worldwide in order to assess the implementation level of

BSM by cattle farmers (**Table 3**). All these studies reported a globally low level of BSM implementation in cattle farms, especially when compared to pig farms (Nöremark, Frössling and Lewerin, 2010; Sahlström *et al.*, 2014). This type of study has not been implemented in Belgian cattle farms yet except for one study performed in BVD-free farms which highlighted a low level of compliance with BS guidelines (Sarrazin *et al.*, 2014).

Table 3 – Main findings of different studies related to the implementation level of biosecurity measures in cattle farms

Reference	Country	Herd type	Type of questionnaire and main findings
Brennan and Christley, 2012	North Western England	All	Face-to-face interviews (N=56) Many BSM "implemented infrequently or not at all" Implementation mainly influenced by cost, unproven efficacy, knowledge of BSM.
Nöremark, Frössling and Lewerin, 2010	Sweden	All	Postal questionnaire (N= 518, with 192 cattle farms) "Many had biosecurity routines that were not satisfactory from an infectious disease prevention perspective », "Only 10% of cattle farmers reported that they isolated animals before introduction into the herd" and "Most farmers perceived their on-farm biosecurity as 'sufficient' (72%)". Lower implementation in cattle farms and smaller herds. Low perception of the disease risk and insufficient knowledge of diseases transmission pathways and BSM.
Sayers *et al.*, 2013	Republic of Ireland	Dairy	Telesurvey and hard copy (N=444) Implementation rate higher in large herds, among older farmers and in regions with higher cattle density
Sanderson, Dargatz and Garry, 2000	USA	Beef-cow calf producers	Personal interviews (N= 1190) "Producers do not always adjust management practices such as vaccination schedules and quarantine procedures appropriately to minimize this risk" "At this point, we lack adequate data to know which, if any, biosecurity practices are worthwhile".
Sahlström *et al.*, 2014	Finland	All	Mailed questionnaires + on-line survey (N=1236) Implementation in cattle farms is lower than in pig farms. Farmers were satisfied with their on-farm biosecurity even though the biosecurity level was not particularly high. Better implementation in larger herds and dairy farms.
Hoe and Ruegg, 2006	USA, Wisconsin	Dairy	Mailed questionnaires (N=587) Overall, most management practices were associated with herd size, but many beliefs regarding important dairy farm issues were consistent. Better implementation in larger herds
Brandt *et al.*, 2008	USA, Central plains	Feed yards	Interviews of feed yard personnel (N=106) Overall, low implementation level of biosecurity measures.

Reference	Country	Herd type	Type of questionnaire and main findings
			Low implementation related to the lack of knowledge on risks and biosecurity measures and to a low perception of the cost-effectiveness of biosecurity measures. Better implementation in larger herds

Based on these findings, most authors highlighted the need to investigate further the reasons of a low implementation of BSM by cattle farmers and farmers' attitudes and perceptions towards biosecurity (BS). Several studies highlighted a higher compliance in larger herds (**Table 3**) as well as an influence of the type of herd (dairy or beef), of the farmers' knowledge of BS and of the farmers 'perceptions and attitudes in terms of infectious diseases risk, BSM benefits and cost-efficiency. The inclusion of socio-psychological factors such as farmers' age, gender and educational level as possible covariates in the models were also suggested. A better understanding of the decision-making processes adopted by farmers regarding the adoption and implementation of recommended BSM is therefore necessary to adapt the educational tool and messages addressed to cattle farmers and ensure a higher compliance.

4.2. Actual knowledge on farms and farmers characteristics, attitudes and beliefs determining the actual implementation of biosecurity measures

The role of the different socio-psychological factors on the adoption and long-term maintenance of desired behaviours is considered as an urgent and important area for research and policy consideration. Five key elements to consider have been highlighted in a recent review (Mankad, 2016):

- Farmers' behaviours have been acquired over time and became habitual. They are usually based on farmers' experience, knowledge and beliefs. Therefore, even for farmers opened to change, they are difficult to change. Furthermore, any change requires a psychological shift.
- Pest or disease eradication requires the adoption of appropriate biosecurity practices in the long term.
- Increasing the level of biosecurity affects the individual but also others. The social aspects need to be considered.
- The farmers will assess the cost-efficiency of proposed BSM; the benefits of BSM need to be worth their time, costs and involvement.
- The farmers need to consider the administrative authorities as a reliable source of information and to trust their capacity to manage the biosecurity initiatives.

Behaviour change requires a complex decision making process influenced by a large number of factors (**Fig. 13**) which can be contextual (e.g. national policies, farming context, laws and regulations) or individual (e.g.: attitudes, beliefs, perceptions or personal experiences) (Ritter *et al.*, 2017).

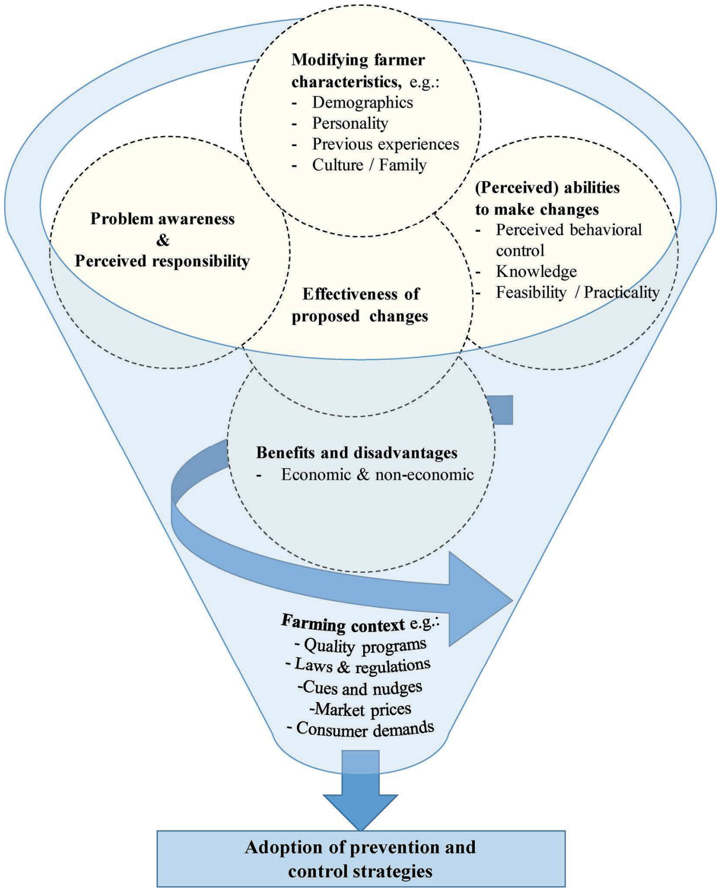

Figure 13 - Socio-psychological factors that influence the adoption of on-farm management strategies for improved infectious disease prevention and control (Ritter *et al.*, 2017)

A 2016-litterature review on psychological influences on farmers' BSM implementation proposed a simplified model (**Fig. 14**) showing the different factors influencing the decision to adopt or not to adopt a specific BSM (Mankad, 2016).

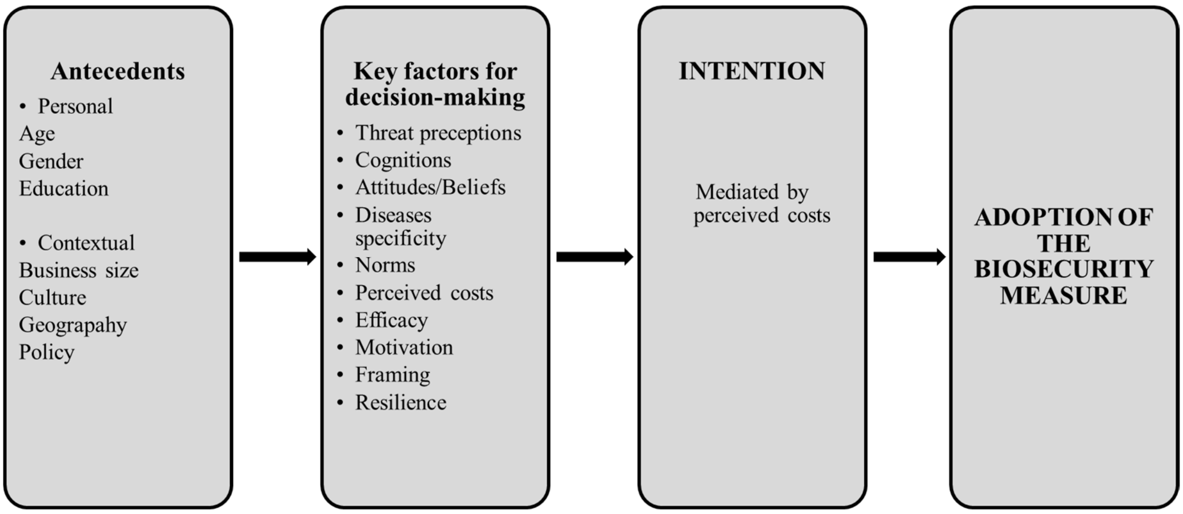

Figure 14 – Exploratory psychosocial model of factors influencing the adoption of biosecurity measures by the farmers (Mankad, 2016)

Attitudes have been defined as "an enduring organization of beliefs, feelings and behavioural tendencies towards objects, events, individuals or groups" (Hogg and Vaughan, 2008). Based on her/his attitudes towards a specific BSM, the farmer will process positively or negatively the information received on this topic and therefore, she/he will be more likely to act if a BSM and its possible outcomes are positively evaluated. In the case of BS, the decision to act on an infectious disease risk by adopting (or not) a BSM will also have consequences on finances, animal and public health, social environment and ethics (Mankad, 2016), making the decision making process even more complex.

- **Risks perceptions or threats**

The risks perception is an important factor to be considered. Biosecurity measures are recommended in order to address the risk of different infectious diseases. Therefore, the adoption of BSM by the farmers will highly depend on their perceptions of risk or attitudes. The risk perception or threats are usually divided into two components: the probability for the disease to occur and its likely impact on the farm. As an example, the risk of introduction of an eradicated disease will likely be perceived as low by the farmers, who will then be less incline to change a practice aimed at preventing such disease. On the other hand, in case of an emerging or endemic disease, the farmers will more likely adopt specific preventive BSM, especially if it allows them to pursue their economic activity (Toma *et al.*, 2013). These risk perceptions are disease-specific and might differ based on pre-existing knowledge and experiences, leading to different decisions.

Independently of the risk perceptions, the farmer's general risk attitude is a key psychological factor which influences the risk-related behaviours and therefore the adoption of BSM by the farmers (van Winsen *et al.*, 2016). A farmer who has a high-risk attitude (personal tendency to take risks) will more likely have a lower perception of risks and will be less likely to adopt any risk management strategy.

- **Attitudes or beliefs towards biosecurity measures**

The farmers' perception of a BSM possible outcomes or benefits will also influence her/his behaviour. These benefits can be financial (e.g. increased herd productivity), ethic (e.g. animal welfare) or social (e.g. professional pride, to be considered as a good farmer). If the perceived benefits are high, the farmers will more likely adopt the BSM (Gunn *et al.*, 2008; Garforth, 2015; Denis-Robichaud *et al.*, 2019; Moya *et al.*, 2019). On the other hand, a BSM benefits might be balanced by perceived constraints (e.g.: cost, time and efforts) or barriers such as the control belief defined as the perception that "the desired outcomes are not achievable in the absence of action by others" (Rehman *et al.*, 2007; Gunn *et al.*, 2008; Garforth, Bailey and Tranter, 2013; Toma *et al.*, 2013; Ritter *et al.*, 2017) or the perceived ability to properly perform the BSM (Garforth, Bailey and Tranter, 2013; Ritter *et al.*, 2017). More than the benefits themselves, the cost-effectiveness of BSM is a key element to consider as it takes into account the possible outcomes as well as the constraints or barriers and weights them to the time, costs and efforts needed to implement the BSM (Rehman *et al.*, 2007; Garforth, Bailey and Tranter, 2013).

- **Perceived costs and financial impacts**

Biosecurity measures can sometimes be really expensive (e.g.: building a separated quarantine area or isolation area for sick animals, double fencing in pasture) or have financial consequences (e.g. the reporting of some diseases might lead to the slaughter of animals and the prohibition to sell animals or their products over a long period of time). Financial incentives to perform the BSM are therefore a key element to be used by the authorities in order to promote the adoption of measures (Mankad, 2016). Such incentives can increase the perception of a BSM benefits (e.g. milk purchased at a higher price if the farmer complies with quality label and the milk somatic cell count remains below a certain threshold), reduce the cost of the BSM (e.g. subsidies for serological tests) or mitigate the negative financial impact of the BSM (e.g. financial compensation in case of animal slaughtering).

- **Social norms, motivation and incentives**

Nevertheless, not all incentives are financial as the opinion and approval of others such as relatives, peers or community members, is also an important social incentive (Hennessy, 2007). Social norms will determine which behaviour is perceived as commonly approved or done and will therefore have a positive or negative influence on the decision-making process.

The farmers' motivation to engage into behaviour change varies and, as mentioned before, can be related to expected financial benefits. Nevertheless, shared responsibility and the benefits of implementing a specific BSM for common goods and for others (e.g. other farms or individuals) is an important part of the farmers' motivation to adopt a BSM (Mankad, 2016; Denis-Robichaud *et al.*, 2019). This is particularly important when it comes to BSM reducing the risk of zoonotic diseases, as these measures increase the production costs with no direct financial benefits for the farmer (Ellis-Iversen *et al.*, 2010; Shortall *et al.*, 2016). In such cases, the individuals' attitude towards health might play a major influence on the decision-making process.

The farmers' motivation could also be triggered by eventual sanctions to non-compliant behaviour. These sanctions could be real (e.g. destruction of products or sub-products) or perceived (e.g. feeling of being judged negatively by others) (Toma *et al.*, 2013; Mankad, 2016).

- **Other factors**

The farmers' attitudes and perceptions regarding the BSM risks and benefits, -as well as its willingness to change their practices, are significantly different, based on different farms or farmers characteristics. Indeed, these determine directly or indirectly, through the perceptions and beliefs, the intention to change and therefore, the behaviours.

The farmers' biosecurity knowledge and level of education influence positively their attitude towards change and their adoption of good practices (Rehman *et al.*, 2007; Toma *et al.*, 2013; Brennan *et al.*, 2016; Denis-Robichaud *et al.*, 2019; Moya *et al.*, 2019). On the other hand, young farmers are usually more opened to changes than older ones, who rely mainly on their experience and practices in the decisions-making processes. This is described as a cognitive bias (Mankad, 2016), that affects mainly the experienced/older farmers. The farmers with little professional experience will rely more likely on the opinion of referent sources or the social norms in their decision-making processes.

Herd size, as well as the type of farmers and their life stage, can also have an influence. Indeed, farmers with a larger herd and professional cattle holders (who depend on their livestock for livelihood) have more to lose in case of outbreaks and are more likely to invest in BSM compared to small-scale farmers or hobbyists whose farming objectives might differ (Hoe and Ruegg, 2006; Ellis-Iversen *et al.*, 2010; Garforth, Bailey and Tranter, 2013; Mankad, 2016).

Some studies also illustrated the influence of being a member of a health scheme (participating to a disease surveillance and control program) (Heffernan *et al.*, 2008a; Toma *et al.*, 2013) and being an organic farmer (Rehman *et al.*, 2007; Toma *et al.*, 2013).

Regarding the different sources of information on BSM, it appears from several studies that the veterinarians remain the most trustful and important referents for most farmers while the government is often considered as not reliable (Rehman *et al.*, 2007; Heffernan *et al.*, 2008a; Toma *et al.*, 2013; Garforth, 2015; Brennan *et al.*, 2016). The other possible sources of information identified are: other farmers, farm insurance companies, scientific community, media and farmers' associations or organizations (Mankad, 2016; Ritter *et al.*, 2017).

4.3. Models of behaviour change

The decision-making process of behaviour change is therefore complex and influenced by numerous factors. Over the years, social sciences have developed several theories and models in order to better explain and predict behaviour changes. These models have been used in many studies.

4.3.1. The pro Transtheoretical Model of Health Behaviour Change (TTM)

The process of change (adoption of a new behaviour) usually goes through five specific stages described in the Transtheoretical Model of Health Behaviour Change (Prochaska and Velicer, 1997). The five stages are described below (see **Fig. 15**):

- Precontemplation: the individuals either are not aware of their problem and therefore of the necessity to change, or they have no intention to change.

- Contemplation: the individuals are aware of their problem and of the need to address it but are not ready to act yet
- Preparation: the individuals are willing to act and gather some additional information in order to do so. This step is essential for the long-term adoption of the changed behaviour
- Action: the individuals implement their plan and change their behaviour based on the information received.
- Maintenance: long-term adoption and strengthening of the behaviour

To facilitate the change process (movement from one stage to another), specific actions are needed at each stage in order to facilitate the transition of the individual from one stage to another. Mass communication and general information are needed in the initial stages in order for the individuals to be more conscious of their unwanted behaviour and the possible benefits of change. For the change process to move forward (from contemplation to preparation and action), the individuals need to gather more information on the possible benefits in order to be convinced of the necessity of changes and to start planning. In the preparation stages, more specific information and technical guidance are necessary before acting. Finally, once the behaviour has been changed and in order to ensure its long-term adoption, the benefits of the change need to be assessed and evaluated.

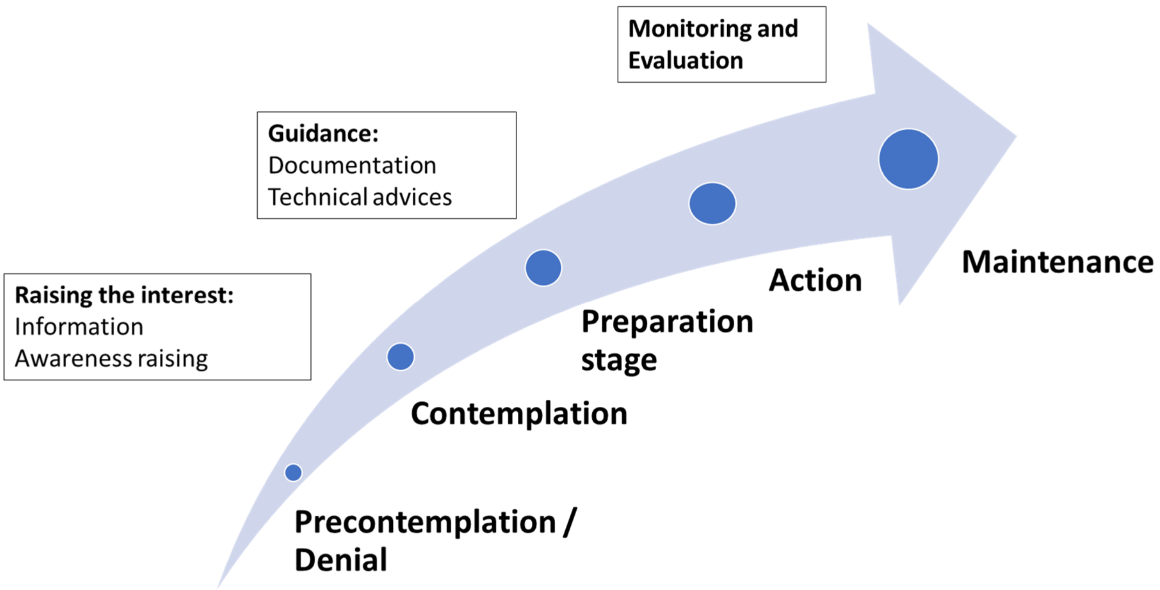

Figure 15 – The five stages of the Transtheoretical Model of Behaviour Change. The text in boxes describes the specific actions needed for an individual to move from one stage to another (adapted from Prochaska and Velicer, 1997)

4.3.2. Factors determining the change of behaviour

Most communication and awareness raising messages aimed at generating a behaviour change focus on scientific rational arguments and are usually insufficient to induce a change. It has been proven that targeted interventions are more effective when relying on a theoretical model taking into account the different determinants of behaviour and behaviour change (Fishbein and Ajzen, 1975). Indeed, in order to be able to properly motivate the farmers to change their behaviour, it is necessary to properly understand their mindset and the specific factors which will convince them to start the change process (Ritter *et al.*, 2017).

The actions of the different factors will influence different stages of the change process (Ellis-Iversen *et al.*, 2010). Intrinsic circumstances will mainly influence the first stages (from precontemplation to contemplation and preparation) and will determine the intention to perform the desired behaviour. Once the intention to perform a behaviour is obtained, extrinsic circumstances will lead (or not) to the action which will then have to be maintained in order to achieve the desired outcomes (**Fig.16**). The extrinsec circumstances are related to the environment and context such as: having the means and ressources to perform the behaviour, the financial pressure or subsidies, the culture and the society (e.g.: laws, regulations and ethical beliefs).

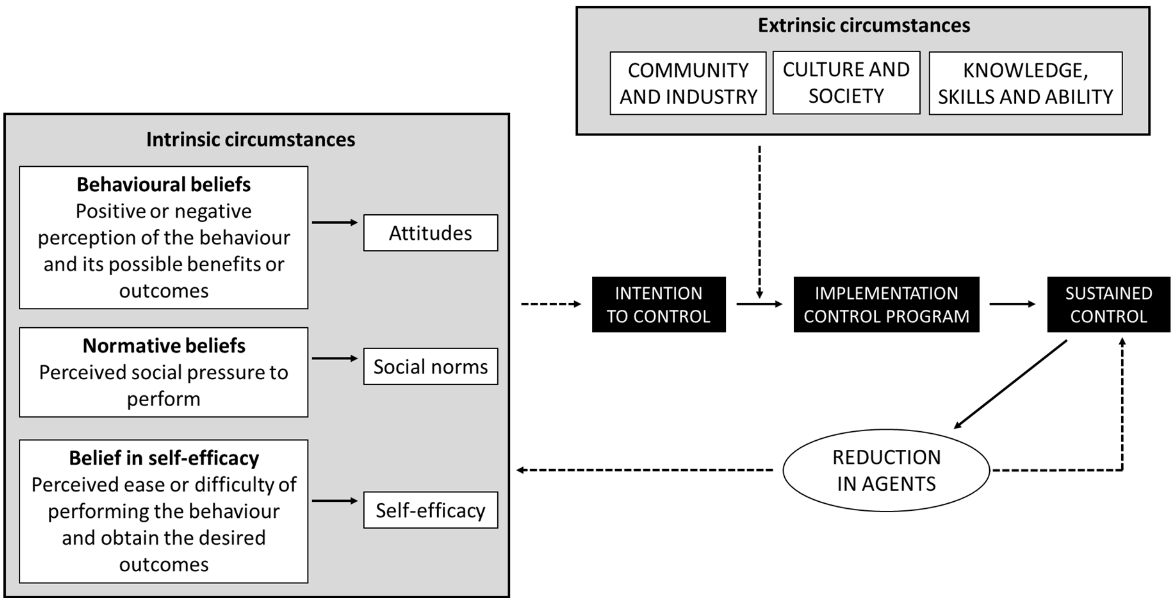

Figure 16 – Conceptual model describing the factors influencing behavioural change for livestock farms. Black boxes = steps in behaviour change process; circle = wanted outcome; grey boxes = circumstances with influence; non-dashed arrows = movements towards wanted outcome; dashed arrows = indicate where circumstances affect movement between steps (Adapted from Ellis-Iversen et al., 2010)

The intrinsec circumstances affecting the intention to change behaviour and used in this framework are based on the Theory of Planned Behaviour (Ajzen, 1991). These determinants have been classified in three categories: the attitude towards the behaviour or behavioural beliefs, the subjective norm or normative beliefs and the perceived behavioural control or belief in self-efficacy. The attitude towards the behaviour relies on personal core values including the positive or negative perception of the behaviour and its possible benefits or outcomes. The subjective norm refers to the perceived social pressure to perform (or not perform) the behaviour, the external influences emanating from the family, the community, the peers or the professionals. The perceived behavioural control refers to the perceived ease or difficulty of performing the behaviour and obtain the desired outcomes. It is assumed to reflect past experience as well as anticipated impediments and obstacles. (Ajzen, 1991).

4.3.3.The Health Belief Model (HBM)

In addition to the Theory of Planned Behaviour, several theories and models have been developped in order to predict behavioural changes. The Health Belief Model (Janz and Becker, 1984) is the most frequently used in studies related to health and farmers behaviours (Ritter *et al.*, 2017) and has been considered as "a usefull framework for understanding individual differences in health behaviour patterns and for designing behaviour change intervention" since the 1970s (Abraham and Sheeran, 2015). Based on the HBM, the intention to perform a behaviour is related to five determinants (Fig.17): the risk perception in terms of probability and severity, the perception of the behaviour benefits or outcomes, the perception of barriers to the behaviour implementation or to the outcome achievement and the health motivation which was included later in the model. The extrinsec determinants defined in the Theory of Planned Behaviour are referred to as 'Cue to action' in the HBM. The HBM does consider some cues to action to be personal (e.g. being affected by the disease). Each of the five perceptions of the HBM are assumed to be influenced by different demographic and psychological variables.

The threats of infectious disease are usually measured based on the probability of the disease to occur and its impact in case of occurrence. The HBM considers the two dimensions of the threat as the perceived susceptibility and the perceived severity. Regarding the perceptions linked to the BSM, two elements are considered: the perceptions of the possible benefits or outcomes of the behaviour in case of implementation and the potential negative aspects of the behaviour called barriers. The Health motivation relates to the level of concern of the individual about health matters, his sense of responsibility.

Several health communication messages targetting the HBM variables to change behaviours were proven successful over the years (Sohl and Moyer, 2007) and a consensus statement was published in 1977 to endorse the HBM framework as a model to better understand the socio-psychological determinants of health and health-related behaviours (Becker *et al.*, 1977). Nevertheless, a possible bias was highlighted in cross-sectional studies as the perceptions of the HBM variables might be influenced positively or negatively by the adoption of a specific behaviour (e.g. after a farmer adopts preventive measures against a disease, her/his perception of the disease susceptibility might be lower) (Rosenstock, 1966; Janz and Becker, 1984). It is therefore assumed that the ability of the HBM to predict a behaviour is higher if the perceptions are measured shortly before the adoption of the behaviour (Carpenter, 2010).

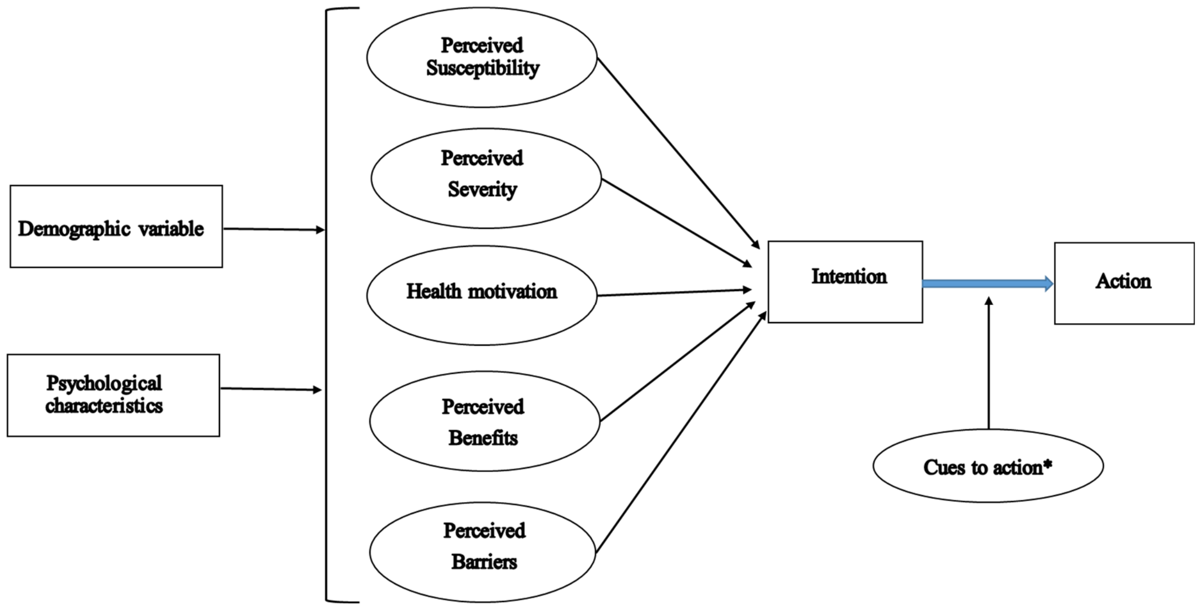

Figure 17 – The Health Belief Model (adapted from Abraham and Sheeran, 2002)
* *Cues to action act as a trigger to the implementation*

4.3.4. Applying of the Health Belief Model in research

The application of the HBM in research studies is based on the development of questionnaires in order to assess the different constructs of the HBM. As perceptions, these constructs are usually assessed indirectly by different questions. Different tools and scales have been developed and validated for assessing the five HBM constructs (Cummings, Jette and Rosenstock, 1978; Champion, 1984). These methods consisted in:

- Rating their attitude/ degree of agreement with a proposed sentence on a seven-point Likert scale
- Selecting among different alternatives the one which best represents their feelings towards a given situation
- Selecting between two or more description of situations or attitudes, the one which best illustrates the way they consider themselves

Based on Cummings, Jette and Rosenstock, 1978, the last method consisting in choosing between two description of situations or attitudes, demonstrated a low convergence and should be avoided.

Some examples of validated scales used to measures the different HBM constructs are provided in **Table 4** (Champion, 1984).

Table 4 – Example of validated items used to measure the different Health Belief Model constructs with the answers provided on a seven-point Likert scale (Source: Champion, 1984**)**

Construct	**Items used to measure to construct**
Susceptibility	My chances of getting .../ are great
	I feel that my chances of getting ... In the future are good
	There is a good possibility that I will get …
	I worry a lot about getting …
Severity	The thought of … scares me
	I am afraid to even think about …
	If I had … my financial security would be endangered
	Problems I would experience from. would last a long time
Benefits	Doing ... prevents future problems for me
	I have a lot to gain by doing …
	I would not be so anxious about that diseases if I did …
	If I do ... I may identify the problem more quickly
Barriers	The practice of … interferes with my activities
	I am afraid I would not be able to do …
	In order to do … I have to give up quite a bit
	Doing ... Is time consuming
Health motivation	I frequently do things for my health
	I always follow medical orders because I believe they will benefit me
	I search for new information related to health

A specific scale was also developed in order to assess the farmers' overall risk attitude (Bard and Barry, 2000). A few examples of proposed risk management statements used to assess the risk attitude are provided below:

- I am always one of the top producers in my area to adopt new technology
- I never keep a line of credit open at my primary lender (reversed score)
- I do not have adequate life insurance / health insurance

The scales used in the HBM studies can be adapted from one study to another but their validity needs to be tested. Several methods have been described but the assessment of the internal reliability of data by calculating the Cronbach's alpha coefficient and running an exploratory and confirmatory factor analysis are the minimal tests to perform (Champion, 1984; Bard and Barry, 2000;

Carpenter, 2010). The Cronbach's alpha coefficient, expressed as a number between 0 and 1, measures the internal consistency of a test or scale (Tavakol and Dennick, 2011). It allows confirming that all items measure the same concept or construct and evaluates the contribution of each item to their common underlying construct. The higher the correlation between the items, the higher the Cronbach's alpha coefficient. Based on the authors, the alpha coefficient can be considered as acceptable for values ranging from 0.7 to 0.95 and above (Tavakol and Dennick, 2011).

Exploratory and confirmatory factor analysis are usually performed as well in order to validate the constructs before testing the model (Schreiber *et al.*, 2006; Teo, 2013). Factorial analysis is a statistical method allowing to reduce a large number of variables into a fewer number of factors, usually called latent variables. In the exploratory analysis, no assumptions are made in terms of number of latent variables or as to which of items contributes to which latent variable. It is used to identify possible underlying factors or to confirm a theoretical model. In the confirmatory factor analysis, a pre-existing model is used defining the theoretical relationships between the observed and unobserved variable and the validity of the model is then confirmed by analysing different fitting indexes (Schreiber *et al.*, 2006).

Once the scale and the construct have been validated, the model can be applied in order to assess the level of influence of each construct on the intention to perform the behaviour or its actual implementation. This can be done through a multivariable regression model using composite score to determine the HBM constructs (Rehman *et al.*, 2007; Sayers *et al.*, 2013; Richens *et al.*, 2018) or by using structural equation modelling (SEM) with latent variables (Toma *et al.*, 2013; Vande Velde *et al.*, 2015; van Winsen *et al.*, 2016).

5. Prioritization of biosecurity measures in cattle farming

The number of BSM recommended in cattle farming is important and each of them represent some time, costs and efforts. It this therefore important to be able to prioritize the different BSM and identify the most important ones. In addition, the co-existence of a wide range of different recommendations in the literature might create confusion and discourage the cattle farmers to engage into biosecurity (Moore *et al.*, 2008). The prioritization of BSM relies on different criteria among which their importance based on specific needs or risks and their cost-efficiency. These two elements needs to be assessed to better convince the farmers of their utility and importance (Sanderson, Dargatz and Garry, 2000; Brandt *et al.*, 2008).

When analysing the cost-efficiency of a BSM, it is important to consider the costs, the benefits but also its feasibility or practicality (Ritter *et al.*, 2017; Shortall *et al.*, 2017). The feasibility needs to be analysed from a practical point of view but should also take into account eventual cultural aspects

(Shortall *et al.*, 2017). In addition, the farmers' expertise should be taken into account as veterinarians and farmers have different perceptions of what is feasible or not (Sorge *et al.*, 2010).

5.1. Priority diseases to be targeted

The priority diseases to be targeted depend on their relative importance either on the farm or on national economy as well as on their possible impact on public health.

The World Organisation for Animal Health (OIE) identified, based on different criteria, a unique list of notifiable terrestrial and aquatic animal disease (OIE-Listed diseases 2021: OIE - World Organisation for Animal Health). It includes 117 infectious diseases out of which 37 concern cattle. Before 2004, these diseases were classified in two lists, i.e. lists A and B. List A included "transmissible diseases that have the potential for very serious and rapid spread, irrespective of national borders, that are of serious socio-economic or public health consequence and that are of major importance in the international trade of animals and animal products". List B included "transmissible diseases that are considered to be of socio-economic and/or public health importance within countries and that are significant in the international trade of animals and animal products". Since then, a unique list was established.

The criteria used to classify a disease into the unique list are:

1. Assessed transboundary transmission of the pathogen
2. At least one country demonstrated the effective or imminent absence of the disease, infections or infestations in susceptible species
3. The disease morbidity or mortality rate in animals is significant in a country or area (in domestic animals or wildlife) AND/OR a natural transmission to humans was assessed with important consequences.
4. A reliable detection and diagnostic method are available as well as an explicit case definition allowing to clearly identify the disease, the infection or infestation and to make a differential diagnosis OR it is an emerging disease or infection, with a clear case definition, and, either with a potential zoonotic risk, spreading rapidly, or a significant morbidity and mortality rates.

In Belgium, a list of notifiable diseases including a majority of the OIE notifiable diseases is in place and any suspicious or confirmed case needs to be reported by the farmers, the veterinarian or the diagnostic laboratory (**Table 5**). In addition to the OIE notifiable diseases, some zoonotic agents or diseases need to be reported if diagnosed by the laboratories.

Table 5 – OIE Notifiable diseases and Belgian context

OIE Notifiable Cattle diseases and infections	Belgian context *	
	Notifiable	**Status**
Anthrax	Yes	Last case in 1989
Bovine genital campylobacteriosis	Yes	Present
Bovine spongiform encephalopathy	Yes	Negligible risk since 2012
Bovine viral diarrhoea	Yes	Present
Enzootic bovine leukosis	Yes	Free since 2003
Infection with Aujeszky's disease virus	Yes	Free since 2011
Infection with bluetongue virus	Yes	Present
Infection with epizootic haemorrhagic disease virus	Yes	Never detected
Infection with foot and mouth disease virus	Yes	Free since 1996, last case in 1976
Infection with lumpy skin disease virus	Yes	Never detected
Infection with Rift Valley fever virus	Yes	Never detected
Infection with rinderpest virus	Yes	Free since 2014, last case in 1920
Infection with *Brucella abortus, B. melitensis* and *B. suis*	Yes	Free since 2003
Infection with *Echinococcus granulosus*	Yes	Present
Infection with *Echinococcus multilocularis*	Yes	Present
Infection with Mycobacterium tuberculosis complex	Yes	Free since 2003
Infection with *Trichinella spp.*	Yes	Negligible risk under industrial housing conditions
Infectious bovine rhinotracheitis	Yes	Present
Rabies	Yes	Free since 2001
Vesicular stomatitis	Yes	Never detected
Q fever	Yes	Present
Bovine anaplasmosis	No	Present
Bovine babesiosis	No	Present
Crimean Congo haemorrhagic fever	No	Never detected
Haemorrhagic septicaemia	No	Never detected
Heartwater	No	Never detected
Contagious bovine pleuropneumonia	No	Officialy free (no OIE status)
Japanese encephalitis	No	Never detected
New world screwworm (*Cochliomyia hominivorax*)	No	Absent
Old world screwworm (*Chrysomya bezziana*)	No	Absent
Paratuberculosis	No	Present
Surra (*Trypanosoma evansi*)	No	Never detected
Theileriosis	No	Absent
Trichomonosis	No	Absent
Trypanosomosis (tsetse-transmitted)	No	Never detected
Tularemia	No	Absent in domestic animals
West Nile fever	No	Never detected

* https://www.favv-afsca.be/santeanimale/zoosanitaire-belgique/#bovins and https://wahis.oie.int

Nevertheless, based on different priorities and criteria, several other classifications have been proposed over time at national or country level as well as per sector impacted such as: zoonosis or wildlife implications (**Table 6**). The methods used in the different studies are either quantitative, semi-quantitative or qualitative and were mainly based on the Delphi method which consists in the following steps (WHO, 2006):

1. formulation of a list of diseases, and criteria to include/exclude diseases for surveillance, by a steering committee;
2. discussion of the proposed criteria and disease list by participants in the prioritization exercise;
3. formulation of a questionnaire in which participants are asked to score the diseases according to the criteria;
4. expression of individual opinion of participants through scoring the diseases according to the criteria;
5. data collection and summary (using statistical parameters) of the scoring, and assessment of agreement;
6. feedback of the individual and group ranking to the participants;
7. and discussion of the results (allowing the experts to eventually adapt their scores).

The initial list of diseases to be assessed, the criteria and ranking methodologies depend mainly on the objective of the prioritization and resources available. The scoring system relies on experts' opinion for scoring the criteria and is mainly informative as literature data is usually insufficient to quantify the criteria in an appropriate way. Several studies, mostly supervised by national or regional control authorities ranked the diseases based on their impact on economy, trade and public health in order to advise the national or regional authorities for disease control and eradication. An OIE study was implemented in 2010 in order to develop a prioritization manual for national applications on disease prioritization. The methodology is described in the methodological manual (Phylum, 2010) and is based on the following criteria: disease epidemiology, feasibility and facility of implementation of control measures, disease status in the country and country priorities, as well as the disease impact on economy, public health, society and environment. Caribvet is a prioritization tool which have been proposed and used by the Caribbean Animal Health Network in order to prioritize diseases (Group, 2012).; an Excel® scoring matrix considers the following criteria: (i) public health impact, (ii) impact on production, (iii) feasibility of control, (iv) impact on trade or animal movements and (v) impact on trade of animal products. The matrix was filled in at a workshop considering experts' opinion. In 2012, the French Agency for Food, Environmental and Occupational Health & Safety (Anses) performed a prioritization exercise with the non-zoonotic diseases affecting ruminants and for which no wildlife reservoir had been identified by then (ANSES, 2012). The grading relied on eight main thematics: disease epidemiology, economic and commercial impact, impact on public health, society and biodiversity, efficacy of control measures, global economic impact of control measures at national level as well as societal and environmental impact of control measures at national level. Another study performed in 2012 focused on prioritizing 100 diseases of food-producing animals and zoonoses (Humblet *et al.*, 2012). This study relied on the expert opinion of 40 international experts using both a deterministic and a stochastic method. The criteria considered included five aspects: (i) the epidemiology of the disease, (ii) the prevention and control measures, (ii) the effects of the disease on economy and trade, (iv) the zoonotic characteristics and (v) the effects of the disease on the society. Zoonoses were prioritized in 2014 (McIntyre *et al.*, 2014): the methodology relied on the scoring of 7 criteria by a panel of experts: disease knowledge, impact on animal health and welfare, impact on public (human) health, impact on the wider society, impact on trade and control tools. A prioritization of wildlife pathogens to be targeted in European surveillance programs was done based on an experts' risk analysis with a focus on the diseases affecting ruminants also (Ciliberti *et al.*, 2015). The criteria used for scoring were the following: pathogen variability, range of animal hosts, potential for contagion, presence in Europe, difficulty of surveillance in wildlife, speed of spread and persistence in the environment. DISCONTOOLS is an EU funded project which objectives were to review the existing approaches of disease prioritization through a review of methodologies, to propose a prioritization tool and to apply it to the main European diseases (DISCONTOOLS, 2016). The prioritized diseases affecting ruminants made by a panel of experts during a workshop, as well as their different scores, is available on the project website (https://www.discontools.eu/) and can be extracted in Excel®.

Priority diseases to be targeted by a biosecurity program will depend on the regional, national and/or local context, as well as the specific farmers' needs. Indeed, based on farm specificities, some farms will be more affected than others to certain diseases (e.g. species susceptibility to diseases, proximity of wildlife and cattle density). In order to increase the interest of farmers towards a specific BSM, the efficacy of the BSM against a disease perceived as having an important negative impact should be emphasized. The farmer would then have a higher perception of the BSM benefits. As most BSM are not disease-specific but rather address a risk of transmission, awareness campaigns should focus on the diseases considered as important by farmers instead of focusing on the public health interest or prevention of emerging diseases that have yet to be detected in the region (or the country). As an example, a Belgian farmer might not be motivated to implement a quarantine to prevent the introduction of lumpy skin disease in the farm, as it is still exotic to Belgium to date; she/he does not perceive the risk while this same farmer might accept more easily to enter a BVD eradication program.

Table 6 – List of prioritization criteria used in different disease prioritization exercises

Reference	**Disease epidemiology**									**Disease impact on**				
	Occurrence	Burden	Control measures / treatment	Epidemic potential	Potential threat	Reservoirs or high resistance in environment	Affected species	Animal-human or human-animal transmission	human-human transmission	Social / Public perception	Environment	Human health	Economy	Trade
WHO, 2006		X	X	X	X					X			X	
CVOs, 2008	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cardoen *et al.*, 2009	X												X	
Havelaar *et al.*, 2010	X	X			X	X		X	X					
Phylum, 2010	X	X	X	X	X	X	X	X	X	X	X	X	X	
Balabanova *et al.*, 2011		X	X	X	X									
Group, 2012			X									X	X	X
Humblet *et al.*, 2012	X	X	X	X	X	X	X	X	X	X	X	X	X	X
McIntyre *et al.*, 2014	X	X	X	X	X	X	X			X		X	X	X
DISCONTOOLS, 2016														
ANSES, 2012	X	X	X	X	X	X	X			X	X	X	X	X
Ciliberti *et al.*, 2015	X			X	X	X	X							
Gibbens *et al.*, 2016	X	X	X	X	X	X	X	X	X	X	X	X	X	X

5.2. Cost- effectiveness analysis of the biosecurity measures

Among the factors determining the adoption of BSM by farmers, the importance/utility of the BSM, as well as the expected positive outcomes, have frequently been identified as the most important factors. Their cost is also frequently listed as one the reasons for not implementing a BSM. Therefore, evidence-based studies assessing BSM efficiency and their ratio cost-benefit are necessary to increase their adoption by farmers and identify the most efficient measures to recommend.

Several disease-specific reviews and studies were implemented over time in order to document the relative risk of outbreak or occurrence of a disease based on the BSM implemented or existing risks. Several methods have been applied, such as: (i) Hazard Analysis and Critical Control Point (HACCP) related framework and mathematical models applied to on-farm practices based on hazard identification, exposure management, risk characterisation and risk management strategies (Wells, 2000; Maunsell and Donovan, 2008), (ii) literature reviews focusing on the transmission routes, associated risks and management (Van Winden, Stevens and McGowan, 2005; John F. Mee *et al.*, 2012) and (iii), field trials (O'Connor *et al.*, 2001; Logue *et al.*, 2012; Krogh and Enevoldsen, 2014; Godden *et al.*, 2015). Several studies also prioritized the BSM for specific diseases. In the relative absence of evidence-based studies, the prioritization is usually performed by collecting experts' opinion on the relative importance of BSM towards the prevention and/or control of a particular disease. Several ranking methods were used for such purpose: the Delphi method (Kuster *et al.*, 2015), the best-worst scaling (Shortall *et al.*, 2017), the conjoint analysis (Horst, Huirne and Dijkhuizen, 1996; Van Schaik *et al.*, 1998) or different questionnaires using a Likert scale, proportional ranking (Sorensen *et al.*, 2002) or any other ranking method .

These studies provide a clear indication of the potential efficiency of BSM addressing different risks or diseases. Nevertheless, such approach underestimates the BSM benefits as they usually focus on one or a few diseases and usually do not consider all possible conditions. In addition, it is difficult to extrapolate the results of controlled field experiments to farms, due to the large variability of practices and environments (Kuster, et al., 2015). Based on an extensive literature review on cattle diseases and their transmission routes, it is nevertheless possible to list the number of diseases potentially addressed by each BSM. Such approach allows identifying the BSM addressing the larger number of diseases (**Appendix 2**).

Few studies have analysed the cost-benefit ratio of BSM. These studies were either disease-specific, such as control strategies ensuring the cost-effectiveness of national control programs, or measure-specific, such as vaccination and testing (**Table 7**). When considering biosecurity as a whole or non-specific BSM such as general hygiene or quarantine, it becomes much more difficult to assess BSM costs and financial benefits.

Table 7 – Examples of published cost-benefits studies

Reference	Country	Disease concerned	Biosecurity measure
Ali *et al.*, 2018	Pakistan	Helminths	Anthelmintic treatments
Aly *et al.*, 2012	United States of America	*Mycobacterium avium* subspecies *paratuberculosis*	Diagnostic strategies to identify super-shedder cows
Beck, Wise and Dodd, 1992	United Kingdom	Bovine mastitis	Dry-cow therapy and teat dipping or spraying
Bernués, Manrique and Maza, 1997	Spain (mountain area)	Bovine brucellosis and tuberculosis eradication programmes	Eradication programs
Cargnel *et al.*, 2018	Belgium	Bluetongue caused by serotype-8 bluetongue virus	Cost sharing vaccination
Dubrovsky *et al.*, 2020	California	Bovine respiratory diseases	Two control measures: - an increased amount of milk fed from birth to 21 days of age - vaccination of reproductive cows
Gethmann *et al.*, 2019	Germany	Bovine Viral Diarrhoea	Control strategies
Gethmann J, Probst C, Sauter-Louis C, 2015	Germany	BSE and Bluetongue disease as examples	Economic analysis of outbreaks
Groenendaal *et al.*, 2015	United States of America	Paratuberculosis in dairy cattle tests.	Vaccination
Hénaux and Calavas, 2017	France	Bovine brucellosis	Costs of the current surveillance system
Larson, Hardin and Pierce, 2004	United States of America	*Neospora caninum*-induced abortions in endemic beef herds.	Diagnostic and control options
Poirier *et al.*, 2019	France	Bovine tuberculosis	Mandatory surveillance protocols
Santman-Berends *et al.*, 2015	The Netherlands	Bovine viral diarrhoea	Control scenarios
van Schaik *et al*,1996.	The Netherlands	Paratuberculosis in dairy cattle.	Vaccination

6. The role and responsibilities of the rural veterinarians regarding biosecurity

Rural veterinarians are key actors of biosecurity in cattle farming as they can provide technical guidance but, as professional visitors, they could also play a role in disease transmission and are at risk of contracting zoonotic diseases.

6.1. Role and responsibility in terms of technical guidance

As animal health professional, rural veterinarians are major guidance counsellors with regard to biosecurity. They are considered as key referents by the farmers in comparison to governmental agencies which are usually not trusted (Rehman *et al.*, 2007; Gunn *et al.*, 2008; Heffernan *et al.*, 2008b; Brennan and Christley, 2013; Toma *et al.*, 2013; Garforth, 2015; Moya *et al.*, 2019). Nevertheless, the involvement of veterinarians in providing biosecurity advices and their perceived skill to do so have been questioned in several studies (Gunn *et al.*, 2008; Pritchard, 2010; Jansen and Lam, 2012). In addition, an increasing number of non-veterinarians have developed an on-farm preventive advisory consultancy in animal herds and management using an 'aggressive' marketing strategy. Veterinary practitioners consider themselves as health professionals rather than as businessmen (Ruston *et al.*, 2016). It is therefore important that veterinary practitioners assert themselves more actively in preventive medicine by promoting advisory services and reinforcing their leading position and expertise in terms of animal health management.

Several constraints or perceptions prevent the veterinary practitioners to adapt to this new market context and focus on disease prevention by providing specialized consultancies and guidance to farmers. The lack of time appears to be a major issue for a majority of veterinarians (Gunn et al., 2008; Pritchard, Wapenaar and Brennan, 2015; Shortall et al., 2016). This is especially important as dedicating some time to guidance does influence the adoption of BSM by farmers (Enticott, Franklin and Van Winden, 2012). In terms of communication and time management, it is also advised to separate curative and preventive services, as their respective objectives and expectations are different (Kleen, Atkinson and Noordhuizen, 2011). Indeed, curative services is problem-orientated in order to solve an acute health problem while preventive services address long-term performance issues.

Veterinarians also feel frustrated and reluctant to advise on biosecurity as they perceive a lack of interest by farmers or their unwillingness to invest in biosecurity (Gunn et al., 2008; Sayers, Good and Sayers, 2014; Shortall et al., 2016). The veterinarians who provide such advices mention few effective changes and a poor adoption of good practices by the farmers. Veterinarians mention the following barriers against the adoption of BSM by farmers: lack of knowledge and understanding (Pritchard, Wapenaar and Brennan, 2015), lack of time, resistance to change as well as financial and logistical constraints. Indeed, the farm design is not always adapted to an appropriate implementation of BSM and cannot be modified easily (e.g. absence of space for a separated quarantine area, impossibility to avoid contact with wildlife in pastures) (Gunn et al., 2008; Pritchard, Wapenaar and Brennan, 2015; Shortall et al., 2016). They also believe that some measures are difficult to implement, e.g. prevention of contacts with wildlife and neighboring stock, work with a closed herd or avoidance of feed and water contamination (Humphry et al., 2012).

Surveys also highlighted that veterinarians would not engage in the topic in the absence of specific request from farmers and consider that providing such advices is time-consuming and farmers do not want to pay for such services (Gunn *et al.*, 2008; Sayers, Good and Sayers, 2014; Pritchard, Wapenaar and Brennan, 2015). This appears to be a perception preventing most veterinarians from proposing paid biosecurity advices while some non-veterinary consultants are already developing, and are being paid for, this type of service (Sayers, Good and Sayers, 2014; Ruston *et al.*, 2016). As mentioned in a previous study, herd health and production management services are now being provided in many countries with a clear interest expressed by the farmers (Lievaart *et al.*, 2008). Cattle holders not yet engaged in such services mentioned they would consider to do so if there was more clarity on the service and its costs, if they had an uncontrollable problem or based on other farmers' advices.

As mentioned previously, the lack of knowledge and consistency on the best biosecurity practices to be recommended feed farmers' concerns about BSM and lead to a general confusion. Some veterinarians do not believe that implementing BSM will benefit their clients. Such lack of knowledge among veterinary professionals could therefore represent a major challenge to a shift from curative to preventive medicine (Gunn *et al.*, 2008; Sayers, Good and Sayers, 2014; Shortall *et al.*, 2016) as well as a certain lack of interest (Gunn *et al.*, 2008). There is a need for standardized information and improved communication among animal health professionals (e.g.: vet practitioners, dairy advisors and biosecurity consultants) (Sayers, Good and Sayers, 2014; Shortall *et al.*, 2016).

In addition, veterinarians providing time and advices on biosecurity reported being frustrated by the lack of actual changes and having interpersonal problems with the farmers which compromise the implementation of BSM (Shortall *et al.*, 2016). It appears from several studies that veterinarians and farmers have different goals and objectives leading to misunderstandings (Derks *et al.*, 2013). They should dedicate additional time to establish clear and shared objectives and priorities to ensure a better compliance with advices provided. The communication skills of veterinarians could therefore play a key role, as well as the establishment of a dialogue and the involvement of the farmer into the identification of solutions acceptable for both parties (Shortall *et al.*, 2016).

6.2. Role and responsibility in terms of disease control and public health

As animal health professionals, rural veterinarians have a responsibility towards animal health by preventing the dissemination of diseases as well as a public responsibility to preserve human and environmental health. Based on the One Health concept, veterinarians play an essential role in protecting animal, human and environmental health as they work at the interface of animals, humans and environment (Van Herten and Meijboom, 2019; FEV and AVMA, 2021). Independently of their responsibility of treating animals and preventing further contaminations, they do play an important role in controlling zoonoses, ensuring food safety of products and sub-products of animal origin and contributing to public health (e.g. through the reduction of antimicrobial or anthelmintic resistance). If most of their missions are fulfilled by routine practices and guidance on biosecurity, veterinarians are a biosecurity risk as professional visitors (van Schaik *et al.*, 1998; John F Mee *et al.*, 2012; Kuster *et al.*, 2015). They are also at risk of contracting zoonoses due to their frequent and close contacts with animals (Baker and Gray, 2009; Sánchez *et al.*, 2017). It is therefore their responsibility to avoid any further animal, human and environmental contamination by spreading pathogens outside a farm and/or introducing them into a farm.

Several reviews and original articles have listed the BSM to be implemented by veterinarians in order to prevent the introduction of a pathogen in a farm (bio-exclusion), the spread of a pathogen within and outside a farm (bio-compartmentation and bio-containment) as well as environmental or human contaminations, including to himself (bio-preservation and bio-conservation) (Elchos *et al.*, 2008; Venkat, Yaglom and Adams, 2019). A list summarizing these measures is presented in **Table 8**.

Few studies assessed the implementation level of such measures by rural practitioners but they highlighted the need for enforcements and a poor implementation of some measures. A study in the United Kingdom (UK) revealed that among 62 respondents, 100% stated knowing the term biosecurity, while none of them mentioned the prevention of disease spreading between farms and only 26% of them mentioned the prevention of diseases introduction onto a farm (Pritchard, Wapenaar and Brennan, 2015). Studies carried out in the United States (US) reported that only 17% of veterinarians change overalls before every visit to a farm (Hoe and Ruegg, 2006) and that many of them used a single needle for up to 20 animals (Anderson, 2012).

Among the different constraints expressed by the veterinarians, some are related to the farm conditions such as the lack of access to soap or water, the absence of water hose with sufficient pressure for boot cleansing, and the absence of on-farm protective clothing and boots for visitors. The lack of time and organisational difficulties are other constraints (Anderson, 2012; Nöremark and Sternberg-Lewerin, 2014). Based on previous studies, it is important for veterinarians and farmers to communicate and agree on their respective responsibilities as both parties have different expectations. Veterinarians would expect the farmer to provide the needed facilities and equipment while the farmer might consider that it is the veterinarian's responsibility (Nöremark and Sternberg-Lewerin, 2014). Farmers should also be more restrictive towards visitors and ensure their compliance to basic rules and protocols instead of relying on the visitors' professional responsibility. It has been proven that, independently of the visitors' attitude towards biosecurity, their behaviour on farm is influenced by the farmers' requirements and the practical and physical conditions on site (Nöremark, Frössling and Lewerin, 2010).

Table 8 – List of different biosecurity measures that should be implemented by veterinarians

1. Clothing
If no clothing is provided by the farmer, change clothes before entering a farm
Use disposable clothing for surgeries
2. Boots
Ideally, use on-farm boots
Cleansing, brushing and disinfection of boots before and after exiting each barn
Use of disposable over-boots
3. Gloves, hands hygiene and masks
Use of disposable gloves when manipulating sick animals
Glove change between animals or animal groups
Washing and disinfection of hands between animals or animal groups
Use of facial protection (mask and safety google) if there is a risk of splashes
4. Medical materials and equipment
Single-use needles
Single-use scalpel and razor blades
Cleansing and disinfection of all re-usable material after use
Correct sterilization all surgical instruments or reusables materials after use
Use of a container for biologically contaminated waste along
5. Work organization
Organisation of visits based on the risk of contaminations
No necropsy performed on site
No pets along during the visits
No parking of the vehicle inside the animal keeping facilities
Regular cleansing and disinfection of the professional vehicle
Prevention of animal injuries through a correct contention
Prevention of needlestick injuries by throwing uncapped needles in specific containers directly after use
Not drinking or eating in animal transit areas
Vaccination against rabies, tetanos and eventually influenza (if working with poultry or pigs)
Follow-up of continuing education

Chap. 2 - Objectives

1. General objective

The overall objective of this thesis is to provide a better and adapted guidance to Belgian cattle farmers to increase the biosecurity level of their premises and their resilience towards infectious diseases.

Specific objectives

For the last decades, cattle holders were asked to implement BSM to prevent infectious diseases and increase the quality of animal products and sub-products. Not all BSM can be implemented at the same time. They should be prioritised based on the needs and their relevance. This could generate some conflicts as the needs of cattle farmers might differ from the needs of the society. The first specific objective will be **to identify the most important animal and public health** issues to be addressed in Belgium **and related BSM** in order to identify the most important measures to be promoted and enforced (Study 1).

The second specific objective will be to assess the **actual implementation level of BSM in Belgian cattle farms** and to understand the different constraints and experiences of cattle farmers regarding the BSM (Study 2).

The third specific objective, and probably one of the most important elements, will be to **understand the factors determining the adoption of BSM** by cattle farmers (Study 3).

The fourth specific objective will be to **assess the possible economic benefits for cattle farmers if they implement BSM** in order to better convince them of their benefit(s). This specific objective will be reached through the implementation of evidence-based studies (Studies 4 and 5).

In a cattle farm, professional visitors represent a high risk of introduction and transmission of infectious diseases. Among the professional visitors, veterinarians play an important and specific role, not only in providing guidance and technical advices, but also as a possible vector of infectious diseases. Mitigation of risks is one of their professional responsibilities. The fifth specific objective is therefore to investigate the **attitude and behaviours of rural veterinarians** as actors and possible guidance counsellors **in biosecurity** (Study 6) but also as professionals at risk of zoonoses (Study 7).

Chap. 3 – Experimental section

Experimental section

Study 1

Classification of adult cattle diseases: a first step towards prioritization of biosecurity measures

Transboundary and Emerging Diseases 2018, 65:1991-2005

Véronique Renault, Bert Damiaans, Steven Sarrazin, Marie-France Humblet, Marc Lomba, Stefaan Ribbens, Flavien Riocreux, Frank Koenen, Dominique Cassart, Jeroen Dewulf and Claude Saegerman.

Preamble

Cattle farmers willing to improve their biosecurity level will usually need to prioritize measures to implement, based on different criteria among which, the BSM importance or relevance vs. the most frequent animal diseases threatening her/his herd.

One way to advise cattle farmers on the BSM to prioritize would therefore be to list the measures related to the most frequent cattle diseases in the Belgian context. Nevertheless, the OIE or Federal Agency for the Safety of the Food Chain (FASFC) list of notifiable diseases rely on public and economic criteria and do not always reflect the most frequent diseases encountered in the field. Indeed, many of the diseases that are listed have not been reported in a long time or are still exotic to Belgium to date.

The objective of this study was to identify the most important infectious diseases affecting cattle in the Belgian context and the BSM allowing their control and prevention, as a first step of a BSM prioritization process.

In order to prioritize the diseases in the Belgian context, the list of notifiable diseases in effect in Belgium were considered. Furthermore, other prioritization exercises that considered other criteria (e.g.: zoonosis and cattle diseases affecting wildlife) as well as a veterinary survey and the laboratory data were also considered in order to identify the infectious diseases most frequently encountered in the field. An Excel® tool and scoring system was then developed in order to prioritize the diseases. At last, a literature review targeted the main cattle diseases in order to list the respective BSM.

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ORIGINAL ARTICLE

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Classification of adult cattle infectious diseases: A first step towards prioritization of biosecurity measures

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Abstract

An emphasis on biosecurity in the cattle industry was made over the years to improve animal and public health. Nevertheless, the level of implementation of biosecurity measures (BSM) remains largely insufficient due to certain constraints. It is therefore necessary to prioritize the different BSM to be applied in accordance with the individual context and the main infectious diseases affecting cattle. Previous prioritization exercises of infectious diseases were neither specific to Belgium nor based on an exhaustive list of diseases. This study aimed at classifying the most important infectious diseases affecting cattle in Belgium. A list of 74 cattle infectious diseases reported in Europe was compiled based on a literature review. Through an online survey, Belgian rural veterinary practitioners (RVP) were asked to assign a score to each disease according to their frequency (question 1), their trends estimated between 2013-15 (question 2), and finally to list the five most important diseases for adult cattle (question 3). Respectively, 107 and 93 RVP answered the first two questions and the last one. Results of the survey were used to classify the diseases based on their frequency, trends, and importance through an additional weighting system and a subsequent regression tree analysis. Belgian laboratory databases and previous disease prioritization exercises were also analysed and taken into account as additional data sources. For the most important diseases identified (those ranked as important by the three data sources), a literature review was performed in PubMed to identify their related risk factors and BSM. A total of 48 infectious diseases were classified as important in Belgium with six of them considered as important from the three data sources: bovine respiratory diseases (BRD), bovine respiratory syncytial virus (BRSV), bovine viral diarrhoea (BVD), infectious bovine rhinotracheitis (IBR), Q fever, and salmonellosis. Their related BSM should be prioritized in terms of BSM implementation.

Keywords

Belgium, biosecurity, cattle, classification, diseases, laboratory, prioritization, ranking, survey, trend, veterinarians

1 | INTRODUCTION

Cattle farming is one of the main food-production species in Belgium. Over the last few years, a shift from curative towards preventive medicine has been observed in the livestock sector and represents a key element of the European Union Animal Health Strategy since 2007 (European Comission, 2007). Nevertheless, several surveys highlight a low implementation level of biosecurity measures (BSM) by the farmers with different constraints expressed such as cost, usefulness, workload, and lack of clarity on the measures (Brennan & Christley, 2013; Gunn, Heffernan, Hall, McLeod, & Hovi, 2008; Hoe & Ruegg, 2006; Kristensen & Jakobsen, 2011; Nöremark, Frössling, & Lewerin, 2010; Sarrazin, Cay, Laureyns, & Dewulf, 2014; Sayers et al., 2013). The rate of implementation of BSM seems even lower in cattle farms versus pig or poultry production facilities (Sarrazin et al., 2014). To better advise cattle farmers and increase their level of implementation, it is essential to prioritize the biosecurity measures, according to the most important infectious diseases affecting or threatening Belgian cattle.

Based on the need to prioritize the infectious diseases (further referred to as diseases only) to address in terms of disease surveillance, control and eradication programs, many prioritization, or categorization exercises were conducted over the last few years. Given the lack of prevalence data for most cattle diseases, most of them followed the Delphi methodology (WHO, 2006) based on: (a) the establishment of an initial list of diseases, (b) the development of a prioritization methodology translated into a questionnaire, and (c) ranking or scoring of the different diseases by a panel of experts. The Delphi method based on a consensus approach has many advantages (e.g., no need of scientific evidence as it relies on experts′ opinion which can be modified through debates and avoids personal and political influence as a consensus is needed) and is recognized by the scientific community worldwide since its development by the RAND Corporation in the late 1960's. The recent prioritization exercises identified in the literature (ANSES, 2012; Ciliberti, Gavier-Widén, Yon, Hutchings, & Artois, 2015; DISCONTOOLS, 2016; Havelaar et al., 2010; Humblet et al., 2012; McIntyre et al., 2014) were quantitative, semiquantitative, or qualitative and based on the Delphi method with the exception of two. One of them was based on the H-index (McIntyre et al., 2014) and the second one on a literature review with a scoring and weighting system applied and validated by a panel of experts (Humblet et al., 2012) (Supporting Information Table S1).

Nevertheless, these scoring systems rely solely on expert's opinion and results will vary depending on: initial list of diseases to be assessed, criteria used, ranking methodology proposed, objective of the prioritization exercise, and available resources (e.g., time and quality of the expert panel involved). In addition, most of them did not consider multipathogen diseases such as mastitis, respiratory diseases, and diarrhoea, which are usually a major concern for both animal and public health and should not be automatically omitted.

The objectives of this study are to (a) identify major diseases of concern for Belgian cattle holders and their related BSM using a prioritization methodology based on the outcomes of a veterinary survey, the analysis of 3-year laboratory databases and the review of previous prioritization articles and (b) summarize BSM related to the six most important diseases of concern, i.e., the only diseases defined as important by the three data sources following the classification process described in Figure 1.

2 |MATERIAL AND METHODS

2.1 |Initial list of cattle infectious diseases

An initial list of infectious cattle diseases was established based on several sources. The list provided by the Center for Food Security and Public Health, Iowa State University (http://www.cfsph.iastate.edu/DiseaseInfo/index.php) was used and completed by the review of five reference books on cattle diseases (Andrews, Blowey, Boyd, & Roger, 2008; Francoz & Yvon, 2014; Institut de l'Elevage, 2000; Kahrs, 2001; Scott, Penny, & Macrae, 2011), prioritization articles (Ciliberti et al., 2015; McIntyre et al., 2014; Phylum, 2010), diseases listed by the World Organisation for Animal Health

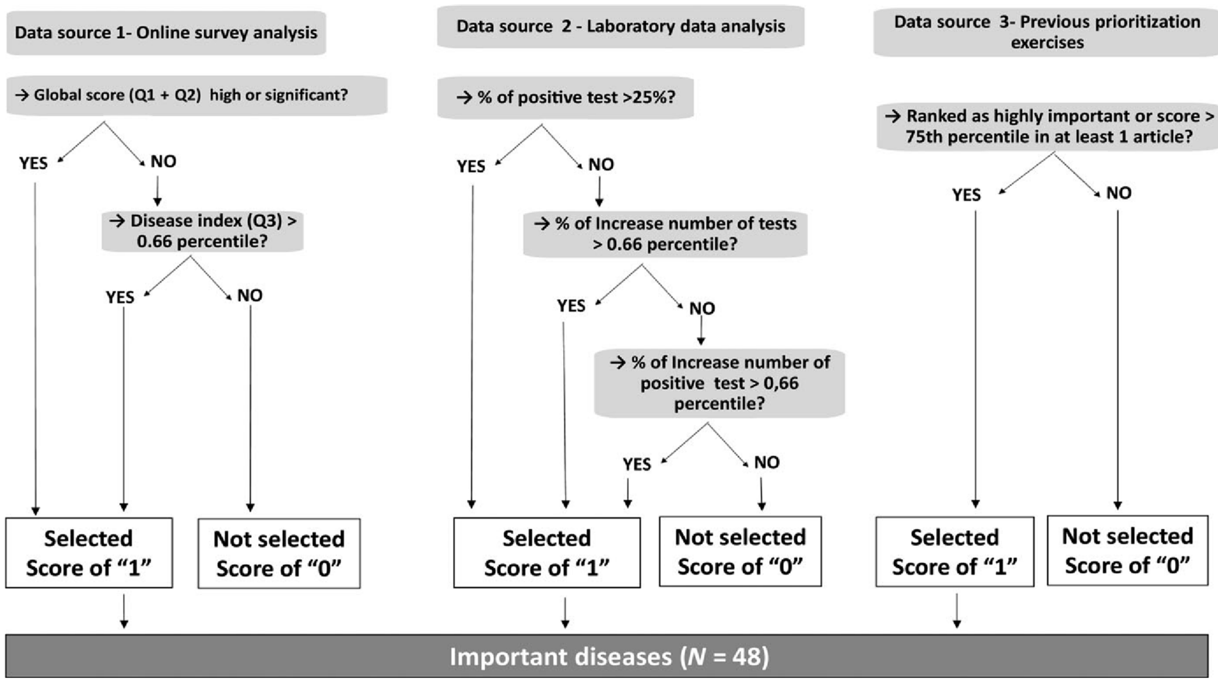

FIGURE 1 Selection criteria for the most important diseases to consider

(OIE), as well as diseases notifiable to the Belgian Federal Agency for the Safety of the Food Chain (FASFC).

Information regarding disease occurrence and importance in Europe and Belgium was collected from the FASFC (AFSCA, 2017a,b), European Centre for Disease Prevention and Control (ECDC, 2017; EFSA-ECDC, 2015) and OIE websites and last reports (FAAV/WIV/ CODA-CERVA, 2015). The diseases for which the occurrence or existence in Europe or Belgium was not specified in those sources, a literature review was performed based on a web search in PubMed with the following combinations of terms: "name of the disease" or "name of the pathogen" and "Belgium" and/or "Europe" to complete the information. A list of 90 diseases was established with their occurrence in Europe and in Belgium, their OIE status in Belgium and basic epidemiological data (last occurrence in Belgium and zoonotic character) (Supporting Information Table S2).

2.2 | Veterinary survey (Datasource 1, DS1)

In order to maintain the length of the questionnaire addressed to the rural veterinary practitioners (RVP) to the minimum, 31 diseases were excluded from the initial list of 90 diseases (16 diseases with no occurrences in Europe and 15 diseases with no occurrences in Belgium). The RVP were contacted on line through the two regional animal health organizations of the country, i.e., Association Régionale de Santé et d'Identification Animale (ARSIA) in Wallonia (southern part of the country) and Dierengezondheidszorg Vlaanderen (DGZ) in Flanders (northern part of the country) with monthly reminders over 4 months. The questionnaire was anonymous, available in French and Dutch version and could only be filled once by the same IP address. The number of persons included in the mailing list of the two organizations are respectively of 1876 and 1356 including both rural and small animal's practitioners as it was not possible to identify the part of RVP within these mailing lists. In Wallonia, the RVP workforce (534 veterinarians having a rural practice out of 1876 veterinarians), was provided for each of the five provinces, by the Board of Veterinary Practitioners. A chi square test has been performed to assess that the sample of responding RVP is not unbalanced from one province to another. The counterpart workforce for Flanders was not available; indeed, in that region, veterinary practitioners have no obligation to provide details on their practices to the Regional Board.

The survey was pretested by four veterinarians before its final validation and included three questions in order to assess the frequency, 3-year trend and the importance of each disease for the Belgian cattle sector. In the first question (Q1), RVP had to assign a score to each disease related to their average frequency based on the following scoring system: (a) never suspected, (b) suspected but never confirmed, (c) several times a year/occasionally, (d) at least once per quarter, and (e) several times a month.

In the second question (Q2), RVP were asked if the disease trend over the last 3 years was decreasing (score of 0), constant (score of 1), or increasing (score of 2).

The third question (Q3) was an open question where RVP were asked to list, in decreasing order of importance, the five main diseases affecting adult cattle; that information would help triangulating the information and identifying eventual diseases of importance omitted in the initial list. Each disease was assigned a score of 1 to 5, depending on its position in the list: (1) fifth disease listed, (2) fourth disease listed, (3) third disease listed, (4) second disease listed, and (5) first disease listed.

The answers to Q1 and Q2 were respectively used to calculate an average frequency score (af) and average trend score (at), for each disease. A global score per disease (GS) was then calculated by adding both averages.

$$GS_{(disease\ X)} = af_{(disease\ X)} + at_{(disease\ X)} \qquad (1)$$

A regression tree analysis based on the GS of the different diseases identified and classified the most important diseases to consider, from the RVP's perspective. The regression tree methodology is a nonlinear and nonparametric test increasingly used by the scientific community in public and animal health. It divides the population (in our case, the diseases) into different subgroups in relation to the GS with minimal within-variance by using cross-validation (Lemon, Roy, Clark, Friedmann, & Rakowski, 2003; Saegerman, Porter, & Humblet, 2011; Salford Systems, 2001).

Q3 was analysed separately. The analysis excluded noninfectious diseases such as foreign bodies and metabolic disorders, as mentioned by the RVP. The list of diseases was standardized in terms of disease denomination and consolidated. A disease index was then calculated for each disease by adding all its scores based on RVPs' ranking. In order to identify the most important diseases, the 66th centile of the disease indexes was used as a threshold (index above 66th centile).

From the veterinary survey (DS 1), a score of "1" was attributed to (a) all diseases with a GS classified as high or important in the regression tree analysis (Table 1), and (b) all diseases having a disease index above the calculated 66th centile).

2.3 |Laboratory databases (DS2)

Due to the subjective character of the veterinary survey (DS1), the risk of underestimating some important diseases was not to be neglected, e.g., (re)emerging diseases with no occurrence in Belgium, and major zoonoses with a slight impact on cattle. These diseases were initially identified through the analysis of laboratory databases (DS2) provided by two regional animal health organizations, i.e., ARSIA in Wallonia (southern part of the country) and DGZ in Flanders (northern part of the country). These regional databases compiled the number of tests performed on cattle, per year and age category (adult, calves, and newborns) and their result (positive/negative), over a 3-year period (2013 to 2015). The Veterinary and Agrochemical Research Centre (CODACERVA), the national reference laboratory, provided additional data covering the period between 2012 and 2014. For each disease, the annual number of tests and the proportion of positive results were analysed. Diseases were considered equally important and attributed a score of "1" if, in at least one laboratory, one of the following arbitrary conditions was recorded: (i) >100 tests performed, (ii) >25% positive results, (iii) increasing number of tests

TABLE 1 Classification of diseases, per category, based on the Regression Tree analysis of global score (GS), according to participants' responses for questions 1 and 2 (*N* = 107)

High GS (score = 4)	Significant GS (score = 3)	Moderate GS (score = 2)	Low GS (score = 1)
BRD	BVD	Actinobacillosis	Ankylostomosis
BRSV	Dermatophytosis	Actinomycosis	Anthrax
Coccidiosis	Distomatosis	Anaplasmosis	Aspergillosis
(Inter)digital dermatitis	Enterotoxaemia	Babesiosis	Aujeszky's disease
Diarrhoea	Giardiasis	Bluetongue	BSE
Intestinal Parasitism	Haemorragic enteritis	Botulism	BoT
Lice and ectoparasitism	Infectious bovine keratoconjuntivitis	Chlamydiosis	Besnoitiosis
Mastitis	Necrobacillosis	Cryptococcosis	Brucellosis
Mycoplasmosis	Q fever	Cysticercosis Dermatophilosis	Campylobacteriosis
Neosporosis	Salmonellosis	Enterotoxaemia (*Clostridium* spp)	Cowpox
Paratuberculosis	Colibacillosis (verotoxic *E. Coli*)	IBR	Echinococcosis
Pasteurellosis		Leptospirosis	Encephalitis
Scabies		Listeriosis	FMD
		Lyme disease	Hypodermosis
		Papillomatosis	Malignant catarrhal fever
		Streptococcosis	Parafilariasis
		Toxi-infections	Pseudocowpox
		Tetanos	Rabies
			Sarcocystosis
			Schmallenberg disease
			Yersiniosis

Notes. BoTB: bovine tuberculosis; BRD: bovine respiratory diseases; BRSV: disease caused by the bovine respiratory syncytial virus; BSE: bovine spongiform encephalopathy; BVD: bovine viral diarrhoea; FMD: foot and mouth disease; IBR: infectious bovine rhinotracheitis.

Requested over the period of concern (>66th centile), or (iv) number of positive results (>66th centile). The tests linked to specific research projects were excluded from the analysis but the tests related to the official sampling scheme have been included.

2.4 |Review of recent diseases prioritization exercises (DS 3)

As a third data source (DS3), six recent prioritization exercises (Supporting Information Table S1) were assessed to identify important diseases in regards to different criteria: zoonotic character (Havelaar et al., 2010; McIntyre et al., 2014), ruminants-wildlife interactions (Ciliberti et al., 2015), European Union policies and priorities (5) and focus on food-producing animals (ANSES, 2012; Humblet et al., 2012). As scoring and/or classification system differed in all articles, diseases were re-classified (Table 2), as follows: 0 (not listed) to 4 (highest score/importance). Class 4 diseases of the different exercises as well as Class 3 diseases of the two articles focusing on food-producing animals, including zoonosis (due to the importance in terms of potential economic impact on farms) (ANSES, 2012; Humblet et al., 2012) were defined as important and assigned a final score of "1".

2.5 |Databases consolidation and analysis

An overall score (OS) was calculated by adding the scores of the three DS (veterinary survey, laboratory databases, and prioritization exercises) (Table 3). Following the process of disease selection (Figure 1), all diseases with an OS > 0 (defined as important by at least one DS) were added to the list of important diseases.

TABLE 2 Scoring system for the reviewing of recent prioritization exercises (literature) and selection criteria

References	Class 0	Class 1	Class 2	Class 3	Class 4	Selection criteria DS 3
Ciliberti et al. (2015)	Not listed	<25th percentile	< median	<75th percentile	**>75th percentile**	Class 4
ANSES (2012)	Not listed	<25th percentile	< median	**<75th percentile**	**>75th percentile**	Class 3 and 4
Humblet et al. (2012)	Not listed	Low imp.	Moderate imp.	**Sign. Imp.**	**High imp.**	Class 3 and 4
DISCONTOOLS project	Not listed	<25th percentile	< median	<75th percentile	**>75th percentile**	Class 4
Global ranking zoonoses (1) + (2)	Not listed	Low imp.	Moderate imp.	Medium imp.	**High imp.**	Class 4
(1) McIntyre et al. (2014)	Not listed	<25th percentile	< median	<75th percentile	>75th percentile	
(2) Havelaar et al. (2010)	Not listed	Low score		Medium score	High score	

Notes. DS: data source; Imp.: importance.. In bold: classes defined as important and being assigned a score of 1 for DS 3

2.6 |Synthesis of biosecurity measures related to the most important diseases identified

For the most important diseases identified (those ranked as important by the three data sources), a literature review was performed in PubMed to identify their related risk factors and biosecurity measures. The keywords used for the search were as follow: "name(s) of the disease" or "name(s) of the pathogen" and "cattle or bovine or cow or beef or calves or dairy" (if disease affecting multiple species only) and "epidemiology" or "pathogenesis" or "control" or "risk".

Among the articles selected, only those articles mentioning an analysis and/or the identification of disease-specific risk factors or BSM were fully read.

3 | RESULTS

3.1 | Veterinary survey

The first two questions were answered by 107 RVP, while 93 of them answered the third question. The Chi square test performed on Walloon survey showed no significant differences regarding the ratio of respondents per province and the distribution of the RVP per province (Chi square(4 df; $\alpha = 0.05$) = 4.98; p-value = 0.29).

A regression tree analysis, based on the GS, classified the diseases according to their importance. Out of the 74 diseases listed, 13 diseases were classified as being of high importance (mean = 5.157, STD = 0.345), 11 of significant importance (mean = 3.975, STD = 0.320), 19 of moderate importance (mean = 2.946, STD = 0.270), and 21 of low importance (mean = 2.118, STD = 0.228) (Table 1, Figures 2 and 3).

Two of the most frequent diseases (bovine viral diarrhoea [BVD] and disease caused by the bovine respiratory syncytial virus [BRSV]) presented a moderate trend, the majority of veterinary practitioners considering them as constant. Eleven diseases were perceived as increasing over the last three years, but with a low or moderate frequency: anaplasmosis, babesiosis, botulism, cryptococcosis, colibacillosis (verotoxic Escherichia coli), enterotoxaemia (Clostridium spp.), giardiasis, leptospirosis, Lyme disease, Q fever, and salmonellosis (Table 4).

The diseases with the lower trend scores, and therefore globally perceived as decreasing or stable in Belgium, were: foot and mouth disease (FMD), hypodermosis, rabies, actinobacillosis, actinomycosis, Aujeszky's disease, bovine spongiform encephalopathy (BSE), bluetongue, brucellosis, infectious bovine rhinotracheitis (IBR), and Schmallenberg disease.

From the analysis of the disease indexes, two diseases mentioned by the RVP and not listed initially were identified: metritis/endometritis and different infectious diseases grouped as secondary infections (septicaemia, umbilical infections, peritonitis/reticulitis, (peri-), and (poly)arthritis) (Figure 4). These two diseases were then added to the initial list of 90 diseases. Mastitis and (inter)digital dermatitis were, by far, the two most important diseases in terms of disease index and GS.

After analysing Q3, three diseases showed a high disease index (>66th centile) but without a high or significant GS: the two diseases not listed in the initial list of diseases, i.e., metritis/endometritis and secondary infections, and IBR, not classified as important by the regression tree analysis. These three diseases were thus classified as important.

3.2 | Laboratory databases

Analysis of laboratory databases revealed that an increasing number of tests or a high proportion of positive results was observed for 19 diseases. Six of them were not classified as important by the veterinary survey. A significantly increased number of tests was requested (>66th centile) for bluetongue, leptospirosis, and bovine enzootic leucosis (BEL) over the last 3 years. In addition, three diseases showed >25% positive results over the same period, i.e., cryptosporidiosis, Schmallenberg disease (>90% positive results), and bovine herpes virus 4 (Bo-HV4; not included in the initial list of diseases but added afterwards). For Bo-HV4, proportions of positive results reached 31% in ARSIA database versus 58% in DGZ database.

Fifteen diseases out of the 27 selected from the veterinary survey analysis are not showing an increased number of tests or percentage of positive tests over the last 3 years in DS 2 (Table 3).

3.3 |Diseases prioritization exercises

In addition to the 34 diseases selected as important based on veterinary survey and laboratory databases, 14 diseases were selected from this data source. Most of them were major zoonoses, OIE/ FASFC notifiable diseases and/or important cattle diseases which prevalence has been widely reduced by control programs: anaplasmosis, anthrax, Aujeszky's disease, babesiosis, bluetongue, botulism, BSE, brucellosis, campylobacteriosis, Crimean-Congo haemorragic fever (CCHF), cryptosporidiosis, cysticercosis, echinococcosis, FMD, leptospirosis, listeriosis, rabies, Schmallenberg disease, and bovine tuberculosis (boTB).

3.4 |Classification tool for adult cattle diseases in Belgium

Results of the final classification after application of the different filters are summarized in Table 3 for the 48 diseases considered as important. Six of them were identified as important by the three DS: BRD, BRSV, BVD, IBR, Q fever, and salmonellosis.

Fourteen diseases came out as important from at least two DS. Finally, 28 diseases were revealed by only one DS: 15 by prioritization exercises, 11 through the veterinary survey, and two based on laboratory databases (Bo-HV4 and BEL).

As a reminder, the initial list of diseases included 77 items (74 diseases initially listed and three diseases added during data analysis), thus 29 of them were not classified as important at the end of the process. They are listed in Supporting Information Table S2, along with the diseases with no occurrence in European countries.

3.5 |Synthesis of the biosecurity measures related to the six most important diseases

A total of 76 articles were reviewed: 6 for BRSV, 17 for BRD, 11 for BVD, 13 for IBR, 15 for Q fever, and 14 for salmonellosis (Supporting Information Table S3). A synthetic table of the six most important diseases-related BSM (Table 4) was developed (i.e., diseases identified by the three data sources). Due to similarities and frequent co-infections, BRSV was included in the BRD.

All six diseases can be transmitted by five possible pathways: direct and indirect contact, inhalation, ingestion, trans-placental/ venereal, and vector-borne. The BSM listed could be grouped into six different risk categories (animal movements, vertical and venereal transmission, direct contact with external shedders/carriers and vectors, feed and water contamination, indirect contamination through fomites, human and environmental contamination) as well as five different practices (general management, general hygiene practices, management of sick animals, calves, and calving management). Seventy-five percent of the 67 BSM listed contribute to the prevention and control of at least three diseases, while 27 BSM contribute controlling and preventing six of them. These measures mainly fall into the following categories: animal movements, contamination through fomites, and general management (e.g., housing density, proper ventilation, clean and dry bedding). Six preventive measures are disease-specific, i.e., (a) cemented floors/concrete floor for BRD, (b) tick control measures, manure treatment before spreading and/or spreading in the absence of wind for Q fever, and (c) preventing access to surface water and pH of drinking water below 8 for salmonellosis.

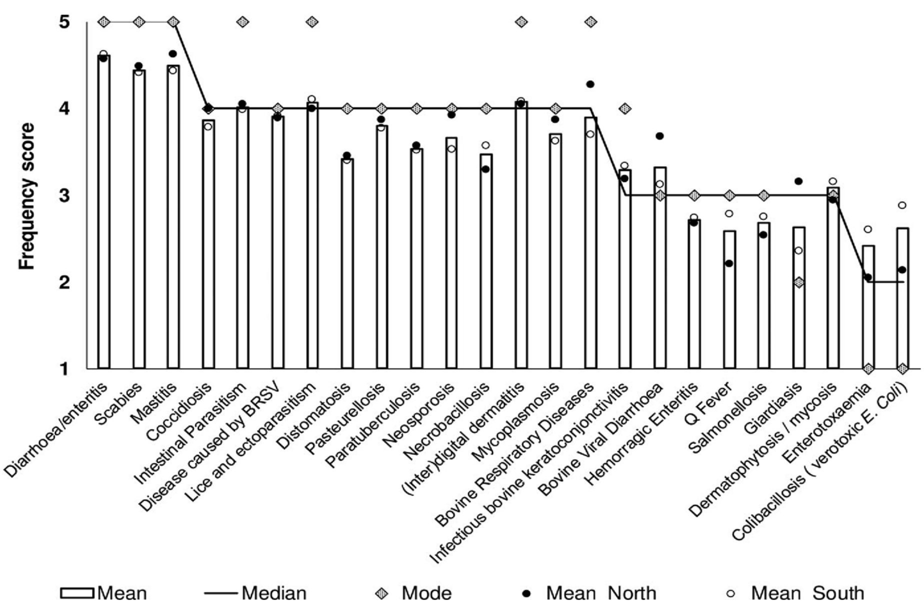

FIGURE 2 Reported frequency score of the 24 diseases of high or significant global score (N = 107)

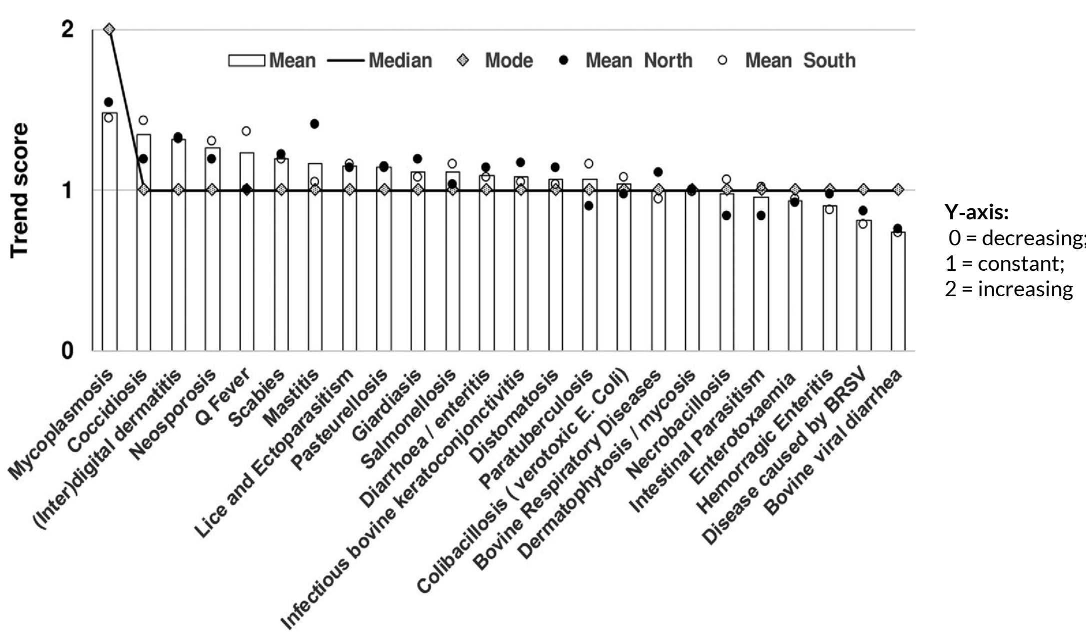

FIGURE 3 Reported trend score for the 24 diseases with a high or significant global score (N = 107)

TABLE 3 Classification of the 48 most important diseases

Disease	DS 1 (Online survey)			DS 2 (Laboratories)	DS 3 (Previous prioritisation exercises)						OS
	Global Score (RT category)	Disease index > 0.66 percentile	Score DS 1	Score DS 2	Ciliberti et al.,2015	Anses, 2012	Humblet et al., 2012	DISCONTOOL, 2016	Global zoonosis[a]	Score DS 3	
Diseases selected from the 3 data sources											
Bovine respiratory diseases	4	1	**1**	**1**	4	2	2	1	3	**1**	**3**
Disease caused by the bovine respiratory syncytial virus	4	1	**1**	**1**	4	2	2	1	3	**1**	**3**
Bovine viral diarrhoea	3	1	**1**	**1**	3	3	1	2	2	**1**	**3**
Infectious bovine rhinotracheitis	2	1	**1**	**1**	3	3	0	1	2	**1**	**3**
Q Fever	3	0	**1**	**1**	4	4	4	2	6	**1**	**3**
Salmonellosis	3	0	**1**	**1**	4	4	3	4	6	**1**	**3**
Diseases selected from 2 data sources											
Coccidiosis	4	0	**1**	**1**	1	0	0	3	0	0	**2**
Colibacillosis (verotoxic *E. coli*)	3	0	**1**	0	0	4	3	4	7	**1**	**2**
Cryptosporidiosis	0	0	0	**1**	0	3	0	4	4	**1**	**2**
Diarrhoea / enteritis	4	1	**1**	**1**	0	0	0	0	1	0	**2**
Distomatosis	3	1	**1**	**1**	1	2	0	2	3	0	**2**
Giardiasis	3	0	**1**	**1**	0	0	0	0	0	0	**2**
Intestinal parasitism	4	1	**1**	**1**	0	0	0	0	0	0	**2**
Leptospirosis	2	0	0	**1**	3	3	3	3	4	**1**	**2**
Lice and ectoparasitism	4	0	**1**	**1**	0	0	0	0	0	0	**2**
Listeriosis	2	0	0	**1**	3	4	0	0	4	**1**	**2**
Mycoplasmosis	4	1	**1**	0	4	2	2	1	3	**1**	**2**

(Continues)

TABLE 3 (Continued)

Disease	DS 1 (Online survey)			DS 2 (Laboratories)	DS 3 (Previous prioritisation exercises)						
	Global Score (RT category)	**Disease index > 0.66 percentile**	**Score DS 1**	**Score DS 2**	**Ciliberti et al., 2015**	**Anses, 2012**	**Humblet et al., 2012**	**DISCONTOOL, 2016**	**Global zoonosis[a]**	**Score DS 3**	**OS**
Paratuberculosis	4	1	**1**	0	4	4	2	3	2	**1**	**2**
Pasteurellosis	4	1	**1**	0	4	2	2	1	3	**1**	**2**
Schmallenberg disease	1	0	0	**1**	0	4	0	0	0	**1**	**2**
Coccidiosis	4	0	**1**	**1**	1	0	0	3	0	0	**2**
Diseases selected from 1 data source only											
Anaplasmosis/ Ehrlichiosis	2	0	0	0	2	0	3	0	5	1	1
Anthrax	1	0	0	0	4	4	4	3	4	1	1
Aujeszky’s Disease	1	0	0	0	4	0	2	0	0	1	1
Babesiosis (bovine)	2	0	0	0	3	0	3	0	1	1	1
Botulism	2	0	0	0	3	2	4	0	6	1	1
Bovine enzootic leucosis (BEL)	0	0	0	1	0	1	1	0	1	0	1
Bovine Herpes virus 4	0	0	0	1					0	0	1
Bovine Spongiform Encephalopathy	1	0	0	0	0	4	3	2	7	1	1
Brucellosis	1	0	0	0	4	0	3	4	5	1	1
Campylobacteriosis	1	0	0	0	2	1	2	2	8	1	1
Crimean-Congo Hemorrhagic Fever	0	0	0	0	4	0	3	1	4	1	1
Cysticercosis	2	0	0	0	0	3	0	4	0	1	1
Dermatophytosis /Mycosis	3	0	1	0	0	0	0	0	0	0	1
Echinococcosis	1	0	0	0	4	1	4	1	4	1	1

(Continues)

TABLE 3 (Continued)

Disease	DS 1 (Online survey)			DS 2 (Laboratories)	DS 3 (Previous prioritisation exercises)						
	Global Score (RT category)	Disease index > 0.66 percentile	Score DS 1	Score DS 2	Ciliberti et al., 2015	Anses, 2012	Humblet et al. , 2012	DISCONTOOL, 2016	Global zoonosis[a]	Score DS 3	OS
Enterotoxaemia	3	0	1	0	0	0	0	0	4	0	1
Foot and Mouth Disease	1	0	0	0	4	0	4	4	3	1	1
Infectious bovine keratoconjunctivitis	3	0	1	0	0	0	0	0	0	0	1
(Inter)digital dermatitis	4	1	1	0	0	0	0	0	0	0	1
Mastitis	4	1	1	0	0	0	2	1	7	0	1
Metritis	0	1	1	0					0	0	1
Necrobacillosis (laryngitis)	3	0	1	0	0	0	0	0	0	0	1
Neosporosis	4	1	1	0	0	1	0	0	0	0	1
Rabies	1	0	0	0	4	0	4	2	7	1	1
Scabies	4	1	1	0	2	1	0	0	0	0	1
Secondary infections	0	1	1	0					0	0	1
Tuberculosis (bovine)	1	0	0	0	4	4	4	4	8	1	1
Winter haemorragic enteritis	3	0	1	0	0	0	0	0	0	0	1
Anaplasmosis/ Ehrlichiosis	2	0	0	0	2	0	3	0	5	1	1
Anthrax	1	0	0	0	4	4	4	3	4	1	1
Aujeszky's disease	1	0	0	0	4	0	2	0	0	1	1
Babesiosis (bovine)	2	0	0	0	3	0	3	0	1	1	1
Botulism	2	0	0	0	3	2	4	0	6	1	1

Notes: [a] Havelaar et al., 2010; McIntyre et al., 2014

TABLE 4 Transmission pathways and biosecurity measures related to the six most important diseases: (a)Transmission pathways,(b) Biosecurity measures related to the diseases.

(a)

Transmission pathways	**Q Fever / Coxiellosis**	**Bovine respiratory diseases***	**Bovine viral diarrhoea**	**Infectious bovine rhinotracheitis**	**Salmonellosis (non typhoidal)**
Direct and indirect contact	Yes	Yes	Yes	Yes	Yes
Inhalation	Yes	Yes	Yes	Yes	Yes
Ingestion	Yes	Yes	Yes	No	Yes
Trans-placental and venereal	No	No	Yes	No	No
Vector	Yes (ticks)	No	No	No	No

(b)

Biosecurity measures	**Q Fever / Coxiellosis**	**Bovine respiratory diseasesa**	**Bovine viral diarrhoea**	**Infectious bovine rhinotracheitis**	**Salmonellosis (non typhoidal)**	**Total**
Animal movements						
Closed herd / No movements	2	2	2	2	2	[illegible]
All in/all out system of each age group and each separate stable	2	2	2	2	2	**5**
Divide calves in high and low risk groups based on veal calves risk classification	0	2	1	2	1	**4**
Purchase from a single source and collect history on the farm of origin (status, disease history, health management history)	2	2	2	2	2	**5**
Pre movement testing (against specific diseases)	2	2	2	2	1	**5**
Quarantine (3 weeks, separate area or building (3m distances) and testing for entering or re-entering animals	2	2	2	2	2	**5**
Good transport conditions: safely, in a clean truck, decent loading ramp, no overcrowding / commingling, calm handling, as short as possible, not passing through a sorting center	2	2	1	2	2	**5**
Vertical or venereal transmissions						
No breeding animals shared with other farms	1	0	2	1	0	**3**
Artificial insemination	0	0	2	2	0	**2**
Direct contact with external shedders/carriers and vectors						
Prevent contact in pastures with animals of neighbouring farms and wildlife (pigs and ruminants) (simple or doubles fences)	0	1	2	2	1	**4**
Closed housing / locked doors (prevent contact with pets, carnivores, rodents,… in stables)	0	2	2	1	1	**4**
Prevent access of pets in stables/ food storage facilities, manure/litter disposal facilities,…	0	0	2	1	2	**3**
Avoid piling manure	0	2	2	0	0	**2**

(Continues)

TABLE 4 (Continued)

(b)

Biosecurity measures	**Q Fever / Coxiellosis**	**Bovine respiratory diseasesa**	**Bovine viral diarrhoea**	**Infectious bovine rhinotracheitis**	**Salmonellosis (non typhoidal)**	**Total**
Preventive measures against ticks (acaricides and environmental measures)	2	0	0	0	0	**1**
Rodents control program	2	2	2	0	2	**4**
Food and water contamination byexternal shedders/carriers						
Storage of feed in clean and closed structures to prevent their contamination	0	2	0	0	2	**2**
Clean water and feed troughs regularly	0	2	2	1	2	**4**
No access to surface water/ Prevent access to running or stagnant water in pastures	0	0	0	0	2	**1**
Cleaning and disinfection of feeding utensils / Not using them for handling manure	0	2	2	2	2	**4**
pH drinking water under 8,0	0	0	0	0	2	**1**
Contamination through fomites						
Prevent contact of farmer or worker with animals from other farms	2	0	2	0	1	**3**
Access restriction for visitors + visitors control and register	2	2	2	2	1	**5**
Restriction of vehicle access / no vehicles in areas where animals are kept/ passing by, separate access routes	2	2	2	2	2	**5**
In-house or clean boots and clothes for visitors (availed by farmer)	2	2	2	2	2	**5**
Footbaths use and hand washing facilities	2	2	2	2	2	**5**
No equipment or vehicles shared with other farms	2	2	2	2	2	**5**
Animal transport vehicle and other vehicles leak proof and cleaned and disinfected before entry, through separate access routes.	2	2	2	2	1	**5**
General management						
Regular monitoring and recording of animal health	1	2	2	2	1	**5**
Identification and elimination/segregation of carriers/ infected animals by regular testing	2	2	2	2	2	**5**
Working from young to old animals	0	2	2	2	2	**4**
Avoid excessive stress or accumulation of stressful events (especially for calves)	0	2	0	2	2	**3**
Bedding/ litter removal; keeping fresh and clean beddings; no recycling of bedding	2	2	1	2	2	**5**
Cemented floors / concrete flooring	0	2	0	0	0	**1**
Tie stall or station facilities	2	2	0	2	2	**4**

(Continues)

TABLE 4 (Continued)

(b)

Biosecurity measures	Q Fever / Coxiellosis	Bovine respiratory diseasesa	Bovine Viral Diarrhoea	Infectious Bovine Rhinotracheitis	Salmonellosis (non typhoidal)	Total
Housing density	2	2	2	2	2	**5**
Good ventilation and air quality (positive pressure ventilation of >15 cubic ft. per minute per calf); maintaining a dry environment	2	2	1	2	1	**5**
House the animals per sex, no mixed groups	0	2	0	1	0	**2**
Proper feeding	0	2	1	0	2	**3**
Experience, training and awareness raising of cattle holders and workers	1	2	2	1	1	**5**
General hygiene practices						
Cleaning and disinfection of equipment after each use (calving, milking, …)	2	2	2	2	2	**5**
Proper cleaning and disinfection of surgical instruments and needles between each animals	2	0	2	2	0	**3**
Hygiene stables: sanitary vacancies, cleaning stables before introduction of new calves, steam or hot water, thorough drying of multiple days,	2	2	2	2	2	**5**
Personal ygiene of workers / farmer (boots, clothes, hands,etc.), especially between age groups	2	2	2	2	2	**5**
Management of sick or quarantined animals						
Quick recognition, isolation and treatment of sick animals	2	2	2	1	2	**5**
Sick animals treated last	1	2	2	1	2	**5**
Quarantine facilities and work organization (capacity = 2% total herds size, separate building, specific clothes and equipments, hands washing facilities, use of gloves)	1	2	2	2	2	**5**
Separate housing of relapses and chronic cases	1	2	2	0	0	**3**
Parturition						
Testing all cases of abortion	2	0	1	0	0	**2**
Maternity pen existent and separated from other areas, easy to clean and drain	2	2	2	2	2	**5**
Not using maternity pens for sick animals	2	2	2	1	2	**5**
Cleaning and disinfection (worker, animal and calving areas)	2	2	2	1	2	**5**
Immediate clearing of airways / navel dipping and disinfection	0	2	0	1	0	**2**
Immediate calf separation from the mother <--> keep the calf with cow for 24 hours (oldest)	0	2	0	1	2	**3**

(Continues)

TABLE 4 (Continued)

(b)

Biosecurity measures	**Q Fever / Coxiellosis**	**Bovine respiratory diseasesa**	**Bovine Viral Diarrhoea**	**Infectious Bovine Rhinotracheitis**	**Salmonellosis (non typhoidal)**	**Total**
Proper disposal of foetal membranes and tissues	2	0	1	0	0	**2**
Calves management						
Proper colostrum intake (delay, quality and quantity)	0	2	1	0	2	**3**
Sufficient supply of milk + proper quality (not infected / pasteurised, proper temperature) Milk quality control and proper quantity	0	2	1	0	0	**2**
Gradual supply of concentrates/hay for better adaptation to new diet	0	2	0	0	2	**2**
Individual hutches adapted (warm, dry, well bedded and ventilated) with no possible contacts between calves (>1.25m apart)	0	2	1	0	2	**3**
Daily cleaning of bedding and housing of calves (stress-free, dust-free)	0	2	1	1	2	**4**
Hutches cleaned, disinfected and thoroughly dried before housing new calves (also underneath)	0	2	1	0	2	**3**
Use of one bucket per calf with a teat / Cleaning the buckets after each feeding	0	0	1	0	1	**2**
Regrouping calves from individual hutches to group pens only after vaccination, with calves of same age and in small groups (7-10)	*0*	*2*	*2*	*2*	1	**4**
Calves and young stock separated from older animals and other age groups	0	2	2	2	2	**4**
Prevent human and environmental contamination						
Prevent human contamination (zoonosis)	2	0	0	0	2	**2**
Proper disposal of manure from other farms within 500 meters	0	0	2	0	1	**2**
Manure spreading in the absence of wind only	2	0	0	0	0	**1**
Manure treatment before spreading on soils (lime or calcium cyanide 0.4%).	2	0	0	0	0	**1**

Notes: [a]includes BRSV, mycoplasmosis, pasteurellosis, para influenza virus 3 and other respiratory diseases. Coding: “2” for measure listed in literature review either as addressing a specific risk factor or BSM; “1” for measure not found as such during the review, but should have an effect on the disease prevention and management due to its different transmission pathway.

4 | DISCUSSION

The most important diseases from different perspectives (farm, animal health, economical, environmental, and public health impacts) were identified using an original prioritization methodology based on the outcomes of three data sources and after correction of biases related to each of them. In particular, nineteen diseases not listed in the previous diseases prioritization exercises have been identified and represent a major concern for cattle holders while not necessarily addressed by a national control program for now.

Discrepancies between the vet survey (DS1) and laboratory data (DS2) for 13 diseases are mainly explained by the fact that they are usually diagnosed and treated in the field, on the basis of clinical signs. It is the case for the two diseases

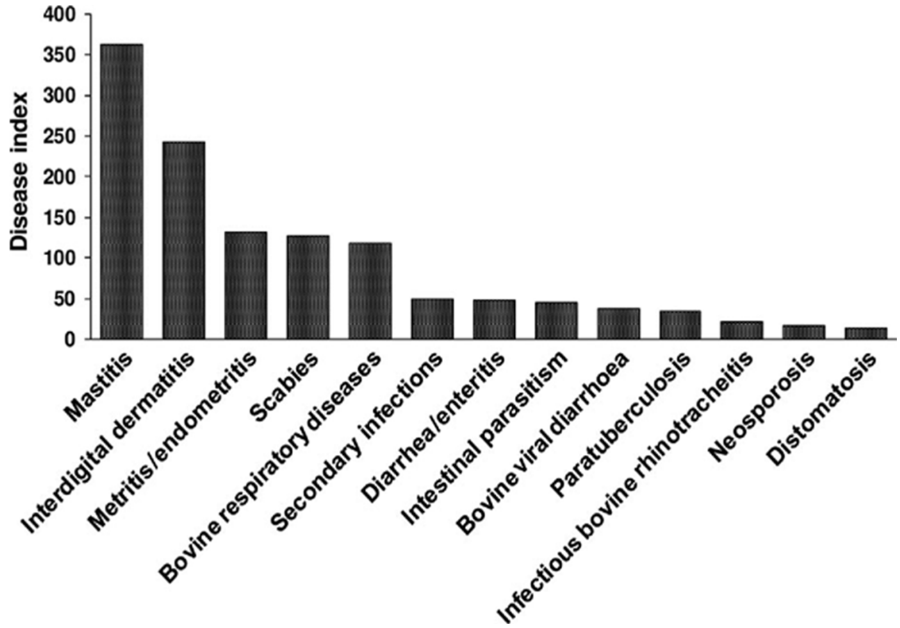

FIGURE 4 Disease index of the most important diseases affecting adult cattle, i.e., disease index above 0.66 centile ($N = 93$). Bovine respiratory diseases (BRD) include: pasteurellosis (Mannheimia haemolytica), pneumonia, bronchopneumonia, tracheitis, respiratory infections, and respiratory complex; diarrhoea/enteritis gathers:cryptosporidiosis, colibacillosis (*E.Coli*), as well as diseases associated with rotavirus and coronavirus

showing the most significant disease index but not coming out from DS 2 analysis (mastitis and interdigital dermatitis). Neosporosis and paratuberculosis did not show an increasing trend but are frequently suspected by the RVP.

Furthermore, they are both part of a national control program with a mean of, respectively, 155,379 and 290,057 annual test requests (DS2). A real increase was therefore unlikely.

Six diseases showed a significant increase through analysis of laboratory databases, but not from the RVP' point of view. Indeed, the number of tests requested over the last 3 years increased for BEL, leptospirosis, and bluetongue. Even though Belgium was declared as BEL-officially free in 1997 (AFSCA, 2017a,b), it is still tested in parallel with brucellosis to maintain this status (CODACERVA, Riocreux Flavien personal communication) and do not represent a real increase of suspicions. Its classification as "important" could therefore be reconsidered. For both leptospirosis and bluetongue, the number of test requests increased significantly in 2015, despite a low frequency reported by RVP. This could be related to increased surveillance motivated by bluetongue outbreaks in France and suspected outbreaks of leptospirosis in Belgium. Indeed, for leptospirosis, a peak of abortions, with icteric syndrome, was observed during the first half of 2014, which led to increased testing (Delooz et al., 2015). In addition, subclinical infections are frequently reported with bluetongue (Brenner et al., 2010).

We observed more than 25% of positive results for Bo-HV4 disease, Schmallenberg disease and cryptosporidiosis. These diseases were not listed as frequent, increasing or important by the RVP. Previous studies have confirmed the endemic status of Bo-HV4 in southern Belgium, along with a high seroconversion rate of cows (Delooz, Czaplicki, Houtain, Dal Pozzo, & Saegerman, 2016). Nevertheless, the relationship between Bo-HV4 and abortion is still subject to controversy and the disease might be underranked by the RVP due to the nonpathognomonic character of clinical signs. In order to further assess the role of Bo-HV4 in abortions, a recent study included the search of the virus in the abortion protocol already implemented in southern Belgium (Delooz et al., 2016; Delooz, Czaplicki, Houtain, Mullender, & Saegerman, 2012) and highlighted a possible association; specific awareness raising messages were already sent in that region (Delooz et al., 2012). Regarding Schmallenberg disease, such high proportion of positive results is probably related to the confirmatory character of the test, within a herd management program or policy, as clinical signs are quite pathognomonic; it does probably not reflect a high disease prevalence nor the current circulation rate of the virus. At last, a high proportion of positive tests was noticed for cryptosporitiosis. Cryptosporidium sp. is a coccidium causing clinical signs mostly in young animals; adult cattle is resistant and, thus, does not show any clinical signs (Geurden, 2007).

The review of previous disease prioritization exercises led to include additional diseases, also considered as important, in the list.These were: (a) major zoonoses with little or no impact on animal health, i.e., campylobacteriosis, CCHF, cysticercosis and echinococcosis, (b) diseases eradicated from Belgium or targeted by an effective national control program (anthrax, Aujeszky's disease, BSE, boTB, brucellosis, FMD, and rabies), and (c) low-incidence diseases such as anaplasmosis, babesiosis, and botulism.

The list of 48 important diseases compiled in this study is coherent with the Belgian context and includes all the OIE notifiable diseases present in Belgium with the exception of trichomonosis. The disease is rarely diagnosed by RVP or tested in the laboratories; in addition, zoonotic strains do not seem to be incriminated in cattle cryptosporidiosis, colibacillosis (*E. coli*), as well as diseases associated with rotavirus and coronavirus abortions (Shaapan, 2016). Its inclusion in the list depends on the objectives and foreseen usage of the disease classification exercise.Out of the 48 diseases, 25 are nonnotifiable but of major importance in Belgium due to their economic impact and/or high occurrence. Nineteen of them were not considered as important by the previous prioritization exercises while relevant in Belgian adult cattle. This additional list could guide the decision makers for future control programs as these diseases are a major concern for cattle holders. The six diseases identified as important by the three data sources are covering the different diseases transmission pathways, therefore the proper implementation of their related BSM (Table 4) should improve the prevention and control of the majority of other cattle diseases. Based on the transtheoretical model of behaviour change, as well as other theories and existing models (Armitage, 2009; Mase, Gramig, & Prokopy, 2017; Morris, Marzano, Danady, & O'Brien, 2012; Prochaska & Diclemente, 1983), the “possible personal benefits” is a constant key factor motivating the adoption of new behaviour. Therefore, identifying the risk factors and associated biosecurity measures related to the six diseases with a high or significant disease index could be used to improve the technical guidance for farmers and better answer their main concerns. Once the farmer has engaged into a behaviour change and is convinced of the efficiency and relevance of biosecurity, the introduction of additional measures will be accepted easily. As the six most important diseases to consider cover all the possible transmission pathways, future researches should focus on the BSM prioritization based on their level of implementation and acceptation by the herders, their feasibility and their cost-effectiveness in terms of disease(s) prevention. In order to ensure the acceptability of the BSM to be prioritized by the farmers a participative approach in recommended in order to take into account the farmers opinions, perceptions, and expertise on the topic.

5 | CONCLUSION

Due to their possible impact on the economy, it is important to raise the level of awareness of the herders regarding emerging and exotic diseases. Nevertheless, starting by addressing the farmer's priority issues is a key strategy for them to adopt the biosecurity measures on a long-term perspective. Identifying the most important diseases affecting cattle farms is therefore necessary in order to initiate the process of change. Specific measures related to public health purposes could be introduced easily afterwards. Future researches should focus on the assessment of the level of implementation of the BSM related to the most important diseases to be targeted (six in the case of Belgian cattle herds), as well as the possible constraints and factors affecting their adoption by the farmers in order to be able to prioritize the most effective BSM to be promoted.

The methodology proposed and relying on the outcomes of a veterinary survey, the analysis of the laboratory databases over the past 3 years and the review of previous prioritization exercises, allowed identifying the diseases of major concern for cattle holders.

The proposed methodology represents a practical tool for other users who could easily adjust the selection criteria to their specific objectives, needs, and context. That makes possible the future development of a biosecurity tool useable at the national level.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Experimental section

Study 2

Biosecurity practices in Belgian cattle farming:

level of implementation, constraints and weaknesses

Transboundary and Emerging Diseases 2018, 65:1246-1261

Véronique Renault, Bert Damiaans, Steven Sarrazin, Marie-France Humblet, Marc Lomba, Jeroen Dewulf and Claude Saegerman.

Preamble

As mentioned in the introduction, at the exception of one survey targeting the BVD-free farms, no studies were done in Belgium to assess the implementation level of BSM in cattle farms.

Based on the most important infectious diseases affecting cattle and that need to be addressed in Belgium, their related BSM were identified and a field survey implemented in 100 randomly sampled farms (50% in Wallonia and 50% in Flanders). The objectives of the survey were to assess the implementation level of BSM in Belgian cattle farms and collect the farmers' opinion towards these BSM.

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ORIGINAL ARTICLE

Biosecurity practices in Belgian cattle farming: Level of implementation, constraints and weaknesses

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Summary
Over the last few years, a shift from curative towards preventive medicine occurred in the livestock sector. This led to an increased importance of biosecurity to better control infectious diseases by preventing their introduction and/or reducing their spread. Farmers are the main responsible actors of biosecurity measures (BSM). Existing studies report a low implementation level of BSM by the cattle farmers. Barriers such as cost, usefulness, importance, workload and lack of knowledge were investigated but the decision-making process of farmers related to a given BSM is not yet clarified. The objectives of this study were to (i) assess the level of implementation of BSM in cattle farms, (ii) assess the correlation between the importance that farmers give to a BSM and its effective implementation and (iii) identify the main reasons of non-implementation. A randomized survey was implemented in Belgium from December 2016 up to April 2017 with face-to-face interviews conducted in 100 Belgian farms. A descriptive analysis of data was performed using Microsoft Excel and Stata14. Chi-square and Spearman's rank correlation tests, respectively, allowed comparing implementation levels in dairy herds *vs*. beef herds and investigating the correlation between the importance that farmers give to a BSM and its implementation level. Biosecurity measures were poorly implemented to prevent disease introduction through direct contact and almost not to avoid indirect transmission. Some measures showed a significant difference in terms of implementation level between beef and dairy herds. A positive correlation was highlighted between the importance that farmers give to a BSM and its actual effective implementation. Perceived lack of efficiency, feasibility and usefulness are the reasons most often mentioned for non-implementation. Other factors potentially influencing the decision-making process should be further investigated and clarified. Evidencebased studies would be useful to convince the farmers of the need of implementing BSM.

KEYWORDS
barriers, Belgium, biosecurity, cattle, constraints, farmers, importance, practices, preventive measures

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1 | INTRODUCTION

Cattle farming is one of the main food-producing industries in Belgium. Over the last few years, a shift from curative towards preventive medicine has been observed in the livestock sector and is a key element of the European Union Animal Health Strategy since 2007 (European Commission, 2007). This shift led to an increasing importance of biosecurity (BS). The BS concept is relatively new and can be differently perceived among countries and sectors. According to the Food and Agriculture Organisation (FAO), "BS is a strategic and integrated approach that encompasses the policy and regulatory frameworks (including instruments and activities) that analyse and manage risks in the sectors of food safety, animal life and health, and plant life and health, including associated environmental risks" (Food and Agriculture Organization, n.d.). Biosecurity includes all measures preventing the introduction of pathogens and/or reducing their spread. As part of the One Health concept, BS is particularly important as it includes the measures preventing the introduction and spread of zoonoses from animals to humans and from a cattle farm to the environment. Biosecurity can therefore be categorized through five different stages (Saegerman, Del Pozzo, & Humblet, 2012): (i) B1, bio-exclusion: limiting the risk of introduction; (ii) B2, bio-compartmentation: limiting the spread within the same facility (intraherd transmission); (iii) B3, bio-containment: limiting the spread to other animal facilities (inter-herd transmission); (iv) B4, bio-prevention: preventing human contamination; and (v) B5, bio-preservation: preventing environmental bio-contamination.

The first actor in terms of cattle farming biosecurity is the farmer him/herself, as well as his/her family and employee(s). Biosecurity practices and farmers' perception were investigated in different countries (Brennan & Christley, 2013; Gunn, Heffernan, Hall, McLeod, & Hovi, 2008; Hoe & Ruegg, 2006; Kristensen & Jakobsen, 2011; Kuster, Cousin, Jemmi, Schupbach-Regula, & Magouras, 2015;€ Laanen et al., 2014; Moore, Merryman, Hartman, & Klingborg, 2008; Noremark, Fr€ ossling, & Lewerin, 2010; Sarrazin, Cay, Laureyns, & Dewulf, 2014; Sayers et al., 2013; Toma, Stott, Heffernan, Ringrose, & Gunn, 2013). These studies reported a poor implementation of biosecurity measures (BSM) by the farmers, along with the different constraints and challenges expressed by the farmers such as cost, usefulness, importance, workload and lack of clarity and knowledge. In order to advise farmers and facilitate behavioural changes, it is important to better understand the perceived importance, efficacy and constraints related to BSM, from the farmers' point of view. This would allow us to communicate more effectively on BSM with the farmers. In Belgium, a first survey conducted in farms free from bovine viral diarrhoea virus, highlighted the poor implementation of BSM in the cattle sector compared to the pig and poultry industries (Sarrazin et al., 2014).

The objective of this study was to assess the implementation level of BSM in dairy and beef herds, the possible associations between the importance farmers assign to a BSM and its implementation level, as well as the main reasons justifying the non-implementation. These results will help us to understand better the strengths, weaknesses and limits of BSM implementation in cattle farms.

2 | MATERIAL AND METHODS

2.1 | Survey design

A literature review allowed identifying all BSM proposed as part of prevention and control of cattle infectious disease. It was performed in PubMed based on the following keywords: "name of the disease" or "name of the pathogen" and "cattle or bovine or cow or beef or calves or dairy" (if disease affecting multiple species only) and "epidemiology" or "pathogenesis" or "control" or "risk". The list of diseases reviewed relied on the outcomes of a previous prioritization process, which provided a list of 75 cattle diseases with occurrences in Europe (Renault et al., submitted for publication). The different BSM, as well as the risk factors identified in the literature, were listed in order to develop an exhaustive questionnaire. The questionnaire included 304 questions and subquestions, grouped in 21 categories (Appendix 1) and was pre-tested in six farms.

From December 2016 to April 2017, the two investigators conducted face-to-face interviews of 50 dairy and 50 beef farmers (minimum herd size of 20 cattle heads). For both dairy and beef categories, 25 farms were randomly selected in the northern and southern parts of the country. The investigator called selected farmers to inform them on the study objectives and survey principles. Upon acceptance of participation, an appointment was scheduled with the farmer. Farmers signed a written consent at the beginning of the face-to-face interview in accordance with the Protection of Private Life Regulations (CPVP, AF N° 25/2016 on the 28 July 2016).

2.2 | Data entry and analysis

Collected data were entered in an online form in order to ensure a uniform entry of data and facilitate their future analysis. As the survey was face-to-face, no answers were missing. Data were cleaned and answers to open questions harmonized and reclassified before analysis.

Regarding the open question on biosecurity definition, the following definition was considered: (i) "complete": the farmer mentioned the three following keywords: prevention, control and infectious diseases; (ii) "partial": the farmer mentioned 1 or 2 keywords; and (iii) "unknown": none of the keywords were mentioned.

Biosecurity measures were classified into different categories related to animal movements, visitors, direct or indirect contact with other animals (other farms or wildlife), vector control, environmental contamination, animal health management systems, compartmentation, stable hygiene and animal density, calving, calves management and dairy unit.

In order to analyse animal welfare and well-being conditions related to infrastructures, the surface per cow and per calf were calculated based on the number of animals declared initially and the available surface mentioned during the survey (m² per cow and per calf). International norms in enclosed areas are of 5 m²/cow (in the absence of exercise yard) and of 2.5 m² per calf up to 200 kg (Department of Agriculture, food and the marine, 2017; FAO, 1988). In Belgium, for calves up to 6 months raised in collective boxes, the minimum area specified for animal welfare is 1.5 m² for calves below 150 kg and 1.8 m² for calves above 220 kg (Royal Decree, 1998).

2.3 | Descriptive analysis

The analysis was performed in Excel (Microsoft 2016) and StataSE14 in order to assess the implementation of the different BSM in both types of cattle farms, as well as the reasons for nonimplementation.

2.4 | Statistical analysis

All statistical analyses were performed with StataSE14 software (StataCorp LLC, 2015).

2.4.1 | Chi-square test

A chi-square test compared the number of beef and dairy farmers applying and not applying the most important measures (Appendix 1) to investigate any significant differences related to herd type. Differences were considered as significant if the p-value was lower or equal to .05.

2.4.2 | Correlation test

After providing the definition of BSM to farmers, these were asked to list the five main measures implemented in their farm. A summary score was calculated per BSM, by summing the number of times it was listed as one of the five main measures implemented. For each measure listed in the top five (N = 33), an implementation score was calculated, based on the number of farmers implementing that measure (Appendix 1). The relationship between the importance attributed by the farmers to the different measures and their real implementation level was assessed through a nonparametric Spearman's rank correlation test.

3 | RESULTS

3.1 | Descriptive analysis

3.1.1 | Farmers' general profile and perception of biosecurity

The farmers' general profile and farm characteristics are presented in Table 1. In many cases, the farmer and his/her family held the farm by themselves. Only 12 farms were employing external staff on a full or part-time basis.

TABLE 1 Respondents' profile, biosecurity knowledge and perception

1. General profile of the farmer		
Years of experience	Average	27 years (range: 3–66 years)
Gender	Male Female	$N = 88$ $N = 12$
Educational level	Lower secondary Secondary	9% 44%
	Superior (short/long)	47%
2. Farm characteristics		
Herd size (cattle heads)	Average	160 heads (range: 24–649)
Farm type	Beef Dairy Lixt Bio label	40% 31% 29% 8%
3. Knowledge and perception of biosecurity		
Definition of biosecurity	Proper definition Partial definition No idea	6% 32% 62%
Importance of biosecurity	Very important Important Not important/ Don't know	34% 62% 4%
Level of implementation	Largely sufficient Sufficient Insufficient	13% 76% 11%
Cheapest	Prevention Treatment I don't know	89% 1% 10%
Less time consuming	Prevention Treatment I don't know	84% 6% 10%

The farmers' prior knowledge of biosecurity is poor, but their perception of the importance and interest of infectious disease prevention and control measures was generally good (Table 1).

From the farmers' perspective, the most important BSM were as follows: control of visitors (limitation and hygiene), vaccination programmes, minimum/no purchases, general hygiene/stable hygiene and appropriate feeding (quantity and quality) (Figure 1). For beef farms, prophylaxis programmes against endo- and ectoparasites were also listed in the top five BSM to be implemented.

3.1.2 | Level of implementation of the different BSM

The level of implementation of the measures preventing the introduction of diseases in a farm and controlling their transmission within the farm is presented in Tables 2 and 3, respectively.

BSM preventing the introduction of a disease in a farm

BSM related to animal movements Among the farmers purchasing cattle ($N = 61$), 59% were doing it directly and only from other farmers, 36% from other farms and through livestock salesmen, and 5% from selection centres or internationally. Only 13% of cattle holders who purchase cattle applied in parallel: status verification of the farm of origin, purchase kit tests and a proper quarantine of at least 15 days in a separated area. Six per cent of farmers were testing for diseases such as brucellosis, enzootic leukosis, mycoplasmosis and Q-fever in addition to the purchase kit test (including paratuberculosis, neosporosis, bovine infectious rhinotracheitis and bovine viral diarrhoea). No farmer implemented specific hygiene measures (prevention of pathogen indirect transmission) when entering or exiting the quarantine area (cleaning or changing clothes and boots, and hand disinfection). The main reasons justifying the failure to screen animals were trust in the seller (50%) in case of purchases and reliance on events requirements in terms of disease-free status (78%) for animals reentering the herd (e.g., following a fair or a competition). Regarding the non-application of quarantine, the main reason expressed by

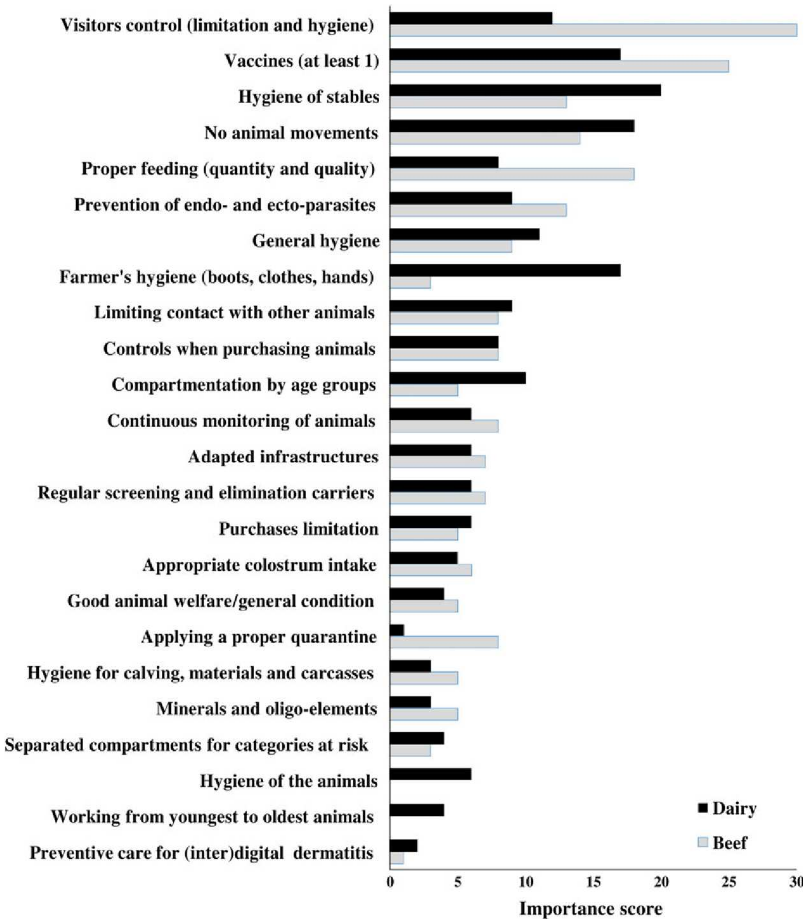

FIGURE 1 Most important biosecurity measures implemented, from the farmers' perspective and by decreasing order of global importance score (N = 100) [Colour figure can be viewed at wileyonlinelibrary.com]

the participants was the lack of feasibility due to the difficulty of physical isolation of purchased animals from other areas hosting animals (83% for purchased animals and 50% for re-entering animals). Testing milk samples of newly purchased lactating cows were usually not tested. The main reasons being that either the measure was unknown (54.5%) or farmers were trusting the animal's previous owner (27.3%).

BSM related to visitors Based on their comments, farmers were well aware of the risk of disease introduction through professional visitors and vehicles. More than 60% of farmers prevent the access of vehicles to animal transit areas and restrict access of visitors to stables, when possible. Nevertheless, professional visitors, including salesmen, generally had a free or controlled access. Despite the risk, hygiene measures for visitors, such as wearing farm-specific clothes and/or boots, hand hygiene, wearing of gloves and passage through a footbath, were poorly implemented (Figure 2a). Constraints limiting the implementation of such measures were the absence of facilities (lack of footbaths and/or hygiene locks), the trust in visitors' professionalism (mainly for veterinarians and inseminators) and the unwillingness to impose such measures to a commercial partner (for cattle salesmen) (Figure 2b).

BSM related to direct or indirect contacts with other animals In pasture, apart from farmers practicing zero grazing, no farmer was able to prevent contacts with wildlife. They considered double fencing as inefficient or useless (31%) and difficult to achieve or excessively burdensome (19%). The most common constraints expressed by farmers were the waste of space and the additional working time needed for the maintenance of an ungrazed corridor. Limiting

TABLE 2 Biosecurity measures preventing disease introduction in a farm. Biosecurity measures related to (a) animal movements; (b) control of visitors; (c) direct or indirect contact with animals

		Yes		
Biosecurity measure	***N***	**Beef**	**Dairy**	**Total**
(a)				
A.1 Purchases				
Not purchasing animals	100	26%	52%	39%
Purchasing bulls only	61	75%	100%	49%
Limiting number of purchases (once per year maximum)	61	65%	71%	67%
Single source purchases	61	24%	42%	31%
Controlling the status of the farm of origin	61	84%	83%	82%
Testing animals (purchase kit)	61	84%	75%	80%
Not purchasing dairy cows	50	/	86%	86%
Testing a milk sample of new dairy animals before introduction in the herd	7	/	0%	0%
Milking newly purchased animals separately	7	/	14%	100%
Ensuring no contact with other animals during transportation	61	70%	67%	69%
Applying a quarantine	61	65%	45%	61%
Systematic quarantine, >=15 days	61	46%	13%	33%
Systematic quarantine, >=21 days	61	30%	13%	23%
A.2 Re-entering animals				
No re-entry of animals after exiting	100	82%	96%	89%
Re-entering animals put in quarantine for at least 15 days	11	33%	50%	36%
Testing the animals re-entering the farm	11	11%	50%	18%
(b)				
B.1 Control of entrances				
Farmyard fenced to prevent intrusions	100	42%	64%	53%
Farmers keeping operational footbaths at the farm entrance	100	18%	16%	17%
Farms having an hygiene lock at the farm entrance	100	34%	30%	32%
Keeping a register for visitors	100			0%
Prevent access to stables for:				
Veterinarians	100	0%	0%	0%
Cattle salesmen	100	20%	32%	26%
Inseminators (if different from the veterinarian)	100	66%	58%	62%
Hoof trimmers	100	84%	60%	72%

(Continues)

TABLE 2 (Continued)

Biosecurity measure	*N*	Yes Beef	Dairy	Total
Advisors	100	94%	78%	86%
Feed suppliers	100	96%	84%	90%
Milk collector	100	–	98%	98%
Other visitors (e.g., school groups)	100	88%	92%	90%
B.2 Vehicles and materials				
Prevent access to animal transit areas for salesman' vehicles	100	78%	60%	69%
If not, salesman truck empty when coming	31	18%	10%	13%
Prevent access to animal transit areas for rendering trucks	100	68%	66%	67%
(c)				
C.1 Reproduction				
Not sharing reproductive bulls	100	100%	100%	100%
Using natural service as reproduction method	100	86%	58%	72%
Safe sources for semen in case of A.I.	100	100%	100%	100%
C.2 Animal contacts (direct and indirect)				
Double fenced (>2 m) in case of adjacent pastures	57	0%	4%	2%
Prevent contact with wild animals in pastures	100	8%	8%	8%
No access to stables for dogs	100	20%	36%	28%
No access to stables for cats	100	2%	2%	2%
Programme of rodent control	100	70%	58%	64%
Farmer/workers not working in/visiting other farms	100	76%	68%	72%
No equipment shared with other farms	100	86%	78%	82%
C.3 Water or food contamination				
No access to surface water in pastures	100	52%	40%	46%
Testing water quality at least once a year	100	44%	92%	68%
No access to food storage for dogs	100	36%	42%	39%
No access to food storage for cats	100	20%	12%	16%

TABLE 3 Biosecurity measures preventing diseases transmission within the farm

Biosecurity measure	*N*	Yes Beef	Dairy	Total
A. Biosecurity measures related to animal health management				
A.1 Health management and prophylaxis treatments				
Keeping a register of animal health data	100	32%	60%	46%
Direct elimination of disease carriers	100	82%	56%	69%
Vaccination protocol	100	80%	84%	82%
Systematic testing of aborted cows	100	70%	70%	70%
Testing aborted cows in case of repeated abortion cases but not systematically	30	73%	100%	87%

(Continues)

TABLE 3 (Continued)

Biosecurity measure	*N*	Yes Beef	Yes Dairy	Yes Total
Preventive treatments against endoparasites	100	88%	72%	80%
Preventive treatments against ectoparasites	100	86%	24%	55%
Preventive hoof trimming at least once a year	100	16%	40%	28%
Cows passing through footbaths	100	16%	40%	15%
Working from younger to older animals	100	30%	24%	27%
A.2 Vector control measures				
Using insect repellent	100	40%	62%	51%
Cleaning pastures from excessive vegetation	100	26%	18%	22%
Chemical treatment of environment	100	18%	32%	25%
Removal of stagnant water	100	32%	20%	26%
Placing traps or nets	100	26%	38%	32%
Regular disposal of manure (avoid piling)	100	56%	58%	57%
A.3 Management of sick animals				
Systematic isolation of sick animals	100	8%	4%	6%
Systematic isolation of aborted cows	100	28%	12%	20%
Isolation of sick animals based on contamination risk/if advised by the vet	100	8%	4%	6%
Physically separated or isolated (>3 m) hospitalization area	100	48%	42%	45%
Specific equipment in the hospitalization area	45	23%	8%	17%
Cleaning area after removing animals (or more frequently)	45	93%	67%	81%
Taking care of sick animals after healthy ones	45	47%	25%	37%
Using farm-specific clothes in the hospitalization area	45	2%	4%	7%
Using farm-specific boots in the hospitalization area	45	2%	4%	7%
Washing hands before entering	45	9%	7%	16%
Wearing gloves in the hospitalization area	45	7%	2%	9%
Using footbaths before entering	45	2%	2%	4%
A.4 Cadavers and manure disposal				
Separate storage space with at least a cemented floor	100	68%	68%	68%
Carcass covering to protect from vermin and predation	68	88%	74%	55%
Cleaning and disinfecting the floor after removal	68	41%	32%	37%
Handle the cadavers with gloves	100	78%	68%	73%
Prevent contact between manure and domestic carnivores (cats, dogs)	100	20%	10%	15%
No manure spreading in other farms	100	86%	52%	69%
B.1 Calving				
Hands cleaned and disinfected before assisted calving	100	94%	74%	80%
Obstetric materials cleaned and disinfected before calving	100	90%	58%	74%
Udder and vulva cleaned and disinfected before calving	100	10%	22%	16%

(Continues)

TABLE 3 (Continued)

Biosecurity measure	*N*	Yes Beef	Dairy	Total
Immediate clipping and disinfection of umbilical cord	64	79%	71%	77%
Immediate separation of the calf (unless suckling animal)	64	100%	100%	100%
B.2 Calves				
Calves housed in individual hutches	83	67%	84%	77%
No contact with other calves from hutches	64	50%	55%	53%
Specific buckets	64	73%	52%	59%
Buckets cleaned after each feeding	64	36%	40%	39%
Grouped with animals of same age	64	73%	64%	67%
Colostrum given within 1–2 hr	91	93%	51%	64%
Not giving milk from other farms	100	74%	92%	83%
B.3 Dairy cows				
Milking robot	50	–	8%	8%
Maintenance more than once per year	50	–	10%	10%
Cleaning the equipment after milking	50	–	98%	98%
Disinfecting the equipment after milking	50	–	52%	52%
Teats cleaned before milking	50	–	89%	89%
Teats disinfected before milking	50	–	20%	20%
Teats dried before milking	50	–	86%	86%
Foremilk examination	50	–	69%	69%
Disinfecting teats after cups removal	50	–	76%	76%
Prevent cows from lying down after milking	50	–	34%	34%
Clipping flanks and udder of lactating cows	50	–	52%	52%
Litter looking dry and clean in individual calves hutches	64	73%	90%	84%
Litter looking dry and clean in calf boxes	100	66%	84%	75%
Litter looking dry and clean in adult boxes	100	72%	84%	78%
Daily cleaning of feed troughs	100	48%	56%	52%
Daily cleaning of water troughs	100	40%	18%	29%
Not using feeding equipment for other tasks (e.g., litter/manure removal)	100	60%	60%	60%

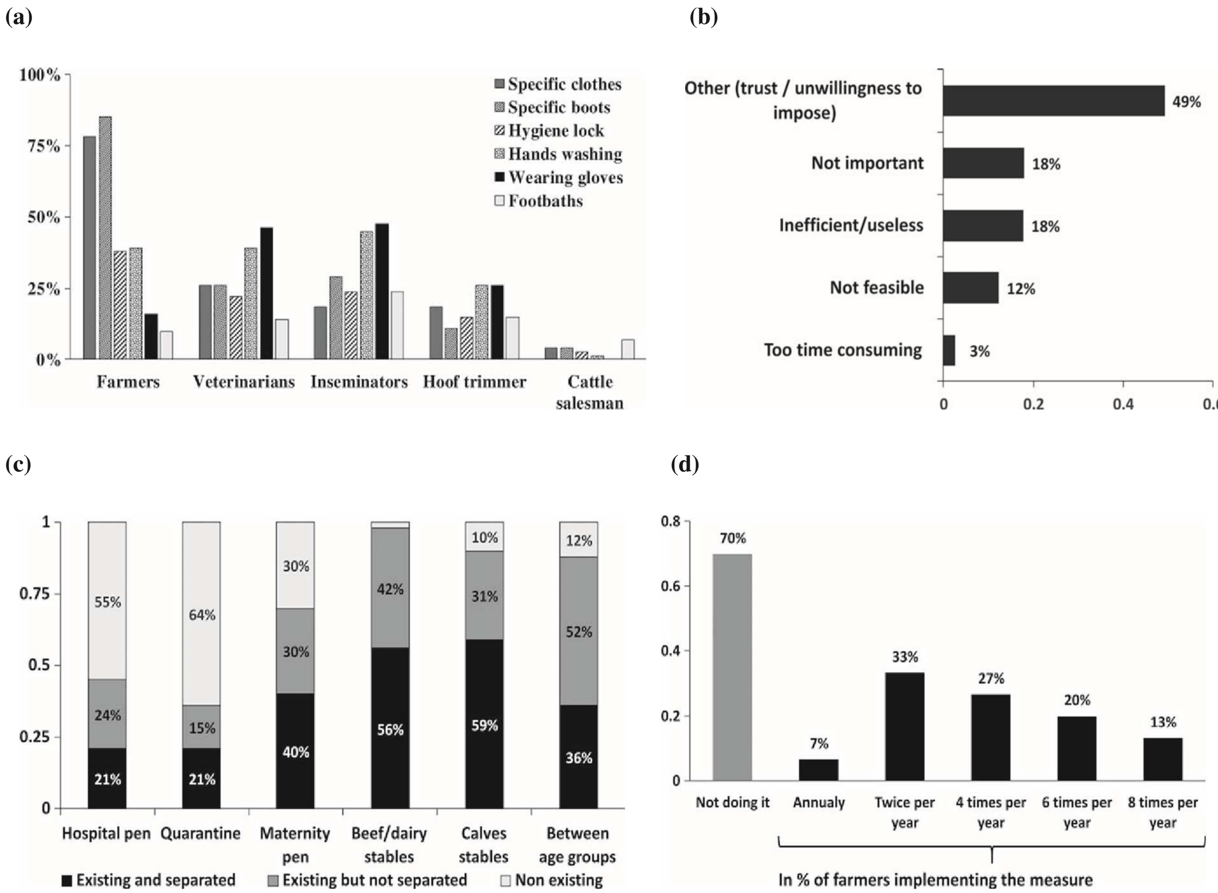

FIGURE 2 Hygiene and compartmentation measures (N = 100). (a) Percentage of visitors (per category) implementing hygiene measures in the farm. (b) Reasons of the non-implementation of hygienic measures by the visitors. (c) Existence of different farm compartments. Areas considered as "separated" when physically separated (walls/different buildings) or isolated from other boxes (>2 m). (d) Percentage of dairy farmers passing cows through footbaths (N = 50)

the access to stables for animals such as dogs, cats, birds and rodent was not possible in most farms visited. Rodent control was relying on traps/poisoned baits for 64% of farmers, while 6% of them resort to a specialized company. Feed, especially hay and silage, was generally accessible to cats, dogs and birds/rodents as well.

In terms of indirect contacts, among the farmers frequently visiting other farms (N = 28), 79% were using specific clothes and boots on their premises and 39% of them properly washed and disinfected their hands before entering their own stables. Among farmers sharing equipment (N = 18), 44% shared machines used for crops only whereas cattle trailers, feed mix trucks and/or slurry tanks were shared by 56% of them. Fifty per cent of farmers who were sharing equipment were not taking any specific measure when re-entering, 40% of them cleaned it and only 10% additionally disinfected the equipment.

BSM preventing the transmission of diseases within a farm

BSM related to animal health management Most farmers had a vaccination programme relying on 1 to 6 vaccines (Figure 3a and b).

Regarding aborted cows, 18% of farmers considered that having the aborted cows tested for possible infectious diseases (e.g., brucellosis, neosporosis, salmonellosis and Q-fever) was not necessary for sporadic cases but would

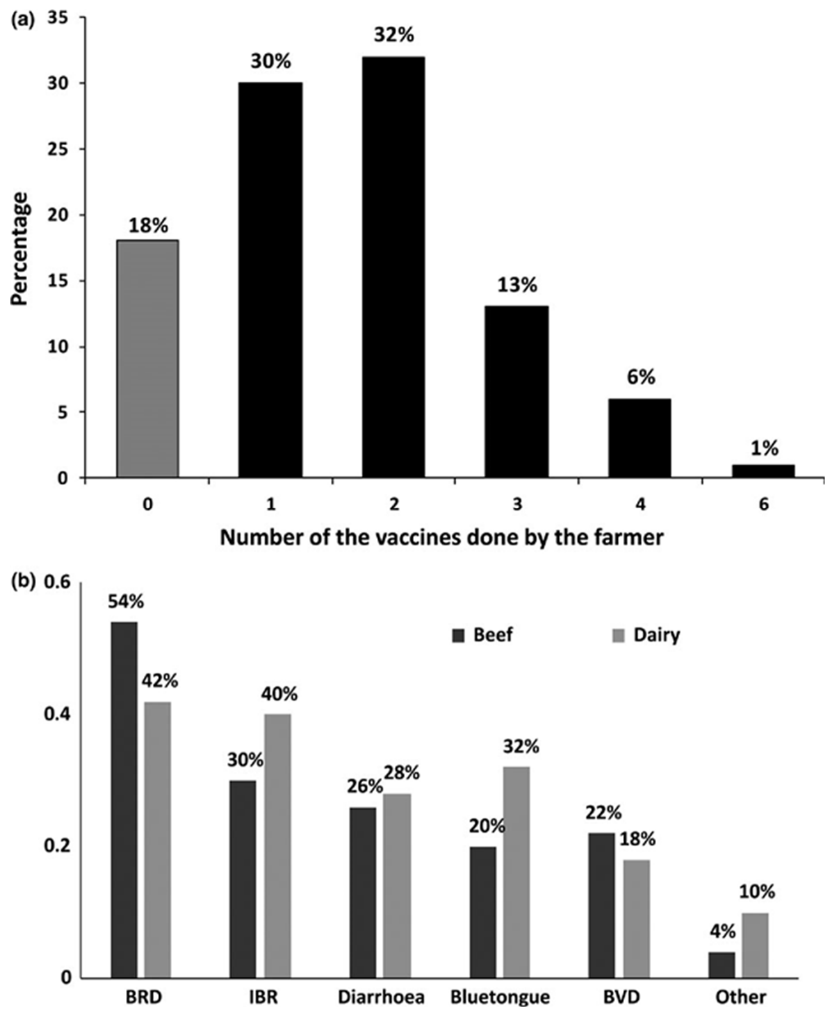

FIGURE 3 Implementation of vaccination programmes (N = 100). (a) Farmers applying a vaccination protocol and number of vaccines effected. (b) Percentage of farmers applying the different vaccination protocols in dairy and beef farms. BRD, Bovine respiratory diseases; IBR, infectious bovine rhinotracheitis; BVD, bovine viral diarrhoea; Other: clostridiosis, mastitis, salmonellosis, coccidiosis and Hiprabovis (*Mannheimia haemolitica* and *Histophilus somni*)

proceed to screening and testing in case of abortion storms (several abortions over a limited period).

Preventive measures against ecto- and endoparasites were generally well implemented, especially in beef herds. The main reasons for non-implementation (89%) were the uselessness as perceived by farmers, due to the absence of problems.

Two preventive measures against (inter)digital dermatitis were included in the survey and were generally poorly implemented (Figure 2d). Several farmers mentioned the difficulty of maintaining footbaths operational but also the lack of efficiency. Disinfectant spraying of suspicious cows while in the milking parlour, but also the passage of cows through lime, was considered as a more efficient and practical curative treatments by some farmers.

In terms of vector control, less than 30% of farmers applied measures such as environmental treatment, removal of stagnant water and excessive vegetation, as well as the use of traps or nets. Indeed, farmers did not perceive insects as an important problem and considered classical measures inefficient or forbidden (organic farms).

Most farmers (94%) were not separating sick animals from others, or only if they were extremely weak and for their comfort. Reasons for non-isolation were mainly the feasibility (especially dairy cows) or the lack of space to maintain a physically separated area (Figure 2c). Some cattle holders also considered it useless to isolate sick animals, as pathogen excretion usually starts before the occurrence/detection of clinical signs. For farmers who were physically separating sick animals (N = 45), few had implemented an entrance hygiene lock and hygienic measures to prevent indirect transmission from the hospital pen to other stables (i.e., specific equipment, hands/boots and clothes hygiene, or a footbath at the entrance). Isolation of aborted cows was poorly implemented, as from the farmers' perspective, such measure was either difficult to implement, due to lack of space or cow lactating status (54%), or inefficient by the time of abortion (potential contamination already occurred) (21% of farmers).

The percentage of farmers combining the following three measures, that is, cadavers left on a cemented area, covered and floor disinfected after removal, reached only 5%. The main reason (41%) expressed by farmers for not leaving cadavers on a cemented floor was that suitable areas (isolated and allowing cadaver removal without entering premises) were not cemented. One farmer mentioned the absorption of fluids when cadavers were left on soil (avoiding their spread) and 13% of farmers mentioned not being aware such measure was considered as a BSM.

BSM related to compartmentation Compartmentation (Figure 2c) mainly depends on farm infrastructures, available space and herd type. Around 70% of farms had calving pens, but these were sometimes used to isolate a sick animal (27% of the farms). In addition, even when physical compartmentation was properly implemented, no equipment was compartment specific (i.e., less than <68%).

Calves were physically separated from adults, especially in dairy herds, and often hosted in separate stables. Nevertheless, 68% of farmers did not have stable-dedicated equipment and less than 5% cleaned the equipment between groups. Footbaths were operational in a minority of farms and positioned at the farm entrance only. Less than 7% of farmers had compartment-specific clothes and boots.

BSM related to hygiene of stables and animal density In terms of average capacity, the surface available per animal was less than 5 m² per cow and less than 2 m² per calf, in, respectively, 39% and 8% of farms (Table 4).

The average proportion of maternity pens reached 7% of the total number of adult cows and heifers (range: 0%–45%). When existing, maternity pens were cleaned and disinfected after calving in 43% of farms. In other cases, new straw was just added on top of the straw litter after calving, in order to maintain it clean and dry.

The majority of farmers were applying an all-in/all-out system for calves, with small groups of 3 to 30 animals (87% of farmers used to form groups of maximum 10 calves). Despite such practice, 56% of farmers were moving poorly growing calves to younger groups to harmonize calf size within a same group. For stables depopulated at least once per year (Table 4), the duration of empty period was variable and depended on stable occupational rate (rarely more than 1 day for dairy stables). The proportion of dairy stables properly applying an empty period at least once per year reached 6%.

The frequency of box cleaning depended on the type of pens, but litter seemed dry and cleaned in most visited farms (78% of adult and 75% of calf stables). Individual calf hutches were cleaned at least daily, weekly or less, and after each calf in, respectively, 39%, 15% and 47% of farms.

Cleaning and disinfection of needles and syringes were performed by 22% of farmers, while 43% of them just used to clean them. A majority of farmers (65%) were reusing needles until damaged.

BSM related to calving, calf management and milking operation (Table 3) More beef farmers were applying a proper hygiene at calving (hand and equipment washing, as well as immediate navel disinfection) compared to dairy farmers (64% *vs.* 24%). Nine farms (eight beef and one dairy) were leaving the calf with the cow and did not administer additional colostrum.

TABLE 4 Percentage of farms properly applying an empty period

Biosecurity measure	Hospital pen			Quarantine			Maternity pen		
	Beef	Dairy	Total	Beef	Dairy	Total	Beef	Dairy	Total
N	24	21	45	24	12	36	32	38	70
Average capacity (proportion of herd size)		3% (1-12%)			5% (1-19%)			7% (0-45%)	
Depopulated and cleaned (at least once/year)	71%	43%	58%	75%	75%	75%	59%	37%	47%
Depopulated, cleaned and disinfected (once per year)	54%	10%	33%	42%	17%	33%	38%	29%	33%
Proportion of farmers applying a ≥ 30 days empty period		53%			31%			20%	
Average duration of empty period (days?)		13 (range: 1-42)			23 (range: 1-60)			16 (range: 1-90)	
Average capacity (proportion of herd size)		7m2/cow (1-30)			8m²/calf (1-44)			111% (16-400%)	
Depopulated and cleaned (at least once/year)	69%	10%	40%	76%	50%	63%	2%	43%	72%
Depopulated, cleaned and disinfected (once per year)	27%	4%	15%	35%	28%	31%	36%	50%	45%
Proportion of farmers applying a ≥ 30 days empty period		42%			57%			11%	
Average duration of empty period (days?)		39 (range: 0-180)			37 (range: 1-180)			11 (range: 0-120)	

3.2 | Statistical analysis

3.2.1 | Chi-square test

A significant difference between beef and dairy herds was highlighted for 10 BSM, in terms of implementation rate (Table 5). Prevention of endo- and ectoparasites, calving hygiene, appropriate colostrum intake and direct elimination of carriers were significantly better implemented in beef farms. Prevention of (inter)digital dermatitis, closed herds, age-based compartmentation and use of farmspecific boots and clothes were significantly better implemented in dairy farms.

3.2.2 | Spearman's correlation test

Six measures listed by the farmers related to general animal feeding and welfare were not assessed in the survey (as they are not specific to disease prevention and control and difficult to score objectively). They were therefore excluded from the analysis. Two BSM measures ranked highly in the top 5 but with 0% of implementation were excluded from the analysis as their implementation depends on other factors (e.g., contact with wildlife and visitors' practices in terms of hygiene on the farm).

The analysis showed a significant positive correlation between the importance attributed by farmers to the different measures and their implementation level (p = 0.016), with a 0.48 Spearman's rho (*Rs*).

TABLE 5 Biosecurity measures showing a significant difference in terms of implementation level, based on herd type

Biosecurity measure	Farms implementing			Farms not implementing			Chi square test results	
	Beef	Dairy	Total	Beef	Dairy	Total	Chi2	p
1. Measures better implemented in beef farms								
Prevention programmes for ecto-parasites	3	2	5		8	5	38.83	<0.01
Hygiene at calving	2	2	4	8	8	6	16.23	<0.01
Appropriate colostrum intake	0	0	0	2	9	1	8.56	<0.01
Regular screening and elimination of carriers	1	8	9		2	1	7.90	0.01
Prevention programmes for endo-parasites	4	6	0		4	0	4.00	0.05
2. Measures with a higher implementation level in dairy farms								
Preventive care for (inter)digital dermatitis		4	2	2	6	8	11.76	<0.01
No animal movements	1	5	6	9	5	4	8.51	<0.01
Compartmentation by age groups	2	5	7	8	5	3	6.90	0.01
Specific/clean farm boots	9	6	5	1		5	3.84	0.05
Specific/clean farm clothes	5	3	8	5		2	3.73	0.05

4 | DISCUSSION

If several studies focused on the implementation level of BSM by farmers (Brennan & Christley, 2012; Gunn et al., 2008; Hoe & Ruegg, 2006; Noremark et al., 2010; Sayers et al., 2013), only one of them was performed in Belgium, in 2014 (Sarrazin et al., 2014). It sampled herds with a history of BVD that managed to get a free status. Such selection criterion limits the representativeness, as the included farms are more likely to have improved their BS levels to eradicate the disease. In addition, only a few studies investigated the reasons why cattle farmers do not implement BSM (Brennan & Christley, 2013; Gunn et al., 2008; Heffernan, Nielsen, Thomson, & Gunn, 2008; Hoe & Ruegg, 2006; Ritter et al., 2017; Toma et al., 2013; van Winsen et al., 2016). The present study was more representative for all Belgian cattle farms and investigated the reasons of non-implementation, which are key elements to better understand the farmers' decision-making process and the constraints to address in order to effectively improve BS level of cattle farms.

The survey did not address elements such as suitable feeding, animal well-being and general animal health status, which also contribute to an optimal natural immunity (Maunsell & Donovan, 2008). Nevertheless, many cattle holders are aware of such key elements in terms of biosecurity. Indeed, a proper feeding, complementary minerals and oligo-elements as well as animal welfare/good body conditions were some of the most important measures listed by farmers (Figure 1). Farmers take into account the stress generated by some BSM in their decision-making process: if too stressful and not essential/useful from the farmer's perspective, it is discarded (e.g., prophylaxis, preventive hoof trimming and animals' isolation).

4.1 | Prevention of disease introduction in a farm

Farmers purchasing animals were estimated to be between 1.4 and 10.8 times more at risk of disease introduction than closed herds, for several diseases (Gates, Woolhouse, Gunn, & Humphry, 2013; Mee, Geraghty, O'Neill, & More, 2012; Rodrıguez-Lainz, Hird, Walker, & Read, 1996; Somers, Frankena, Noordhuizen-Stassen, & Metz, 2005). Disease introduction through animal movements is prevented, either by keeping closed herds, or through pre-movement (e.g., checking the status of the herd of origin), movement (e.g., not transporting other animals in the same truck) and post-movement measures (e.g. quarantine and serological testing). In our study, keeping a closed herd was significantly more frequent in dairy farms ($p < .01$). Indeed, natural breeding, requiring regular replacements of reproductive bull(s), is significantly more frequent in beef farms ($p < .01$) as well as farms purchasing bulls only ($p < .01$).

The study revealed that none of the farmers purchasing animals properly addresses the risk of disease introduction. Those opting for animal testing and applying a systematic quarantine in a separated area until getting the tests results (15 days in average) are exposed to a risk of introduction of diseases not tested for or with a longer incubation period. A period of 3–4 weeks is generally advised, even for diseases with a short incubation period (Bazeley, 2009; Maunsell & Donovan, 2008; Mee et al., 2012). In addition, due to the absence of hygienic measures between the quarantine area and the rest of the stables, the risk of indirect transmission is still present. The majority of cattle holders do not test animals reentering after gathering events (fair or competitions) and do not apply quarantine; indeed, they trust sanitary requirements for an animal to participate. Nevertheless, these are restricted to a few diseases only (usually tuberculosis, brucellosis, BVD and IBR).

Regarding control of visitors, access restriction, in-house or clean boots and clothes as well as their personal working hygiene were perceived by experts as very important measures (Kuster et al., 2015). If not implemented, they were identified as significant risk factors for several diseases such as Q-fever (van Engelen et al., 2014), BVD (Gates, Volkova, & Woolhouse, 2013), IBR (van Schaik et al., 1998) and other bovine respiratory diseases (Ohlson et al., 2010). If farmers are well aware of the risk and usually prevent vehicle access to animal transit areas, they are unwilling or do not feel comfortable with imposing measures to visitors; they usually rely on their professionalism and tend to believe their boots and clothes are clean. Such belief is a real threat, as several studies demonstrated that most professional visitors do not implement suitably the BSM preventing the spread of infectious diseases (Noremark & Sternberg-€ Lewerin, 2014; Pritchard, Wapenaar, & Brennan, 2015; Renault et al., 2017; Sayers, Good, & Sayers, 2014; Shortall et al., 2016). Implementation rates were significantly higher in dairy farms for the use of farm-dedicated clothes and boots. This is probably linked to the milk sector quality system (QFL) requiring such measures to be implemented for certification (QFL-Production, 2017).

In a previous study, experts mentioned contacts with other farm animals or wildlife as an important risk factor for disease introduction for which no effective solutions have been suggested (Kuster et al., 2015). It is a major issue for eradication and control programmes of diseases with a wildlife reservoir (e.g., badgers and wild boars are considered as reservoirs of *Mycobacterium bovis* in the United Kingdom and in Spain, respectively (Naranjo, Gortazar, Vicente, & de la Fuente, 2008; Scantlebury, Hutchings, Allcroft, & Harris, 2004)). If the risk of feed and water contamination might be reduced through appropriate measures (e.g., farmers who prevent access to surface water in pastures), they cannot be fully controlled (contamination of fodder by birds and rodents is difficult to prevent after opening the silo or bale) and contacts with wildlife while grazing can hardly be prevented. The only BSM would be the zero grazing system (not applicable to most farms in Belgium) and double fencing, perceived as ineffective, unfeasible or unpractical by farmers.

4.2 | Prevention of within herd-disease transmission

Measures aiming at controlling the within herd transmission of pathogens are lowering the infectious pressure, increasing animal's immunity and/or preventing the direct/indirect transmission of the disease within the farm.

The implementation level of disease-specific preventive measures (including vector control) varied considerably and mainly depended on the actual or recent impact of the disease on production. Indeed, the main reasons justifying their non-implementation were the absence of problems and the perceived lack of usefulness of the BSM. This explains the significantly different implementation levels between beef and dairy herds for two measures: (i) prevention against ectoparasites, significantly higher in beef farms due to the susceptibility of the Belgian blue breed to scabies (Losson, Lonneux, & Lekimme, 1999), and (ii) the preventive treatment of (inter)digital dermatitis more often implemented in dairy farms as the Holstein– Friesian breed are more affected by the disease (Holzhauer, Hardenberg, Bartels, & Frankena, 2006). Specific BSM implemented in most farms were vaccination against at least one disease (mainly respiratory diseases) and deworming at least once per year.

Biosecurity measures aiming at preventing environmental contamination and further disease spread were poorly implemented (e.g., only a few farmers stored cadavers on a cemented floor, covered them and cleaned/disinfected the area after removal). Further investigations are needed in order to check whether it is due to a lack of concern or other constraints.

Compartmentation is recommended to prevent direct and indirect contaminations from one group of animals to another, within the same herd. Minimal compartments should include maternity pen, individual calf hutches, age group-specific stables for calves and adult stable. Ideally, these areas should be physically separated, to prevent direct contact, and specific hygiene measures should be implemented to prevent indirect transmission of pathogens between compartments (recommended for the quarantine and hospitalization areas). Our survey revealed that, beside separating adult and calf stables, only some farms had a physically separated area for hospital pens while the majority of farms did not have maternity pens (mostly collective maternity boxes). The proportion of maternity boxes compared to the farm global population of cows and heifers reached an average of 7%, which is above the recommended proportion (University of Minnesota Extension, 2004). Constraints expressed by farmers were mainly the feasibility of creating compartments, due to the infrastructure itself and, for dairy herds, milking organization. This highlights the importance of an appropriate design of farm buildings allowing an easy implementation of BSM and the need for an increased collaboration between agricultural engineers, veterinarians, farmers and entrepreneurs.

Biosecurity measures aiming at preventing indirect transmission of pathogens between two compartments were poorly implemented; the main reason was the convenience of repeating such procedures several times a day when passing from one compartment to another. The efficiency and usefulness of compartmentation can reasonably be questioned if correct hygiene measures are not fulfilled, knowing that many pathogens are also transmitted through fomites. The reuse of needles is an important weakness in terms of biosecurity.

In order to reduce the infectious pressure, stable hygiene is essential, both from the daily cleaning and existence of regular empty periods (at least annually) points of view. In a recent study, irregular cleaning of bedding was shown to be a risk factor for *Q*-fever [OR = 2.8; CI = 1.1–7.1] (van Engelen et al., 2014). Regular cleaning seemed well implemented in all farms and stable hygiene was considered as one of the most important BSM by farmers (Figure 1), confirming the findings of Kuster and collaborators (Kuster et al., 2015). Nevertheless, the application of an empty period, at least once a year (depopulation, cleaning, disinfection and emptiness until it dries) seemed more difficult to implement, especially in dairy stables.

Calving and milking are two moments at risk in terms of disease transmission to calves, dairy cows and humans (for what zoonoses are concerned). Most measures linked to calving, milking and calf management were implemented with the exception of (i) cleaning udder and vulva before calving, considered as useless in case of Caesarean and not performed for unassisted calving and (ii) cleaning calf buckets after each feeding. Some farmers considered pre-milking teat disinfection and after-birth navel disinfection as inefficient and even as risk factors. Indeed, in the absence of problems, they mentioned that the less teats and/or navel were manipulated, the lower the risk of infection. Farmers' remarks on navel dipping are in line with the controversial results of previous studies; evidence is still lacking regarding the impact of navel disinfection on the reduction in calf navel infections (Mee, 2008). In addition, recent studies highlighted the navel dipping practices as a possible risk factor for BVD, probably due to the use of contaminated solutions (Windeyer et al., 2014). If considering current knowledge, navel antisepsis could be recommended only in herds facing navel infections. The same controversy exists with respect to pre-milking teat disinfection. Often part of mastitis control programmes (National Mastitis Council, 2009), some studies reported pre-milking disinfection as having no influence and even as a risk factor (Detilleux, Theron, Beduin, & Hanzen, 2012). Therefore, further evidence-based researches are needed to confirm the potential benefits of these two BSM (navel and pre-milking disinfection).

Hygiene at calving (hands and material cleaned and disinfected, and after-birth navel disinfection), as well as the respect of an appropriate delay for colostrum intake (ideally within 4 hours after birth, but less than 6 hours after), was better implemented in beef farms. This is probably due to the high frequency of natural (unassisted) calving in dairy herds: if the cow calves during the night, most farmers do not get up and wait until the next morning to care for the calf (navel disinfection and colostrum administration).

4.3 | Correlation between scores of importance and of implementation

A significant and positive correlation was observed between the importance attributed by farmers to a BSM and its effective implementation for 25 BSM investigated. It is therefore important to raise the farmers' awareness and perception on the key BSM poorly implemented in order to increase their adoption rate. Some measures were not listed as important measures by farmers, despite a high implementation level (e.g., not using feeding materials for other purposes, testing of aborted animals or individual calf buckets). This might be due to the lack of understanding of biosecurity by farmers, despite the prior explanation, and/or some standard practices not considered as BSM. The relatively small rho coefficient illustrates the influence of factors other than BSM importance in the decision-making process of biosecurity adoption. Such processes are complex, from a biosecurity point of view, and require further sociological studies to be clarified.

5 | CONCLUSION

Our survey demonstrated that, despite the farmers' awareness on the importance of preventing and controlling infectious diseases, the implementation level of BSM is generally low and leaves ample room for improvement. In particular, disease introduction or transmission through fomites is not controlled in any of the farms visited and should be urgently improved. For BSM linked to visitors and reentering animals, most farmers tend to rely on visitors' and event organizers' professionalism instead of implementing their own control measures. Further investigations on these actors' level of confidence would therefore allow a better risk assessment.

Regarding farmers' perceptions of BSM and expressed constraints, the costs of measures do not seem to influence the implementation level, as it was not mentioned as a constraint. The key factors in the decision-making process seem rather to be the importance of the measure (mainly relying on the actual risk or impact of the disease on farm production), its efficiency, its feasibility in terms of work organization and the infrastructures themselves when it comes to compartmentation. When recommending BSM to the farmers, it is therefore essential to ensure they address the actual infectious risks and that they are feasible (prior exchanges with the farmer) and cost-efficient. Evidence-based research aiming at demonstrating the cost efficiency and usefulness of BSM should be planned in order to prove the cost efficiency of the proposed measures in the future and modify farmers' negative perception towards some measures. A socio-psychological survey of farmers' perceptions and decision-making processes would be useful to better understand and promote implementation of BSM at farm level. In addition, a longitudinal study on farms' biosecurity level of implementation would be interesting as a follow-up study.

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APPENDIX 1 CALCULATION METHOD OF THE DIFFERENT IMPLEMENTATION SCORES FOR THE MOST IMPORTANT BIOSECURITY MEASURES LISTED BY THE FARMERS

Biosecurity measure	Calculation of the implementation score
Visitors control (limitation and hygiene)	Not used because does not depends on the farmers only but mainly on visitor's practices
Limit contact with other animals/animals from other farms	Not used because does not depends on the farmers only; furthermore, no biosecurity measure can prevent contacts in pastures
Vaccines (at least 1)	Number of farms applying at least 1 vaccination protocol
Hygiene of stables	Number of farms where dry and clean litter was observed in all stables (adult stables, calves stables/boxes and individual hutches)
No animal movements	Number of farms with no animal movements (no purchases AND no re-entering animals)
Prevention programmes for endoparasites	Number of farms preventing endoparasites
Controlling animal status in case of purchase (history, farm status and serological tests)	Number of farmers checking status of the farm of origin AND testing the animals
Compartmentation by age groups	Number of farm with separated calves stables
Specific/clean farm boots	Number of farmers using farm-specific boots
Regular screening and elimination of carriers	Number of farmers eliminating carriers systematically when detected
Appropriate colostrum intake	Number of farmers giving colostrum within 2 hours after birth
Limitation of purchases	Number of farmers purchasing once per year or less
Prevention programmes for ectoparasites	Number of farms preventing ectoparasites
Applying a proper quarantine in case of purchase	Number of farmers purchasing animals who have a separated quarantine area and apply a quarantine of at least 15 days (remark: no control of indirect transmission)
Hygiene during milking operations	Number of farmers cleaning and disinfecting teats before and after milking, and cleaning and disinfecting equipment after each milking
Specific/clean farm clothes	Number of farmers using farm-specific clothes
Hygiene at calving	Number of farmers with hands and equipment cleaned at least before calving and navel disinfected
Preventive care for (inter)digital dermatitis	Number of farmers who perform preventive hoof trimming AND/OR have footbaths for cows
Limiting visits to other farms (or changing boots)	Number of farmers limiting their visits to other farms
Not sharing equipment with other farms (or cleaning them before re-entering)	Number of farmers with medical materials cleaned at least after use
Working lines (youngest to oldest)	Number of farmers working from youngest to oldest animals
Isolation of sick animals	Number of farmers who have an hospitalization pen and isolate sick animals (always or sometimes)

Biosecurity measure	Calculation of the implementation score
Proper cadaver management	Number of farmers: cadavers covered and on cemented floor
Clean shared engine or equipment when returned	Number of farmers not sharing equipment in contact with animals or animals products OR cleaning and disinfecting them after use
Milk infected cows separately	Number of farmers milking infected cows separately (last)
Separated maternity pen	Number of farms with a separated maternity pen
Apply an all-in/all-out system	Number of farmers applying all-in/all-out system (and not moving poorly growing calves with younger animals)

Experimental section

Study 3

Cattle farmers' perception of biosecurity measures and the main predictors of behaviour change: The first European-wide pilot study

Transboundary and Emerging Diseases 2020, 00:1-15

Véronique Renault, Bert Damiaans, Marie-France Humblet, Saúl Jiménez Ruiz, Ignacio García Bocanegra, Marnie L. Brennan, Jordi Casal, Etienne Petit, Laura Pieper, Celine Simoneit, Isabelle Tourette, Linda van Wuyckhuise, Steven Sarrazin, Jeroen Dewulf and Claude Saegerman.

Preamble

The implementation level of BSM by Belgian cattle farmers is overall low and different reasons were expressed by the farmers. The cost itself was not expressed as a reason for not implementing a BSM. The key factors highlighted by the farmers were the importance of the BSM (based on the risk level), its efficiency and its feasibility. As mentioned by previous authors, in order to improve the level of BSM adoption by cattle farmers, a more efficient communication addressing the determining factors of behaviour changes needs to be implemented by the technical counsellors and authorities. A socio-psychological survey of farmers' perceptions is therefore useful in order to better understand their decision-making processes and the determining factors to be addressed.

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Cattle farmers' perception of biosecurity measures and the main predictors of behaviour change: The first European-wide pilot study

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Abstract

The importance of biosecurity as a strategy to prevent and control infectious diseases has increased substantially over the last few decades. Several studies have reported a low implementation level of biosecurity measures (BSM), particularly in cattle farms. In addition, a recent study demonstrated that cattle farmers are well aware of the recommended BSM and recognize them as more effective (in terms of time and costs) than treatment for disease. Therefore, other factors must be considered when it comes to understanding the decision-making process followed by a farmer regarding the adoption of BSM. This study analysed the possible influence of five mental constructs described in the health belief model (HBM) on the adoption of BSM and assessed the possible association of these constructs with different demographic and socio-psychological factors. Through an online survey, 988 questionnaires were completed by cattle farmers originating from Belgium, France, Germany, Spain and the Netherlands. The study revealed that the actual implementation of the BSM seems to be significantly influenced by the farmers' perception of the measures' benefits and the perception of health responsibility. Both constructs are influenced by the farmers' personality in terms of risk aversion and biosecurity knowledge. It was also found that organic farmers had a significantly lower perception of the BSM benefits and of their responsibility towards animal, public and environmental health when compared with other types of farmer. Organic farmers in this study seemed less likely to implement biosecurity measures. To increase the adoption of BSM by cattle farmers, it is therefore important to emphasise the actual evidence-based benefits of the measures and to investigate further how to strengthen cattle farmers' sense of responsibility towards animal, public and environmental health.

Keywords

behaviour, biosecurity measures, bovine viral diarrhoea, brucellosis, calf diarrhoea, cattle farmers, health belief model, organic farming, practices, risk perception

1 | INTRODUCTION

In animal production systems, the proper implementation of biosecurity measures (BSM) by farmers permits the prevention of infectious diseases and enables better control of transmission within or outside individual production units. The importance of biosecurity as a strategy to prevent and control infectious diseases has increased substantially over the past few decades. Since 2007, biosecurity measures have been part of the European Union Animal Health Strategy (European Commission, 2007).

Several studies have investigated the degree of implementation of BSM in cattle farming. These studies have reported a low level of implementation (Brennan & Christley, 2013; Renault et al., 2018) and highlighted different constraints and barriers such as the efficacy or the cost-effectiveness of measures, the workload required, the BSM feasibility, the lack of motivation and the relevance of the BSM with regard to the actual risks (Brennan et al., 2016; Gunn et al., 2008; Laanen et al., 2014; Renault et al., 2018). A recent study showed that farmers have knowledge of the recommended BSM and recognize these as more effective (in terms of time and costs) than disease treatment (Renault et al., 2018). Therefore, other factors have to be considered when it comes to understanding the farmers' decision-making processes regarding the adoption of BSM. The complexity of this decision-making process has been described in two recent reviews (Mankad, 2016; Ritter et al., 2017). Based on these reviews, different factors are likely to have an influence: (a) the farmers' psycho-sociological profile (e.g. personality, culture, risk aversion, previous experiences, (b) the perceived responsibility towards animal, public and environmental health and biosecurity knowledge), (c) the farming context (e.g. national and international regulations, demands and market prices), (d) the perception of possible barriers, (e) the risks (disease susceptibility and severity) and (f) the cost-effectiveness of proposed BSM (benefits).

Over the last decade, the importance of socio-psychological studies in the field of veterinary epidemiology has increased significantly, as illustrated by the increased number of publications since 2012 (Wauters & Rojo Gimeno, 2014). Many behaviour change theories have been developed over time to try to predict the implementation of a given behaviour by users, as well as to identify the key factors to be targeted in order to increase the adoption rate of desired practices. In the field of animal production and health, two of the most common models that have been applied are the Theory of Planned Behaviour (Ajzen, 1985) and the Health Belief Model (Janz & Becker, 1984; Rosenstock, 1974; Figure 1). In both cases, the models assume that the behaviours are mainly depending on mental constructs and analyse the relationship between these mental constructs and the behaviours. These constructs relate to different beliefs and perceptions influenced by different demographic, socio-psychological and contextual variables. The health belief model (HBM) is made up of five mental constructs: (a) the health responsibility (perceived responsibility towards animal, public and environmental health); (b) the risk susceptibility (likelihood of disease occurrence); (c) the risk severity (perceived impact of the disease if it occurs); (d) the barriers (perceived difficulty of performing a BSM and the possible level of control); and (e) the benefits (perceptions of the possible positive outcomes related to the implementation of a BSM) (Janz & Becker, 1984; Rosenstock, 1974). On the other hand, the theory of planned behaviour (TPB) relies on the influence of three main constructs on the intention of performing a behaviour: (a) the attitude towards the behaviour (beliefs and evaluation of the expected behavioural outcomes); (b) the subjective norms (social factor referring to the social pressure to perform or not perform a behaviour); and (c) the perceived behavioural control (beliefs about capability and control; Ajzen, 1991). Different researchers have applied both models with slightly different results from one study to another, based on specificities or new findings (e.g. some HBM models included an additional element called 'cue to action' and others considered the disease severity and susceptibility as one sole element; Carpenter, 2010; Janz & Becker, 1984). When comparing both models, it appears that the elements taken into account are similar but

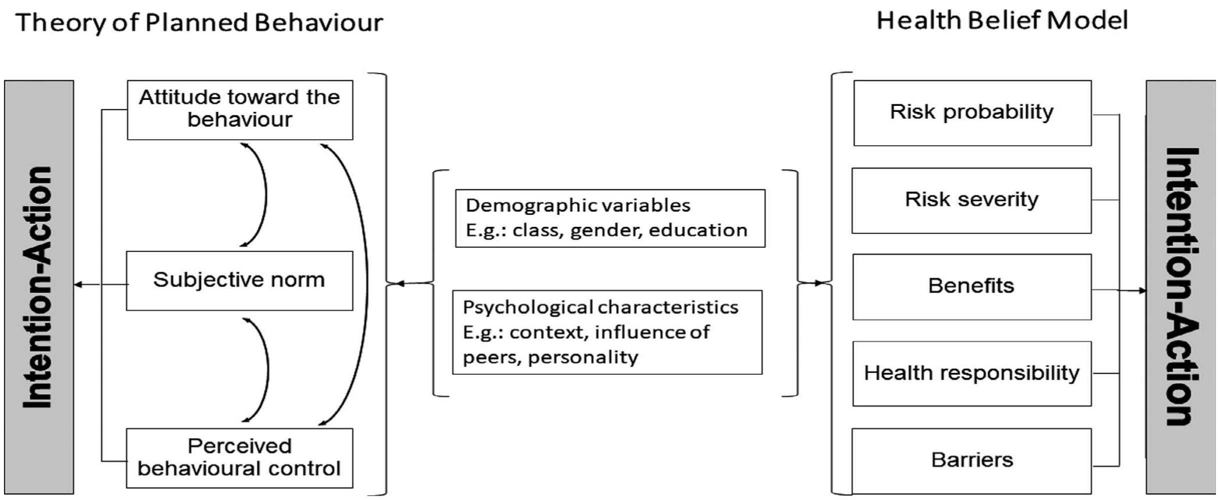


FIGURE 1 Comparison of the Theory of Planned Behaviour and the Health Belief Model

regrouped into different constructs (Figure 1). In comparison with the TPB, the HBM is specific to health behaviours. It is also the most frequently used model in veterinary medicine as illustrated by a search in PubMed with 'name of the model' and 'veterinary' used as keywords and Boolean operator showing more than 42,818 results for the HBM model and 895 results for the TPB (search effected on June 16th 2020). The HBM also appears more detailed as it includes five constructs compared to three constructs in the TPB.

The aim of this study was to use the outcomes of an online survey to identify the important HBM constructs when assessing the intention to implement or the implementation of different BSM by cattle farmers. The possible associations between different demographic socio-psychological factors and the different constructs were also investigated.

2 | MATERIALS AND METHODS

2.1 | Theoretical framework: The Health Belief Model

The current study applied the HBM to explore the different factors influencing cattle farmers' behaviours. Figure 2 provides an overview of the nine components included in the model. The components included different demographic variables, two psychological variables (risk aversion and biosecurity knowledge) expected to have an influence on the mental constructs, the five mental constructs of the HBM assessed through different questions (3 to 8 questions per construct) and the model outcome formulated as the intention to implement or the actual implementation of the behaviour.

As the perception of susceptibility, severity and any benefits of the BSM are risk-specific, these perceptions were assessed for three different diseases: these were selected as they have a different susceptibility and severity and illustrate different possible transmission pathways of infectious diseases:

- An eradicated disease: brucellosis (BRU)
- An endemic disease: young calf diarrhoea (YCD)
- An endemic disease targeted by national or regional control programmes: bovine viral diarrhoea (BVD).

Perceived benefits were expressed as the perceived effectiveness of the different BSM at preventing and controlling the three diseases. In order to build the HBM model, 17 BSM (Table 1) were selected from the BSM listed in a previous study (Renault et al., 2018). The BSM selected were deemed efficient against one, two or three of the selected diseases, showed variability in terms of implementation level and represented different stress levels (e.g. time-consuming, costly, involving (or not) a specific organization of work and requesting (or not) specific infrastructures).

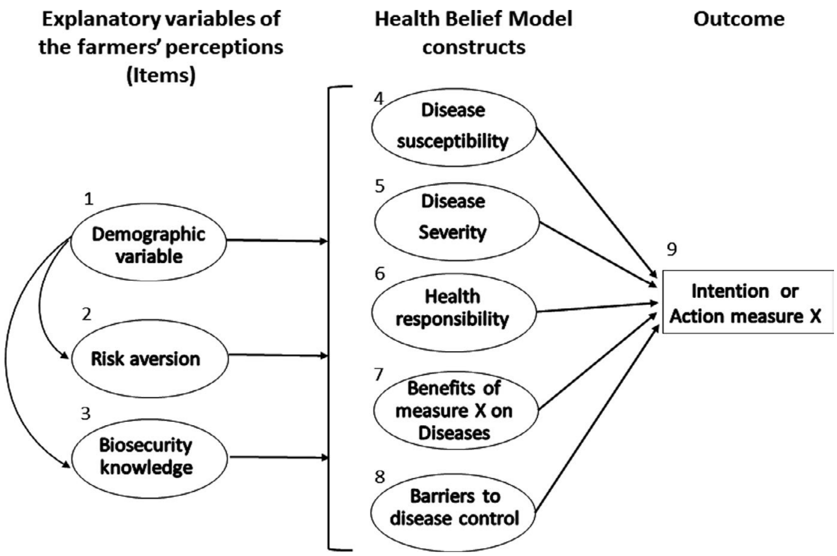


FIGURE 2 Health Belief Model applied in the study. * Calculated score: variable measured by a composite score in the multivariable regression model (see Appendix S1)

2.2 | Survey development and methodology

The online survey included 66 questions, that is 64 closed questions and two open questions (Appendix S1). The questions used to assess the different HBM constructs were identified and formulated based on a previously validated questionnaire (Champion, 1984). The survey was developed in an open source software, LimeSurvey, in five languages (English, Dutch, German, French and Spanish). The survey was pre-tested among four farmers in each language before its validation and disseminated by the different authors in six countries (i.e. Belgium, France, the Netherlands, Germany, Spain and the United Kingdom). In Belgium, France and the Netherlands, the invitations to fill in the survey were sent by the regional animal health associations through their mailing lists. In Germany, invitations were sent by farmers' insurance companies and government veterinary offices. In the UK, invitations were sent through personal contacts of the research team and social media (i.e. professional journals). In Spain, the invitation to participate was disseminated through personal networks with a very low response level due to Spanish farmers' poor access to online technologies. The survey in Spain was thus mainly conducted through face-to-face interviews with farmers randomly selected in livestock meetings (e.g. fairs or exhibitions) or farmers enrolled in a specific research programme (managed by IREC (Instituto de Investigación en Recursos Cinegéticos) and the University of Cordoba) to improve general biosecurity measures against bovine tuberculosis.

In Belgium, the Regional Association for Animal Health and Identification (ARSIA for the Walloon Region) added a specific add-on to their 'CERISE' application webpage (used by farmers for birth notification and statements of purchases), in addition to the use of its mailing list. This add-on opened a pop-up window inviting individuals to fill in the questionnaire when the farmer connected to the application. It was addressed to all cattle farmers, independently of the herd type and production system. Data were collected from November 2017 to February 2019; several reminders were sent during this period to increase the number of respondents. The selection of the different demographic and sociological variables was based on two articles describing the determinants of farmers' behaviours (Mankad, 2016; Ritter et al., 2017). The following demographic variables were considered in the survey: experience (years), education

TABLE 1 List and typology of the biosecurity measures addressed in the questionnaire

Biosecurity measures		Benefits	Possible constraints			
		Diseases l /	Operational	Major cost	Depends concerned[a] aspects on others	Workload infrastructure
M1	Mandatory or recommended control programme	3	Yes	Yes	Yes	Yes
M2	Maintaining a closed herd	3	Yes	No	No	No
M3	Applying an all-in/all-out system (for veal calf farms)	3	Yes	No	Yes	No
M4	Control status/serological test of animals before purchase	2	No	No	No	No
M5	Applying a proper quarantine (21 days min., separated barn with no physical contact with other animals, specific or cleaned and disinfected clothes/boots and materials affected to that area)	3	Yes	Yes	Yes	No
M6	Controlling entering vehicles (no access to animal transit areas)	2	Yes	No	No	Yes
M7	Physical isolation of sick animals and/ or aborted cows (separate barn with no physical contact with other animals, specific or cleaned and disinfected clothing/boots and materials affected to that area)	2	Yes	Yes	Yes	No
M8	Avoiding access to surface water in pastures (e.g. rivers, streams, ponds)	1	No	No	Yes	No
M9	Having a proper carcass disposal system (cemented area and carcass cover)	1	No	No	Yes	No
M10	Having feeding-dedicated equipment, not using feeding utensils for other usage (e.g.litter/manure handling, …)	2	Yes	No	No	No
M11	Proper work organization (attending the animals from the young to the old and from the healthy to the sick)	2	Yes	No	No	No
M12	Having maternity boxes or pens physically separated from other animals	3	Yes	Yes	Yes	No
M13	Regular testing of animals for carriers detection and elimination	2	No	No	No	No
M14	Placing calves in individual boxes/hutches with no possible contact with others (if suckling herds: leave blank)	2	Yes	Yes	Yes	No
M15	Ensuring usage of disposable clothes and boots and hands disinfection by professional visitors (veterinarian, inseminator, cattle salesman) before entering into the barns	3	Yes	No	Yes	Yes
M16	Keeping the litter dry and clean, good hygiene in barns	1	Yes	Yes	No	No
M17	Having double fencing in pastures to prevent contact with animals from other farms	3	No	No	Yes	Yes

a Number of infectious diseases which can be partially controlled by this BSM among the three diseases proposed.

level, gender, herd type, herd size, business stage (starting or expanding, settled or stable, reducing or retiring) and production type (organic/ conventional).

Two psychological characteristics were assessed: 'risk aversion' was determined indirectly by asking the farmers their degree of agreement with three sentences: (a) I consider myself as a cautious person, (b) I anticipate risks and take specific measures to mitigate them and (c) I always bring basic medical products with me for personal use (disinfectant, bandages and pain killers; Appendix S2). The farmers' 'Biosecurity knowledge' regarding BSM was determined by asking them to list three BSM, in order to verify if she/he knew the term 'biosecurity' and its associated measures.

The formulation of the questions regarding the different perceptions and beliefs was based on the good practices and practical examples provided in an article describing the construct validation of the HBM (Cummings et al., 1978). The questions were labelled and grouped in order to assess the five HBM constructs: risk susceptibility, risk severity if it occurs, health responsibility, benefits of BSM and barriers. For each construct, the farmers were asked to rate their degree of agreement with different statements via a visual analogue scale ranging from 0 (fully disagree) to 100 (fully agree).

The intention to implement or the actual implementation of the different BSM was assessed through a 6-level Likert scale with the following levels: '0: Not implementing it and I do not intend to', '1: Not implementing it but I might consider it','2: Not implementing it but I will do it', '3: Yes, I do implement it but sometimes only', '4: Yes, I do implement it most of the time' and '5: Yes, I always implement it'. An additional category ('Other') was proposed to allow additional comments (e.g. not applicable, based on the production system). If the comments provided were not useful (i.e. lack of comment or comment did not permit classification into one of the 6 levels), the country-specific mode was used for unimodal distributions, and a random value-based on the most frequent modes of the country in case of bi-modal distributions.

Data were extracted into a Microsoft Excel spreadsheet and consolidated.. The responses given by the participants were coded and the attributes of the different variables defined as explained in Appendix S2. The incomplete questionnaires and the questionnaires originating from countries with less than five respondents were excluded.

2.3 | Scoring methodology for the different constructs

In order to estimate the perception scores for each HBM construct, the scores of questions in which the construct was negatively formulated were reversed to enable uniformity across questions. The farmers' perception of the different constructs was determined either directly (for the disease susceptibility and BSM benefits constructs) or indirectly by calculating the degree of agreement (agreement score) with the different statements used in the questionnaire (Appendix S2). The degree of agreement was assessed through a visual analogue scale providing a score ranging from 0 (fully disagree) to 100 (fully agree), representing the degree of agreement with the proposed statements.

The construct 'Susceptibility' was assessed by asking the farmer what the probability of each disease occurrence was in his or her farm in the absence of general or disease-specific preventive measures. The overall susceptibility score represents the average of the disease-specific scores.

The construct 'Severity' was determined by asking the farmer her/his degree of agreement with three statements: (a) If this disease was occurring, there would be an important negative effect on my herd productivity (perception), (b) The economic impact of this disease on my activity over the last 10 years was very high (personal experience) and (c) Many farmers I know have been affected by this disease over the last 10 years (experience of other farmers). The questions were repeated for each disease. The farmer's overall severity perception was calculated as the average score obtained from the nine questions (three questions for each disease) and reflects the farmer's overall degree of agreement with the statements.

The construct 'Health responsibility' was assessed indirectly. The farmers were asked their level of agreement with eight statements illustrating their responsibility towards animal, public and environmental health (Table 2). The average score was then calculated accordingly.

The construct ‘Benefits’ was calculated for each BSM (N = 17), as well as for the overall benefits (across the 17 BSM). For each BSM, the farmers were requested to provide their perception of BSM benefits regarding the prevention or control of each of the three diseases; the average score was then computed to obtain the BSM specific-benefit score. The benefits of a BSM were defined as ‘the measure of efficiency (in terms of cost and time effectiveness) and its capacity to prevent disease and/or reduce losses’.

The construct ‘Barrier’ assessed the farmer's perception regarding her/his level of disease control. The farmer was asked her/ his degree of agreement with two sentences: ‘I am able to prevent the disease by implementing appropriate measures’ and the opposite statement, ‘The prevention of the disease relies mainly on measures to be implemented by the authorities, there is not much I can do’. The two questions were asked for the three diseases and the average score calculated in order to determine the ‘Barrier’ score.

TABLE 2 List of statements used to assess the perceived responsibility towards animal, public and environmental health

No.	Sentence
1	Infectious diseases represent an important risk for my farm
2	I make a lot of efforts to maintain a good general hygiene in the farm
3	The monitoring by the veterinarian is really important for my herd health status
4	I call the veterinarian directly if I have a problem
5	Disease prevention and control measures are important to preserve a good health status for my herd
6	Disease prevention and control measures are important to preserve the environment
7	Farmers have responsibilities towards animal food consumers in terms of public health
8	I am responsible for the implementation of infectious disease prevention and control measures

2.4 | Negative binomial regression models

2.4.1 | Effects of demographic and psychological variables (explanatory variables) versus psychological variables and Health Belief Model constructs (dependent variables)

A backwards stepwise regression model was applied in Stata SE/14 (StataCorp LP) to assess the influence of different explanatory variables on the five HBM constructs (Figure 2). The possible influence of demographic variables on risk aversion and biosecurity knowledge was also considered. A negative binomial regression was used as the variables did not seem normally distributed (based on a Shapiro test), and the goodness of fit of the Poisson models was insufficient.

Firstly, a univariable analysis was performed using a negative binomial regression to assess the level of influence of the different explanatory variables on each dependent variable. Secondly, for each construct, a multivariable analysis including all the explanatory variables with a *p*-value below 0.1 (in order to be conservative) was conducted. The model was progressively simplified by removing the least significant variable with a $p > .05$. The model was considered complete, either when all variables had a significant *p*-value (<.05), or when it could not be further simplified without having a significant difference between the most complex and the simpler model (likelihood ratio test with $p < .05$).

As the model presented in Figure 2 assumes a possible influence of the demographic variables on both the psychological variables and the perceptions, a test was performed in order to identify possible high associations between variables which could interfere with the multivariable regression models. If both a psychological and associated demographic variable (based on the Kruskal–Wallis test) were to be included in the multivariable regression model, the psychological variable was the only one included as it is assumed to have a higher direct influence on the HBM constructs.

TABLE 3 Farmers and farm profiles of the respondents

Variable		Belgium	France	Germany	Netherlands	Spain	Total
	Number of respondents	701	68	128	27	64	**988**
Gender	**Female**	16.1%	20.6%	16.4%	11.1%	6.3%	15.7%
	Male	83.9%	77.9%	81.3%	88.9%	93.8%	83.9%
	No answer	0.0%	1.5%	2.3%	0.0%	0.0%	0.4%
Higher education[a]	**Yes**	31.8%	38.2%	51.6%	44.4%	39.1%	35.6%
	No	68.2%	61.8%	48.4%	55.6%	60.9%	64.4%
Herd type	**Beef**	55.3%	60.3%	14.8%	0.0%	54.7%	48.9%
	Dairy	27.7%	32.4%	55.5%	81.5%	26.6%	33.0%
	Mixed	16.4%	5.9%	11.7%	18.5%	3.1%	14.3%
	Other[b]	0.6%	1.5%	18.0%	0.0%	15.6%	3.8%
Business stage	**Starting or expanding**	22.5%	19.1%	26.6%	18.5%	42.2%	24.0%
	Reducing or retired	26.7%	27.9%	18.0%	48.1%	12.5%	25.3%
	Settled and stable	50.8%	52.9%	55.5%	33.3%	45.3%	50.7%
Organic farm	**Yes or In conversion**	10.0%	13.2%	18.0%	3.7%	25.0%	12.0%
	No	90.0%	86.8%	79.7%	96.3%	73.4%	87.6%
	No answer	0.0%	0.0%	2.3%	0.0%	1.6%	0.4%
Experience (years)	**Average**	27.3	28.41	29.01	33	28.7	27.9
	Standard deviation	11.88	11.71	12.32	13.25	17.16	12.39
	Range (min - max)	1 - 70	1 - 50	4 - 55	0 - 55	3 - 65	0 -70
Herd size (number of animals)	**Average**	174.5	205.5	216	182.5	246.2	186.9
	Standard deviation	146.3	173.3	285.48	175.06	263.6	182.81
	Range (min - max)	0 - 1075	2 - 1110	3 - 1900	45 - 1003	21 - 1300	0 - 1900
Mortality rate	**Average**	5.3	5	3.8	5.3	4.6	5.1
	Standard deviation	6.44	4.08	3.41	3.97	4.5	5.83
	Range (min - max)	0 - 105	0 -30	0 -25.9	0 - 12.5	0 - 17.9	0 - 105
Risk aversion	**Average**	220.05	209.54	203.3	1965.26	338.89	216.76
	Standard deviation	41.98	38.07	45.73	40.31	59.92	43.12
	Range (min - max)	88-300	105-290	44-298	114-275	94-300	44-300
Biosecurity knowledge	**Average**	1.97	2.01	1.87	1.81	2.48	1.99
	Standard deviation	1.15	1.06	1.1	1.36	0.83	1.13
	Range (min - max)	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3	0 - 3

2.4.2 | Association between the Health Belief Model constructs (explanatory variables) and the intention to implement or the actual implementation of BSM

A backward stepwise regression model was applied in Stata SE/14 (StataCorp LP) to assess the influence of the different HBM constructs on BSM implementation (or intention to implement). This was performed for each BSM (N = 17) as well as for the overall BSM using the average scores of each BSM as an overall benefits score and BSM implementation score. As variables were not normally distributed based on a Shapiro test, a negative binomial regression was used (larger variance compared with the Poisson model assumption).

3 | RESULTS

3.1 | Respondents' profile

A total of 996 complete answers were received from nine countries with an average completion time of 24 min (range: 4.7 to 3,945.85 min; quartile 1:16.2, median: 20.7 and quartile 3:28.4 min). The four questionnaires received from the UK and three questionnaires from unsolicited countries were not considered in the analysis due to the very small number of answers (less than five). One Belgian questionnaire was deleted as the farmer mentioned 'Not Applicable' to all the BSM when asked about his or her intention or action regarding measure implementation. Therefore, 988 respondents originating from five countries were considered in the data analysis (Table 3): Belgium (701 farmers), Germany (128 farmers), France (68 farmers), Spain (64 farmers) and the Netherlands (27 farmers). Among the respondents, 12% were organic farmers (or in conversion to organic farming) and the farm types identified were 49% beef farms, 33% dairy farms, 14% mixed farms and 4% other farm types (e.g. fighting bulls). The herd size ranged from 0 to 1900 head of cattle. The farmers mentioning having zero head of cattle were kept in the survey based on the assumption that they represent farmers having cattle but not willing to provide the size of their herds as this is often a sensitive question.

3.2 | Farmers' perceptions

The farmers' perception of the occurrence probability of BVD, BRU and YCD (susceptibility) ranged from 0 to 100 with a median of 50%, 28% and 73%, respectively (Figure 3a). Regarding the diseases' severity, the median of the degree of agreement was of 44%, 34% and 58% for BVD, BRU and YCD, respectively (Figure 3b). The diseases' severity and their economic impact are therefore perceived as 'not really important' by the farmers.

The farmers' perceptions regarding their responsibility towards animal, public and environmental health (health responsibility) was overall high (quartile 1:63%, median: 72%, quartile 3:81% and range: 0 to 100%). The majority of farmers agreed with the proposed statements on: the importance of risks, the need for proper health monitoring and the need for actions to preserve animal, environment and public health.

The farmers' perception regarding the level of control required to prevent infectious diseases on their farm was used as an indirect measure of the perceived barriers. Overall, most farmers disagreed with statements relating to having little control or depending on others (e.g. the government) to prevent or control infectious diseases (median of the degree of agreement below 40%; Figure 3c).

The possible benefits of the 17 BSM proposed can be described for each disease (mean score of the BSM benefits for a given disease) or overall (mean score of all the benefits related to that BSM). The majority of the farmers (more than 50%) perceived the efficiency of the different BSMs as greater than 50% (Figure 4), at the exception of having double fences for YCD for which the average farmers perception of the measure efficiency was below 50%.

The level of intention to implement the BSM was also assessed in the survey (Figure 5). Seven measures were nominated as being implemented by more than 60% of the farmers (control programmes, closed herds, test at purchase, proper carcass disposal, feeding-dedicated equipment, regular screening of animal health status and litter and barns' hygiene) and four measures revealed a low level of implementation (<40%): all-in all-out system, isolation of sick animals, visitors' hygiene and clothing and double fences in pasture.

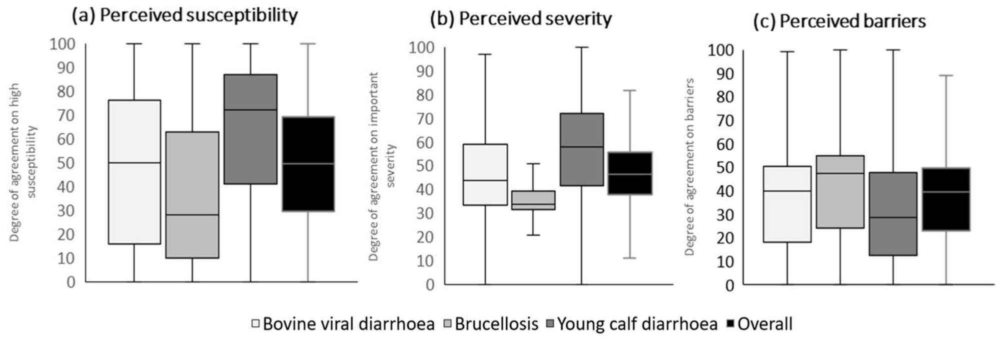


FIGURE 3 Farmers' perception of disease susceptibility and severity and of the possible barriers to their control. Box plot showing the different quartiles representing the three different diseases (three shades of grey) and an overall score (black), with the horizontal line representing the median. 'Overall': Perceived susceptibility of the three diseases (average of the three disease-specific susceptibility scores)

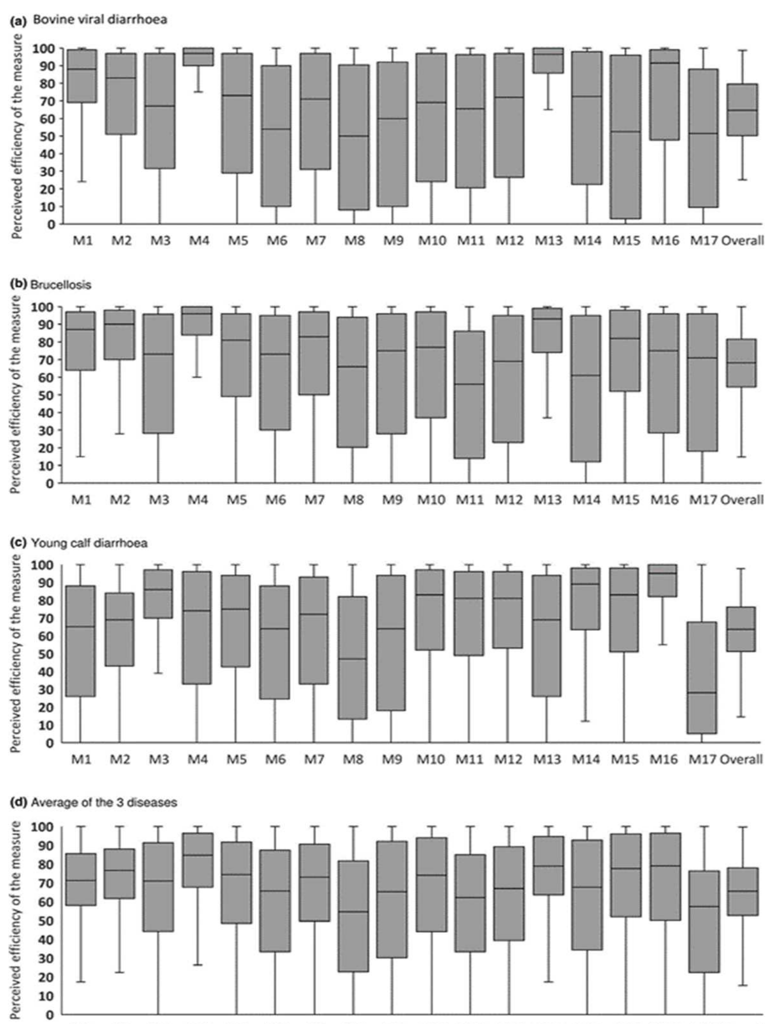


FIGURE 4 Perceived benefits of the different biosecurity measures on the prevention and control of: (a) Bovine viral diarrhoea, (b) Brucellosis, (c) Young calf diarrhoea and (d) the three diseases. M1 - Control programmes, M2 - Closed herd; M3 - All-in all-out system; M4 - Test at purchase; M5 - Proper quarantine; M6- Control of vehicle access; M7 - Isolation of sick animals; M8 - No access to surface water; M9 - Cemented area and cover for carcasses; M10 - Feeding-dedicated equipment; M11 - Proper working order (from young to old and from healthy to sick animals); M12- Isolated maternity boxes or pen; M13 - Regular screening of animal health status; M14 - Individual boxes for calves; M15 - Control of visitors' hygiene and clothing; M16- Litter and barn hygiene; M17 - Double fences in pastures

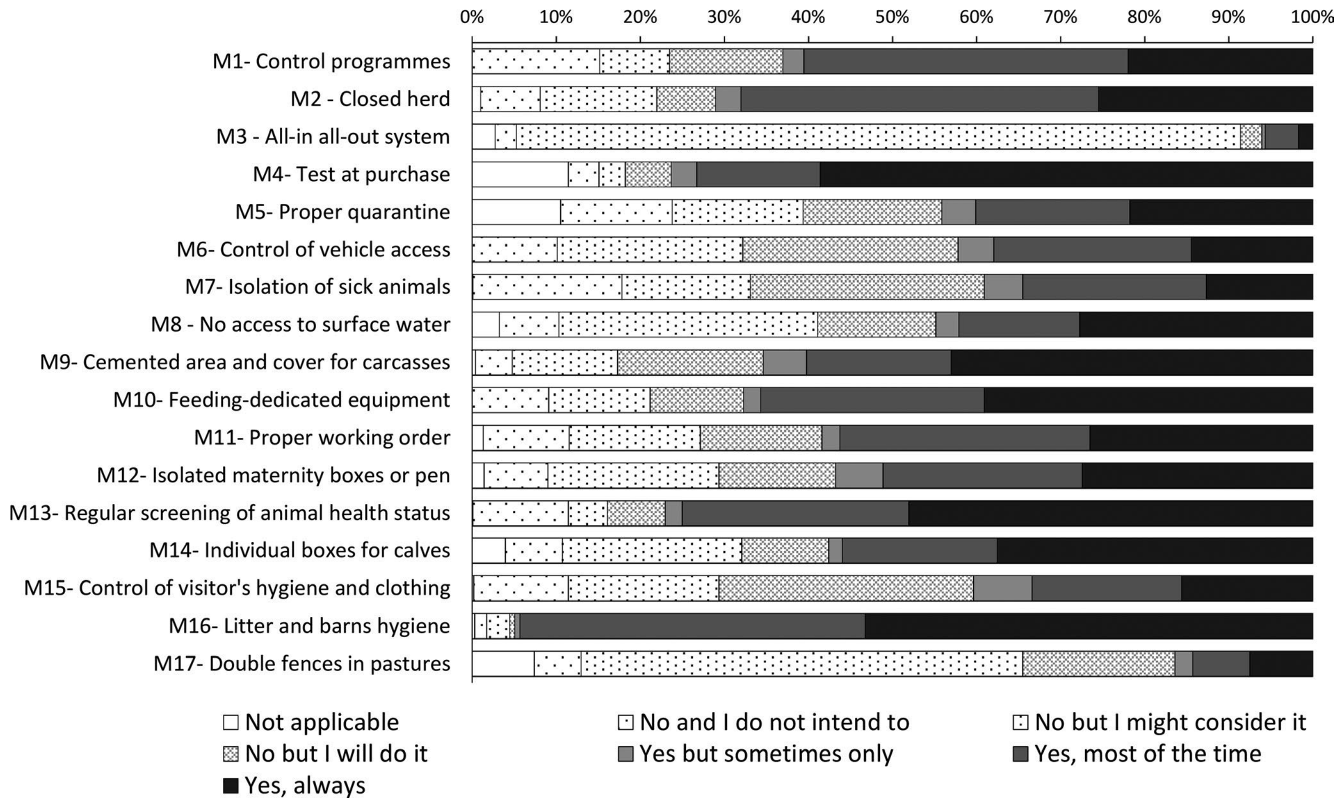


FIGURE 5 Intention to implement or implementation of biosecurity measures by the farmers

3.3 | Negative binomial regression models

3.3.1 | Effects of demographic and psychological variables (explanatory variables) versus psychological variables and farmers' perceptions (dependent variables)

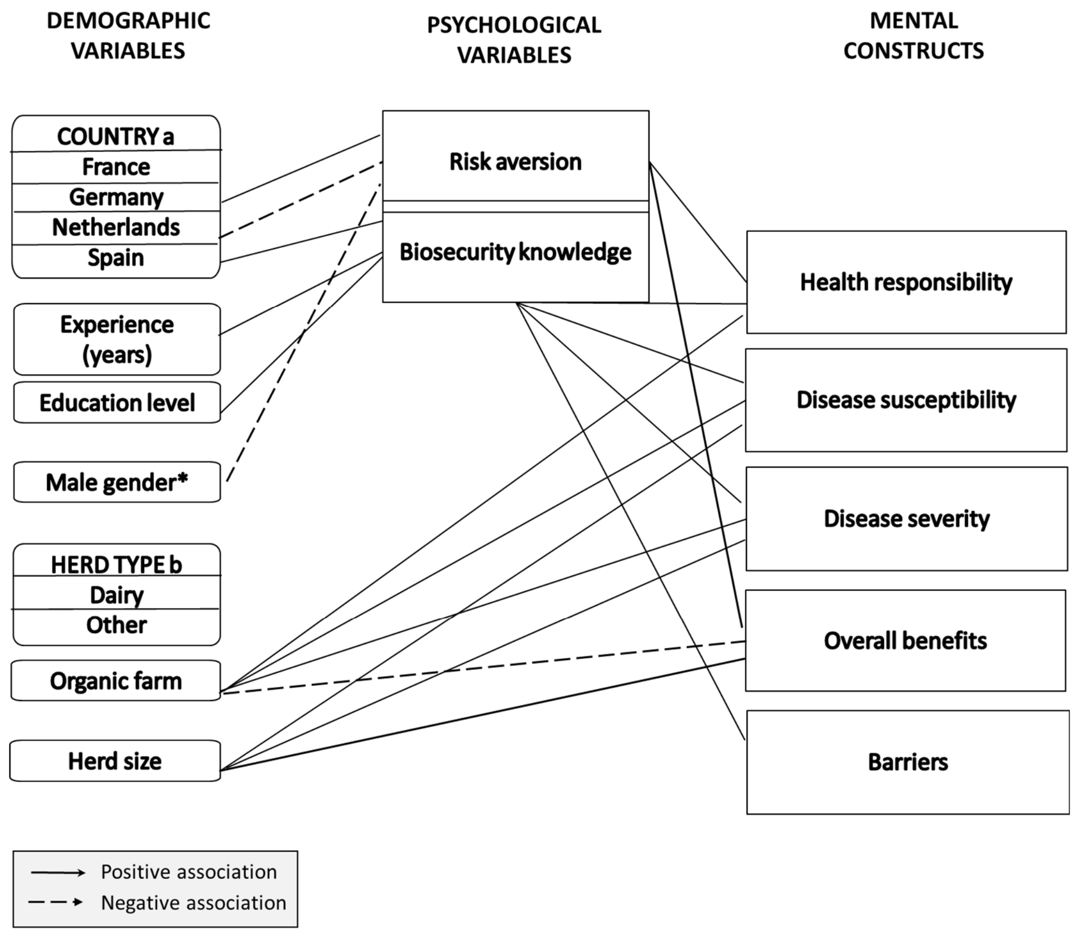
The stepwise backward regression analysis highlighted an association between several demographic and psychological variables and the farmers' perceptions, as well as between some demographic and psychological variables (Figure 6a). The different regression models are provided in Appendix S3A,B. The Kruskal–Wallis analysis confirmed a high association between country and risk aversion ($p < .0001$), and country and biosecurity knowledge ($p < .008$). Additionally, there were high associations seen between education level and the biosecurity knowledge ($p = .0001$), and between gender and risk aversion ($p < .0002$). Therefore, if two associated variables were to be included in the multivariable model ($p < .1$ in the univariable model), the psychological variable was the one included.

Regarding the association between demographic and psychological variables, risk aversion was significantly lower for males, and for farmers in two specific countries (i.e.: Germany and the Netherlands) when compared to Belgium. Biosecurity knowledge was significantly higher for farmers in Spain, those who were experienced and those with a higher education level.

The farmers' sense of responsibility towards animal, public and environmental health was significantly higher for individuals with higher biosecurity knowledge and risk aversion as well as for non-organic farms. It was also significantly higher for farmers in Spain, and significantly lower for farmers in Germany, compared with farmers in Belgium. The overall perception of the different disease susceptibility and severity was significantly higher for non-organic farmers, farmers with a better biosecurity knowledge, and those with a larger herds size. The perceived barrier was significantly lower for farmers with a higher biosecurity knowledge. The perception of BSM benefits was significantly lower in organic farms and higher for farmers owning a larger herd and having a higher risk aversion.

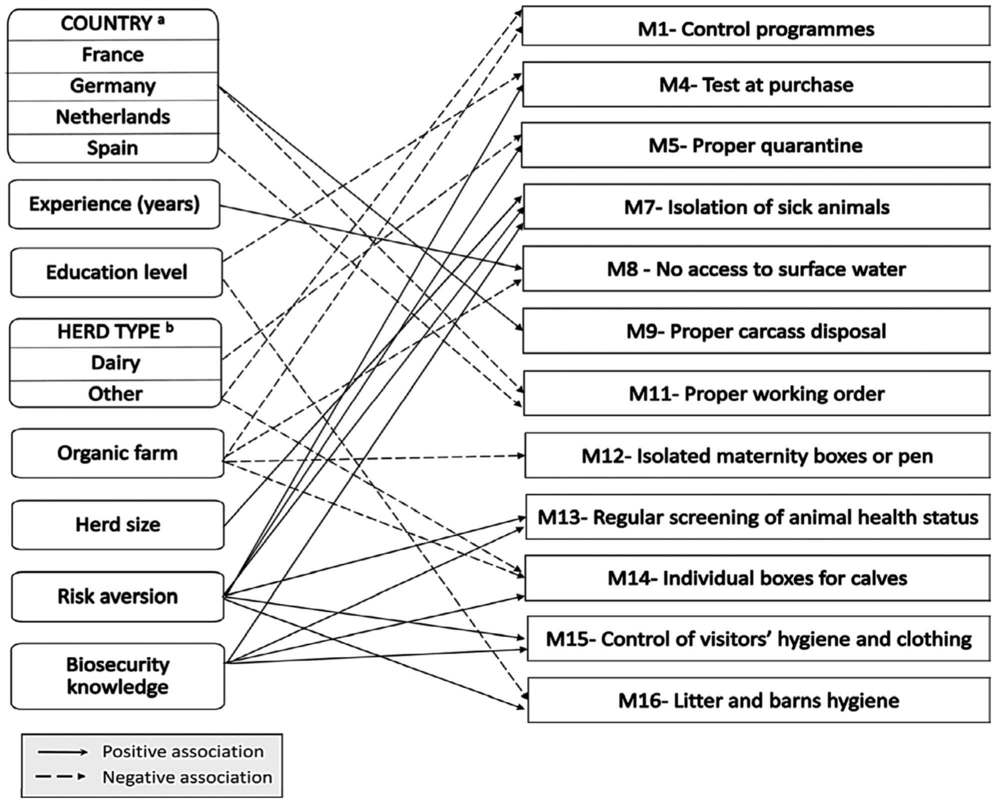
FIGURE 6 Significant associations identified from the different final models obtained by the backward stepwise regression analysis. (a) Significant associations between the demographic and psychological variables and the Health Belief model constructs: [a]Significant association compared with Belgium; [b]Significant association compared to Beef herds. (b) Significant associations between the demographic and psychological variables and the benefits of the biosecurity measures: [a]Significant association compared with Belgium; [b]Significant association compared with Beef herds. The gender variable as well as the biosecurity measures without any association were removed from the figure (M2, M3, M6, M10 and M17). (c) Significant associations between the Health Belief model constructs and the intention to implement or the implementation of biosecurity measures

(a)



** Typo error corrected in the figure compared to the original article (negative association between male gender and risk aversion).*

(b)



(c)

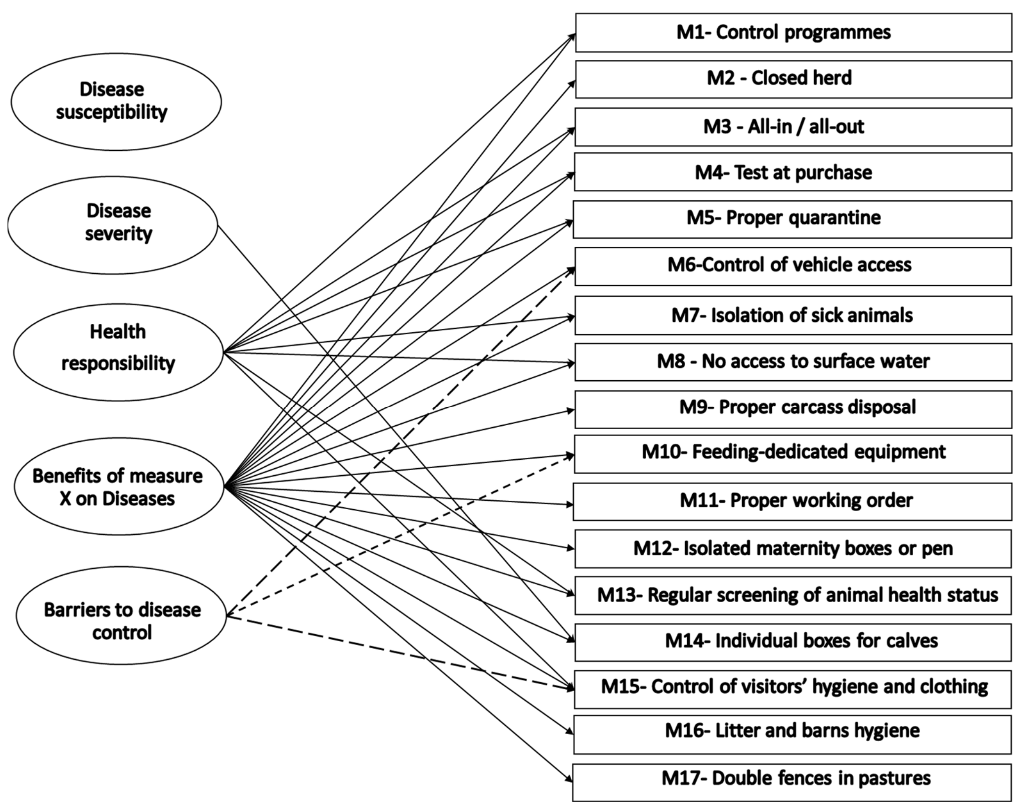


FIGURE 6 Continued

3.3.2 | Association between the Health Belief Model constructs (explanatory variables) and the level of intention to implement the BSM

The five HBM constructs were used as explanatory variables in 18 multivariable models; one model was tested for each BSM, and an additional model tested the overall implementation of BSM (Appendix S3C). The final models (Figure 6c) showed that the perception of disease susceptibility and severity did not make any significant difference in terms of BSM implementation with the exception of keeping the calves in individual boxes. This BSM seemed more likely to be implemented when the farmers had a higher perception of the disease severity and BSM benefits. The level of intention or implementation of a given BSM was significantly higher when the perception of its benefits was higher and when the sense of responsibility towards health was higher. When analysing the influence of HBM constructs on the implementation of individual BSMs, health responsibility was associated with a significantly higher level of implementation for nine measures, and perception of BSM benefits was associated with a higher level of implementation for all 17 measures. Three BSM appeared to be significantly less likely to be implemented when the perceived barriers were higher: controlling vehicle access, the use of feeding-dedicated equipment and controlling the visitors' hygiene and clothing.

4 | DISCUSSION

The influence of psycho-socio-demographic factors on farmers' behaviour is now largely recognized and taken into account in the different communication and awareness raising strategies related to BSM or prevention of infectious diseases (Mankad, 2016; Ritter et al., 2017). As mentioned in a previous study, the theories of behaviour change (mainly HBM and Theory of Planned Behaviour) have been increasingly tested or applied to behaviours related to animal health (Brennan et al., 2016). Most of these studies used the HBM to assess the implementation of a specific BSM or risk (e.g. the application of nematode control programmes; Vande Velde et al., 2015a, 2018). Nevertheless, to our knowledge, only one study has applied multiple behaviour change models to actually identify the determinants of BSM implementation in general and assess their level of influence on the actual behaviour (Richens et al., 2018). Being able to identify the most important beliefs and perceptions to address and change in order to facilitate the adoption and long-term implementation of BSM is a key element of any communication strategy.

This study showed that, among the five HBM constructs, three significantly influenced the level of BSM implementation. The perception of the benefits of using BSM and the farmers' perception of their responsibility towards animal, public and environmental health influenced significantly and positively the use of 17 and nine BSM, respectively, as well as the overall level of BSM implementation. The perception of the barriers to using BSM influenced significantly and negatively the implementation of three BSM. As the model assumes that the HBM constructs are influenced by different demographic and socio-psychological variables, it is therefore important to analyse which of these variables appear to influence these three HBM constructs.

One potential limitation of the study relates to questionnaire development and its lack of validation. The questionnaire's capacity to properly capture the HBM constructs has not been properly validated. However, the questions were developed along similar lines as in previous studies (Brennan et al., 2016; Mankad, 2016; Ritter et al., 2017; Vande Velde et al., 2015a, 2018), and guidelines described by Champion (1984) were consulted. The total number of complete questionnaires achieved (*N* = 988) was substantial. Nevertheless, the over-representation of Belgium is likely to be a bias as well as the different methods used in each country to contact farmers. For example, these disparities might explain the result relating to the higher biosecurity knowledge in Spain compared with Belgium as the majority of Spanish farmers who participated in the survey were involved in a biosecurity research programme. The country-specific context regarding mandatory BSM and/or disease control programmes as well as the country-specific disease status' might also have influenced the farmers' perceptions. As an example, the perception of the disease susceptibility related to a given disease is more likely to be lower in a disease-free country compared with a country where the given disease is endemic. The perception of a disease severity is also more likely to be higher if the country has an eradication programme targeting this disease, which could lead to additional economic losses in case of outbreaks. The farmer differences between countries should therefore be considered with caution. Nevertheless, the identified country bias should only influence the correlation between the demographic variables and the HBM constructs themselves and, based on the HBM model assumptions, should not affect the results of the multivariable analysis performed to determine the influence of the mental constructs on the behaviour. The use of a pop-up on the web page of the farmer associations' website (generating the opening window inviting them to fill in the questionnaire) appeared to increase the number of responses and should be considered for similar future studies.

The two psychological variables, risk aversion and biosecurity knowledge, were significantly associated with a higher health responsibility and a higher perception of the benefits of the BSM (for six and four BSM, respectively). The farmers with a higher biosecurity knowledge and a higher education level also had a significantly lower perception of the barriers. This would likely lead to a higher implementation of these BSM negatively influenced by barriers: controlling vehicle access, using feeding-dedicated equipment and ensuring proper hygiene and clothing for visitors.

Some demographic variables such as organic farms and herd size did not significantly influence the psychological variables but seemed to influence the three most prominent HBM constructs: the health responsibility, the benefits and the barriers. Organic farmers (N = 119) showed a significantly lower responsibility towards health and a lower perception of the benefits of four BSM: existence of a disease control programme, preventing animal access to surface water, existence of isolated maternity pens and individual housing for calves. Therefore, their implementation level was likely to be lower compared with non-organic farmers. As the number of treatments per year and per animal is limited under organic farming systems, it would be expected that effective BSM would be considered essential to reduce the occurrence of infectious diseases on these farms. These finding are therefore somewhat surprising.

In the univariable model, country seemed to influence several perceptions significantly. Nevertheless, due to high associations with the psychological variables, country was not considered in the multivariable analysis whenever the psychological variables were included. The possible direct influence of country on the intention to implement or implementation of BSM was therefore not systematically assessed. In addition, due to a possible country bias due to the different ways of diffusion of the survey invitations, no conclusions can be taken as to the eventual causal link between the country and the perceptions.

This study, performed across a number of European Union Member States, is one of the first to analyse the influence of different perceptions on the overall implementation of BSM with the exception of work performed in Great Britain (Richens et al., 2018). Other previous studies have focused on a specific behaviour. To our knowledge, the current study is also the first study to include the 'health responsibility' construct and some psychological factors as possible explanatory variables.

This study confirms the findings of previous studies on behaviour change regarding the importance of farmers' perception of the efficacy or effectiveness of a BSM (Jansen et al., 2010; Moya et al., 2019; Richens et al., 2018; Vande Velde et al., 2015b) and the communication strategies focusing on the BSM effectiveness to promote behaviour change (Jansen & Lam, 2012).

The influence of farmers' perceptions of their responsibility towards animal, public and environmental health on whether BSM are implemented is an interesting finding in this study, which is worth investigating further. The role of 'the beliefs regarding the existence of a problem' was previously identified as an important element in terms of behaviour change (Jansen & Lam, 2012). The possible influence of the motivation behind the cattle farmers' behaviours is also considered by some policy makers such as the Department for Environmental, Food and Rural Affairs in the UK (DEFRA, 2008): they defined five categories of farmers, influenced by different communication strategies, in order to better promote behaviour changes. These five categories were: 'custodians' (strongly influenced by their commitment to protect the countryside; they see themselves as guardians of a farming heritage), 'lifestyle choice' (eager to achieve a high-standard of farming with their main source of income being non-farming activities); ‘pragmatists’ (they love farming and want to make enough money to achieve a satisfactory standard of living), ‘modern family businesses’ (focused on profit and running an efficient business) and ‘challenged enterprises’ (facing major challenges and anxious about farm survival). It might be interesting to further explore how the farmers’ sense of responsibility towards animal, public and environment health could be used as a trigger for behaviour change in a similar way to DEFRA.

A commonly held belief is that behaviour might be highly influenced by risk perception in terms of disease susceptibility and severity and many communication strategies therefore rely on the fear of a given disease. Nevertheless, this mental construct did not seem to influence our results, as the risk perception, either in terms of susceptibility or severity, did not significantly influence the implementation of BSM, with the exception of housing calves individually.

The results found in the current study confirms a number of previous findings in the veterinary literature, demonstrating no influence of the risk perception (perceived susceptibility and severity) on the level of intention to implement a specific BSM (Vande Velde et al., 2015b). Nevertheless, it contradicts other studies (Garforth, 2015; Moya et al., 2019) in which any public health problems or disease outbreaks on the farm or neighbouring farms were reported as triggers to behaviour change. The possible influence of such events was taken into account in the present study. Indeed, questions relating to individual experience of disease outbreaks on the farm or neighbouring farms were included, in order to assess the perception of risk severity. Nevertheless, this construct did not significantly influence the level of intention to apply BSM. Based on these contradictory findings, future investigations into the influence of these personal experiences as a unique construct with direct effect on BSM implementation should be considered. This element has been included in some HBM and referred to as ‘Cues to action’ (Rosenstock et al., 1988).

5 | CONCLUSION

It is now widely recognized that communication strategies should address different mental constructs in order to improve the adoption of BSM by farmers. Nevertheless, the relative importance of these constructs on actual behaviour change has not been properly investigated in veterinary medicine so far. This study confirms previous findings, which highlight the importance of basing communication strategies on evidence-based benefits whilst acknowledging the low influence of risk perception in the decision-making process. It also highlights a new psychological element, as health responsibility and attitude seem to highly influence the perception of the BSM benefits. Future studies should focus on determining the efficiency of the different communication strategies that have been targeted using the findings from this current study.

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ETHICAL APPROVAL

Due to the nature of the study and the low risk exposure of the participants, formal approval from an Ethics Committee was not a requirement at the time of the study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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Experimental section

Study 4

Economic impact of contagious caprine pleuropneumonia and cost–benefit analysis of the vaccination programmes based

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Véronique Renault, Haret A. Hambe, Guy Van Vlaenderen, Eddy Timmermans, Ahmed M. Mohamed, Olivier Ethgen and Claude Saegerman.

Preamble

Based on the study 3 as well as on similar studies, the cost-efficiency determines the perceived importance and utility of BSM and therefore is an important factor considered by cattle farmers before adopting a new behaviour. As mentioned in the introduction, several studies tried to assess the cost-efficiency of a specific BSM when it addresses only one disease (e.g.: vaccination, footbaths and deworming). The following study presents a methodology used to assess the cost-benefits of contagious caprine pleuropneumonia vaccination in Kenya pastoral areas. It relies on a longitudinal herd monitoring and a stochastic model assessing the possible herd evolution over ten years in the presence or absence of vaccination and converting the animal numbers into an economic value to measure the benefits of vaccination while its cost per head is calculated based on data provided by the Ministry of Livestock. This methodology could be applied to cattle production in order to assess the cost-benefits of equivalent measures.

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ORIGINAL ARTICLE

Economic impact of contagious caprine pleuropneumonia and cost–benefit analysis of the vaccination programmes based on a one-year continuous monitoring of flocks in the arid and semi-arid lands of Kenya

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Abstract

In Kenya and East Africa, contagious caprine pleuropneumonia (CCPP) is one of the most prevalent infectious diseases affecting small ruminants in pastoral areas with adverse consequences on livelihoods. This is so despite the implementation of bi-annual vaccination campaigns. Unfortunately, the impact of the disease and the cost-effectiveness of its prevention and control in a pastoral context have been difficult to assess due to a lack of reliable data. The dynamic of flock population, high illiteracy and limited outreach are the main challenges for proper data collection. Nevertheless, such analysis is important to justify the implementation of national vaccination campaign for livestock disease control and to contribute to pastoral households' economy support programme. A continuous flock monitoring was performed for a year in Turkana County to collect data on flock dynamics and the different causes of mortalities.
A stochastic model was developed to evaluate the annual economic losses due to CCPP in a standard flock of 100 heads and evaluate the cost–benefit ratio of the vaccination programmes based on different scenarios of 95%, 50% and 20% vaccination effectiveness. The annual economic losses due to CCPP for a standard flock of 100 heads were estimated at Euros 1,712.66 in average. The benefits-costs ratio of the vaccination supports the current bi-annual vaccination campaigns, even with a vaccine effectiveness limited to 20% (average benefits-costs ratio of 5.715 with SD of 3.914). This justifies the campaigns as part of a food security or livelihood support programme. However, from an overall health perspective and for long-term effects on livestock asset protection and disease control, a higher vaccination effectiveness is required.

K E YWORDS
Contagious caprine pleuropneumonia, continuous monitoring, economic analysis, flock, goats, Kenya, pastoralism, vaccination

1 | INTRODUCTION

Over the last decades, pastoralism was affected by many constraints, especially in arid and semi-arid lands (ASALs) of Africa. Pastoralists are highly vulnerable and sensitive to many hazards affecting their main livelihoods: the livestock assets. The main hazards affecting those communities are droughts, animals diseases and, in some areas, insecurity. Regarding animal diseases, different biosecurity measures (BSM) can be implemented to better prevent and control the animal diseases and reduce their incidence and impact on the household's livelihoods. Vaccination is the main BSM recommended to prevent outbreaks of infectious livestock diseases in high prevalence areas. Other measures (e.g., isolation of sick animals, limitation of animal movements, and quarantine of animals at purchase) are difficult to apply in pastoral systems. Large-scale vaccination campaigns against major infectious livestock diseases (e.g., contagious caprine pleuropneumonia (CCPP) and peste des petits ruminants (PPR)) are recommended annually or bi-annually in most African countries (AU-IBAR, 2016). These campaigns represent important logistic costs and many constraints. The benefits-costs ratio of the vaccination campaigns is a key element to analyze and evaluate the utility of this BSM regarding the protection of the livestock assets of the population (Lipner and Brown, 1995).

Goats have an important role in the pastoral system linked to: (i) their use as the key resource to respond to financial needs such as medical and school fees, (ii) their high nutritional value in terms of animal protein intake, especially for malnourished or sick children and (iii) their social role as part of the dowry and traditional social integration system. CCPP is a highly infectious disease caused by *Mycoplasma capricolum sub. spp. capripneumoniae (*mccp*)* (Thiaucourt and Bolske, 1996). It is transmitted by direct and close contact between animals with a mortality rate reaching 70% and a morbidity rate between 80 and 100% (Lefèvre and Thiaucourt, 2018). World Organization of Animal Health (OIE) lists it as one of the notifiable diseases. In endemic regions and high prevalence areas, it is a major threat with serious consequences on people's livelihoods and economy. Several studies report CCPP as one of the main infectious disease affecting the goats in the ASALs (Bett *et al.*, 2009; Peyraud *et al.*, 2014; Kipronoh *et al.*, 2016). The disease is well known by the pastoralists who describe it as a respiratory disease with a high mortality rate identifiable by its pathognomonic necropsy lesions of fibrinous pleuropneumonia (Asmare *et al.*, 2016). These lesions are described by the pastoralists as "adhesions between lungs and ribs".

Since the early 1980s, the Ministry of livestock organizes bi-annual free vaccination campaigns. The vaccine used, Caprivax TM, is an inactivated vaccine produced locally by the Kenya Veterinary Vaccines Production Institute (KEVEVAPI) with known historical challenges in terms of production (contamination (mold growth) and inability to respond to the demand). From 2010 to 2013, the Vaccines for the Control of Neglected Animal Diseases in Africa Project (VACNADA) improved the vaccine quality produced locally through a better process, the establishment of a quality control procedure and a certification (Pan African Veterinary Vaccine Center of African Union -AU-PANVAC certificate) established to ensure a proper quality of the vaccine. The intensity and duration of the post-vaccination sero-conversion is directly dependant on the level of antigen content and the amounts of saponin adjuvant (Rurangirwa *et al.*, 1987; Peyraud *et al.*, 2014). The vaccine efficacy for quality vaccines has been tested in experimental conditions and was estimated at 95% (Rurangirwa *et al.*, 1991). Apart from the vaccine efficacy, other factors can interfere with the vaccination effectiveness during the campaigns and need to be considered. As the vaccine used has to be stored at 2-8°C, it requires a well maintained cold chain up to the end users. This represents a major challenge as the resources of the veterinary services are limited and local conditions cannot guarantee a proper cold chain (Lipner and Brown, 1995). The health and nutritional status of the animal and the adherence to the vaccination protocol can also affect the overall vaccination effectiveness (Matios *et al.*, 2014). The effectiveness of the vaccination regarding disease control and eradication also depends on the vaccination coverage, which is quite low in the area. Therefore, the overall effectiveness of the vaccination campaigns is limited and its economic benefit is subject to a high level of variability. These key elements need to be properly evaluated.

The objectives of the study are to assess the economic impact of CCPP in the area and the benefits-costs ratio of the bi-annual vaccination campaign organized in Turkana, Kenya, against CCPP. The study is based on a yearly continuous flock monitoring and on different scenarios regarding vaccination effectiveness.

2 | MATERIALS AND METHODS

2.1 | Study area

Turkana County is located in the Rift valley region in the northwestern part of Kenya. It borders Uganda, South Sudan and Ethiopia (Figure 1). Turkana is the second biggest county of Kenya as well as the poorest with 94% of the population living below the poverty line and 19% literacy rate compared to a national average of 79% (Governement of Kenya, 2006). Turkana county is part of the ASALs of Kenya, characterized with low and erratic rainfalls as well as very high temperatures -as high as 40°C- during the dry season. The area is divided into pastoral and agro-pastoral areas. An household survey estimated that “35% of households were classified as very poor, 30% poor, 20% in the middle category and 15% as better-off” (King, Mark, *et al.*, 2012). The large majority of the population practices pastoralism. Goats are the main species and play an important role in the rural households livelihoods and social life (Kipronoh *et al.*, 2016). The flock monitoring survey was implemented from November 2012 to the end of October 2013 in Turkana East and South Districts. The short (October to December) and long (March to June) rains of this period were reported as average to above average in terms of rainfall with good levels of pasture and water (FAO, 2013).

Contagious caprine pleuropneumonia is endemic in the Rift valley region with a sero-prevalence ranging from 63.9% in Turkana West and 29.2% in East Pokot (Kipronoh *et al.*, 2016). The disease is considered by the pastoralists as the most frequent disease affecting their flocks with a reported incidence of 25% and a case fatality rate of 62.5% (with 10th and 90th percentiles of 25 and 100%) (Bett *et al.*, 2009).

2.2 | Longitudinal survey: continuous flock monitoring methodology

Field interviewers went through a five days training by Veterinarians[3] Without Borders - Belgium (VSF-B) experts to ensure consistency of the flock monitoring methodology of data collection and proper usage of the tools. A protocol describing the process of the monthly monitoring was developed for the field interviewers (Appendix S1).

Eleven villages were selected (6 in Turkana South and 5 in Turkana East) based on: accessibility even during the rainy season and being representative of the different agro-ecological zones of the area (Figure 1). Selected communities had a long-term relationship with the local association in charge of the survey in order to facilitate the trust and open discussion between the interviewers and the livestock keepers. One or two flock owners were identified in each village on a voluntary basis with the following selection criteria: being representative of the different ethnic groups and owning a flock of 20 to 60 goats. In total, 20 flocks were selected including 845 animals. None of them was vaccinated against CCPP the year before and during the survey. After flock selection, a physical inventory of the flock was performed to count the number of heads for the following age and sex categories: adult females (Af), adult males (Am), young females (Yf) and young males (Ym). Due to social constraints and traditional beliefs, the animals were not ear-tagged. Monthly monitoring visits were conducted during which each birth, entry (purchases and animals received as gifts or dowry) and exits were recorded. In addition to the monthly monitoring, physical counts of the flocks were performed on a quarterly basis to minimize eventual mistakes in the movement records. The young females, which gave birth during the month, were moved to the adult category. The exit rates recorded were due to either mortalities, exploitation of the animals (voluntary exits) or losses (involuntary exits). Different type of mortalities were recorded: mortality related to CCPP (necropsy on the

[3] *Typo error in the original article corrected*

site performed by the livestock owner with typical fibrinous pleuropneumonia lesions described) and mortalities due to other diseases or rains (animals flushed out by temporary rivers or dying during or after heavy rains). The possible animal exploitations

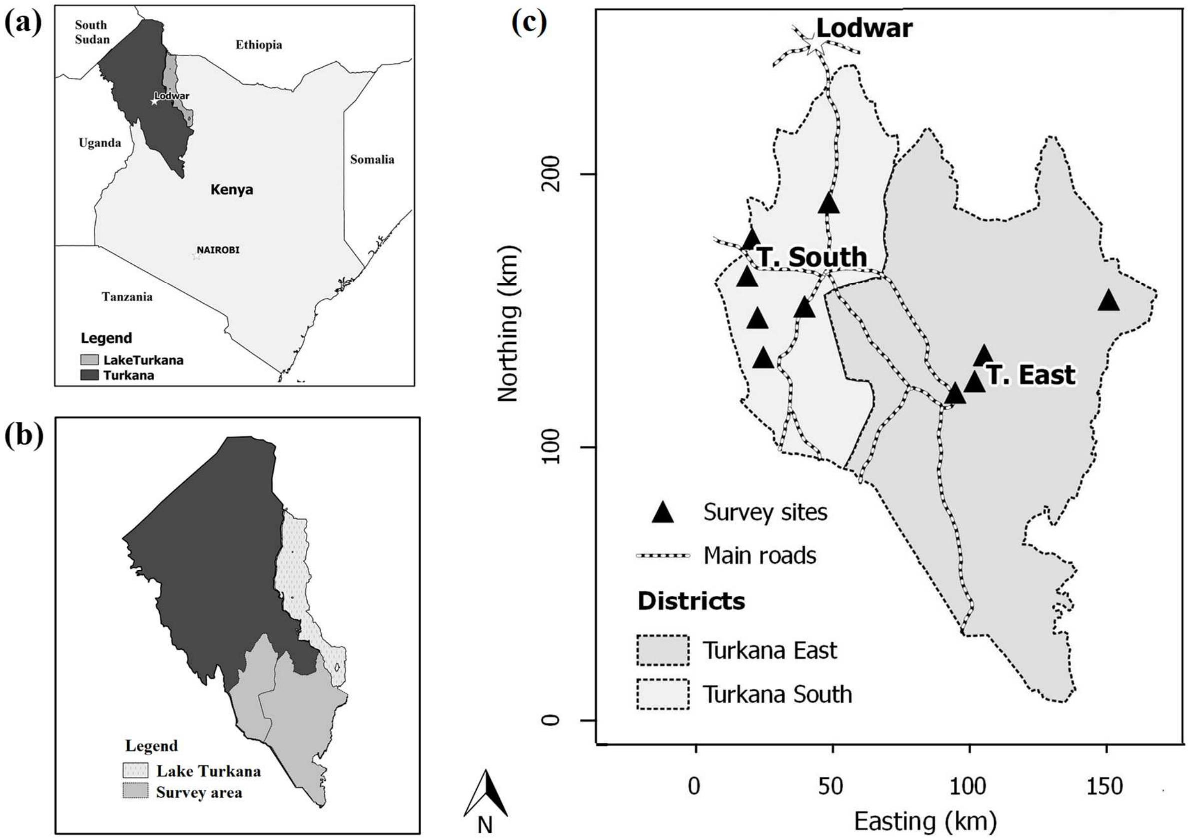

FIGURE 1 Localisation of the survey area and survey sites. Legend: (a) Kenya and Turkana county localisation in the horn of Africa, (b) localisation of the survey area in Turkana county and (c) survey sites in Turkana East and South districts

were self-consumption, sales, gifts and dowry. The possible type of losses were theft, predation or lost animals. More details on the survey methodology can be found in Renault, 2014. The different monthly rates calculated based on the data survey are presented in the Appendix S2.

The case definition used in this survey to define a CCPP related mortality is the post-mortem observation by the livestock keeper of the pathognomonic signs of fibrinous pleuropneumonia described as “the lungs sticking to the ribs” or “lungs full of liquids”. It could represent a methodological bias in terms of misdiagnosis leading to a misclassification of the mortality cause. If lesions of fibrinous pleuropneumonia are known to be pathognomonic of acute cases of CCPP, other endemic diseases of the area might induce similar lesions such as PPR, pasteurellosis and other mycoplasma infections (Thiaucourt *et al.*, 1996) leading to an misclassification and over estimation of mortalities due to CCPP. This case definition excluded from CCPP related mortalities the CCPP cases which were not presenting the pathognomonic lesions of fibrinous pleuropneumonia. Such cases could be frequent in an endemic areas. An underestimation of the mortality cases due to CCPP is therefore another possible bias. The study relies on the hypothesis that this case definition leads to an overall underestimation of the CCPP related mortality cases due to a higher frequency of non-diagnosed cases compare to the cases misdiagnosed as CCPP. This seems realistic taking into account that the CCPP and its necropsy signs are well known by the pastoralists in endemic areas (Asmare *et al.*, 2016).

2.3 | Establishment of the different inputs to be used in the model

2.3.1 | Monthly demographic rates issued from the survey data

Monthly demographic rates used in the model were based on age and sex data collected during monitoring as proposed by Lesnoff, Lancelot and Moulin (2007). The calculation method and the different rates are shown below (Appendix S3).

Equation 1: Monthly birth rate for females and males:

$$\frac{\text{Nr of newborns (x) during the month}}{\text{Nr of Af first of the month} + \frac{(\text{Nr of Af entering} - \text{Nr of Af exiting})}{2}} \quad (1)$$

With: Nr, number; x, being male or female; Af, adult female.

Equation 2: Monthly entry rates for each of the four age and sex categories:

$$\frac{\text{Nr of animals from category x entering the herd}}{\text{Total herd size at the beginning of the month}} \quad (2)$$

With: Nr, number; x, the age and sex category.

Equation 3: Exit rate of exit type "y" for the animal category (x):

$$\frac{\text{Nr of exits of type y in x during the month}}{\text{Nr(x) first of the month} + \frac{(\text{Nr (x) entering} - \text{Nr (x) of other exits}}{2}} \quad (3)$$

With: Nr, number; y, the animal category (x).

Note that the CCPP related mortality rates were only calculated for the herders and the months for which at least one mortality due to CCPP had been reported during the month in at least one of the four animal categories.

Equation 4: Monthly rate of young females moving to the adult category after giving birth (CC_Yf)

$$\text{CC\_Yf} = \frac{\text{Nr of Yf giving birth during the month}}{\text{Nr of Yf in the herd at the beginning of the month}} \quad (4)$$

With: Nr, number; Yf, young female.

After calculation of the different rates for the four animal categories, the rates corresponding to the rainy and dry months were assessed in Stata/SE 14.1(© StataCorp LP, College Station, TX, USA) using a Welch test for unequal variances to determine if there were significant differences of a given rate between the rainy and the dry seasons. It determined if seasonal rates were to be considered in the model.

2.3.2 | Inputs from other sources

The information on the vaccination costs was obtained from the office of the Turkana County Veterinary Department. The costs used are the estimation of vaccine costs during a national vaccination campaign (**Table 1**). It does not reflect the vaccination cost in case of a specific farmer request (private services).

The International Livestock Research Institute (ILRI) and the Ministry of Livestock provided the 2017 animal prices per category (*non-published data*) through their monthly market monitoring system.

The costs (vaccination costs and animal prices) were provided in Kenyan shillings and converted into euros using the official rate from the Central Bank of Kenya on 18th of January 2018.

TABLE 1 Daily costs of a vaccination campaign for 4.000 goats (expressed in Euros)

Description of cost	Cost (Euros)
Team allowances (1 veterinarian, 3 animal health auxiliaries (2 seniors and 1 junior) and 1 driver)	162
Average cost of Fuel per day	9
Cost of CCPP Vaccine for 4000 animals	309
Total cost for 4,000 heads	480
Daily cost per head	0.12

2.4 | Stochastic model for the estimation of the benefits-costs ratio of CCPP bi-annual vaccination campaign

The different monthly rates obtained were then recorded in an Excel spreadsheet and their best-fitted distribution established with @Risk® Version 7.6 (Appendix S3). These distributions were used as inputs in the stochastic model to project the flock dynamic over a one-year period (Appendix S4). The model was based on four successive steps of calculation and provided three outputs (Figure 2).

2.4.1 | Step 1- Modelling the flock evolution based on the monthly entry and exit rates.

The initial standardized flock size was established at 100 heads with the average ratio for each animal category (based on survey data) applied to determine the composition of the initial flock.

The monthly evolution of the flock was calculated over a year in the stochastic model by applying the different exit and entry rates to the number of animals present in each age and sex category at the beginning of the month. The different entry categories considered were births, gifts

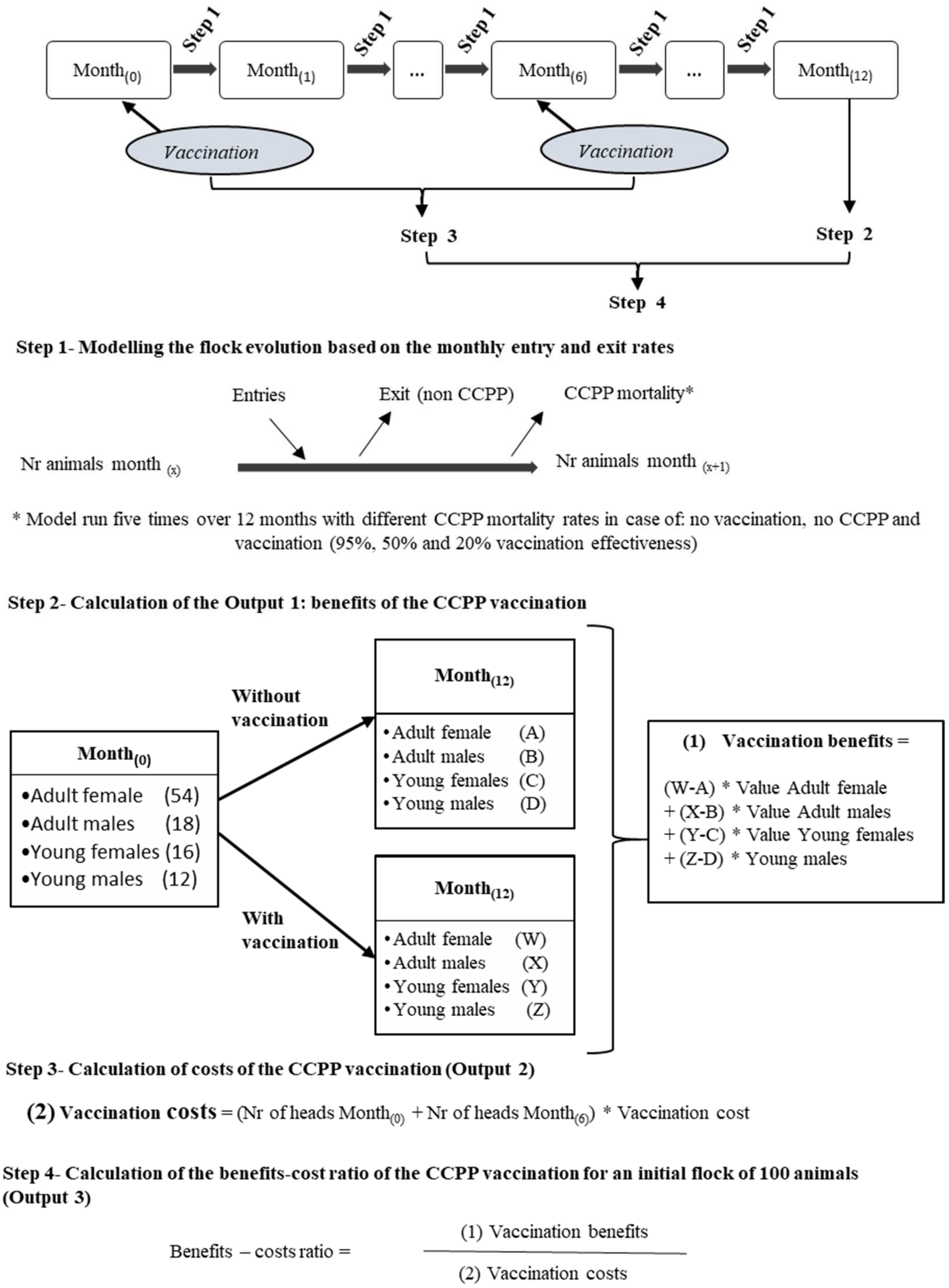

FIGURE 2 Stochastic model processs followed at each iteration (10.000 iterations and 95% confidence interval)

and purchases. The different exit categories were mortalities due to CCPP and to other diseases, rain related mortalities, voluntary exits (sales, self-consumption and gifts) and involuntary exits (thefts, losses or predation). These rates were kept separated in order to consider eventual seasonal disparities for each of them.

The flock evolution with and without CCPP vaccination were simulated over a 12 months period using different

CCPP mortality rates. For the scenario without vaccination, the CCPP mortality rate distribution as observed during the survey was applied and a final flock composition obtained and used as a reference for the calculation of the economic losses due to CCPP mortalities. In order to estimate the economic losses related to CCPP mortalities, the model was run with 0% mortalities due to CCPP.

For the flock evolution in case of vaccination, three scenarios were considered based on different vaccination effectiveness. The effectiveness of a vaccination campaign (percentage of animals properly protected against the disease after being vaccinated) depends on the vaccine quality and efficacy (percentage of animals properly protected against the disease after vaccination in a clinical trial) and the conditions under which the vaccination campaign is implemented in the field.

Three scenarios were selected based on an expert opinion from the OIE reference laboratory (CIRAD, Montpellier, France) and ILRI as well as the observations on the field and the local context:

Scenario 1 (Ideal situation): 95% effectiveness of the vaccination based on the usage of a good quality vaccine with 95% efficacy (Rurangirwa et al., 1991), the maintenance of cold chain and the consideration of nutritional and health status of animals at the time of vaccination at the time of vaccination.

Scenario 2 (Optimistic): 50% effectiveness of the vaccination considering a proper quality vaccine with a few disruptions of the cold chain during the storage and/or the campaign itself.

Scenario 3 (Most likely scenario based on the actual field conditions in Turkana): 20% effectiveness of vaccination due to an average quality vaccine, the non-respect of the cold chain as well as the poor animal health and nutritional status of the animals at the time of vaccination frequently organized during or at the end of the dry period.

The CCPP mortality rates applied in the model were of 5%, 50% and 80% of the CCPP mortality rate distributions observed during the survey for the different vaccination effectiveness of 95, 50 and 20% respectively.

2.4.2 | Step 2- Calculation of the benefits of CCPP vaccination (output 1)

The final composition of the flock at the end of the 12 months simulations periods in the reference situation (without vaccination) was compared to the final composition of the flock in the absence of mortalities due to CCPP and in case of vaccination for the 3 scenarios. The difference in terms of animal heads of the different age and sex categories multiplied by their respective monetary value (in euros) represents the benefits of CCPP vaccination. These benefits are related to the prevented deaths and future births (from preserved adult females). The other costs related to production losses and treatment costs were not considered, as they were not evaluated during the flock monitoring.

2.4.2 | Step 3- Calculation of the costs of CCPP bi-annual vaccination (output 2)

The costs of the BSM were calculated considering a bi-annual vaccination of the flock (as actually recommended by Government of Kenyan and the African Union) and the vaccination of all the animals present in the flock at month 0 and month 6 of the survey.

2.4.4 | Step 4- Calculation of the benefits-costs ratio of CCPP vaccination for an initial flock of 100 animals.

The benefits-costs ratio of the bi-annual vaccination was evaluated by calculating the ratio between the benefits and the costs of a bi-annual flock vaccination (for a standardized flock of 100 heads at month$_{(0)}$).

The evaluation of the economic losses due to CCPP was estimated by calculating the difference in terms of animal heads of the different age and sex categories multiplied by their respective monetary value (in euros) between the model without vaccination and the model with no CCPP mortalities.

2.5 | Statistical tools

The model was built in Microsoft excel (Microsoft® Office 2016, Redmond, WA) and run with @risk version 7.6 (© Palisade Corporation, Ithaca, NY). A total of 10,000 Monte Carlo iterations were requested to allow the convergence of the output probability distributions using a 1.5% convergence tolerance with 95% confidence level.

A sensitivity analysis based on the Spearman rank correlation coefficient (r_s) calculation was performed using the sensitivity analysis tool in @Risk® version 7.6

TABLE 2 Characteristics of the 20 herders sampled

		Gender		Literacy level		Agro-ecological zone	
Turkana county	**N.**	Female	Male	Illiterate	Primary or more	Agro-pastoral	Pastoral
Turkana East	10	2	8	6	4	6	4
Turkana South	10	1	9	5	5	7	3
Total	**20**	**3**	**17**	**11**	**9**	**13**	**7**

in parallel to the model iterations to identify the most influential inputs regarding the model final output.

3 | RESULTS

3.1 | Longitudinal survey

A total sample of 20 flocks with 845 animals were monitored for a period of over a year. Of the 20, thirteen flocks were reared in agro-pastoral areas and seven in pure pastoral areas (Table 2). Three flocks were owned by women while the rest were owned by men. The illiteracy level among the livestock keepers selected was 55% with 44.5% of them at primary and 0.5% above primary education levels respectively. Only five livestock owners, all located in the agro-pastoral area of Turkana East, regularly dewormed their flocks. None of the flocks were vaccinated against CCPP before and during the survey.

The overall herd analysis showed a decrease in terms of animal numbers during the survey period. The total population dropped from 845 to 748 animals (**Figure 3[A]**). Over the year, the adult population decreased while the kid population slightly increased. Four peaks of births were observed in December, February, April and July, corresponding with July, September, November and February mating periods, respectively.

Regarding the evolution of the different mortality rates over the survey period, three peaks are observed in December, March and June-July, respectively (Figure 3[B]). A peak of mortalities due to rains is observed in March, corresponding to the beginning of the rainy season. The peaks of December and June-July seem related to an increased mortality due to CCPP. The death counts disaggregated by reported mortality cause were analyzed. The main cause of mortality was CCPP (47% of the mortalities, 57% in adults and 32.1% in kids) and rains (14% of the mortalities, 11% in adults and 18% in kids). Other reported causes of death included food poisoning, sudden death, diarrhoea/PPR and secondary wound infections. They were grouped as “Other” causes of deaths and accounted for 20.4% of the mortalities (18% in adults and 24% in kids). The cause of death was unknown in 19% of the cases (14% in adults and 26% in kids).

The gross offtake rate is the sum of the voluntary and involuntary exit rates. The voluntary exit categories are slaughtering, sales and other exits. Animals included in the other exit category were mainly kids and adult females given out as dowry payment or for other social events. Most of the animals sold or slaughtered were males. Four peaks are observed in December, February, April and June-July (Figure 3[C]). The losses include the involuntary exits (theft, predation or animals getting lost). The majority of the losses were reported from January to February, and in June. The difference between the gross offtake rate and the entry rates (purchases and gifts) is the net offtake rate. The evolution of the net offtake rate shows three peaks in December, April and July (Figure 3[C]). These peaks seem closely related to the corresponding peak of voluntary exits made by the livestock owners. A more detailed analysis of the longitudinal survey results is presented in a previous study (Renault, 2014).

The findings of the study are similar to a study by Otte and Chilonda (2002) in arid zones of Sub-Saharan Africa. This study reported an offtake rate of 16.7% and kids mortality rates of 28.3% in semi-arid areas for the mixed systems. For the pastoral systems, it reports an offtake rate of 30.2%

and 17.2% and kids mortality rates of 27.4 and 33.1% in arid and semi-arid areas respectively. These seem comparable to the average rates observed in our study, which are of 18% for the gross offtake rate and 48 % for the kids mortality. The kids mortality rate appears higher in our study but the goats were considered as "kids" until

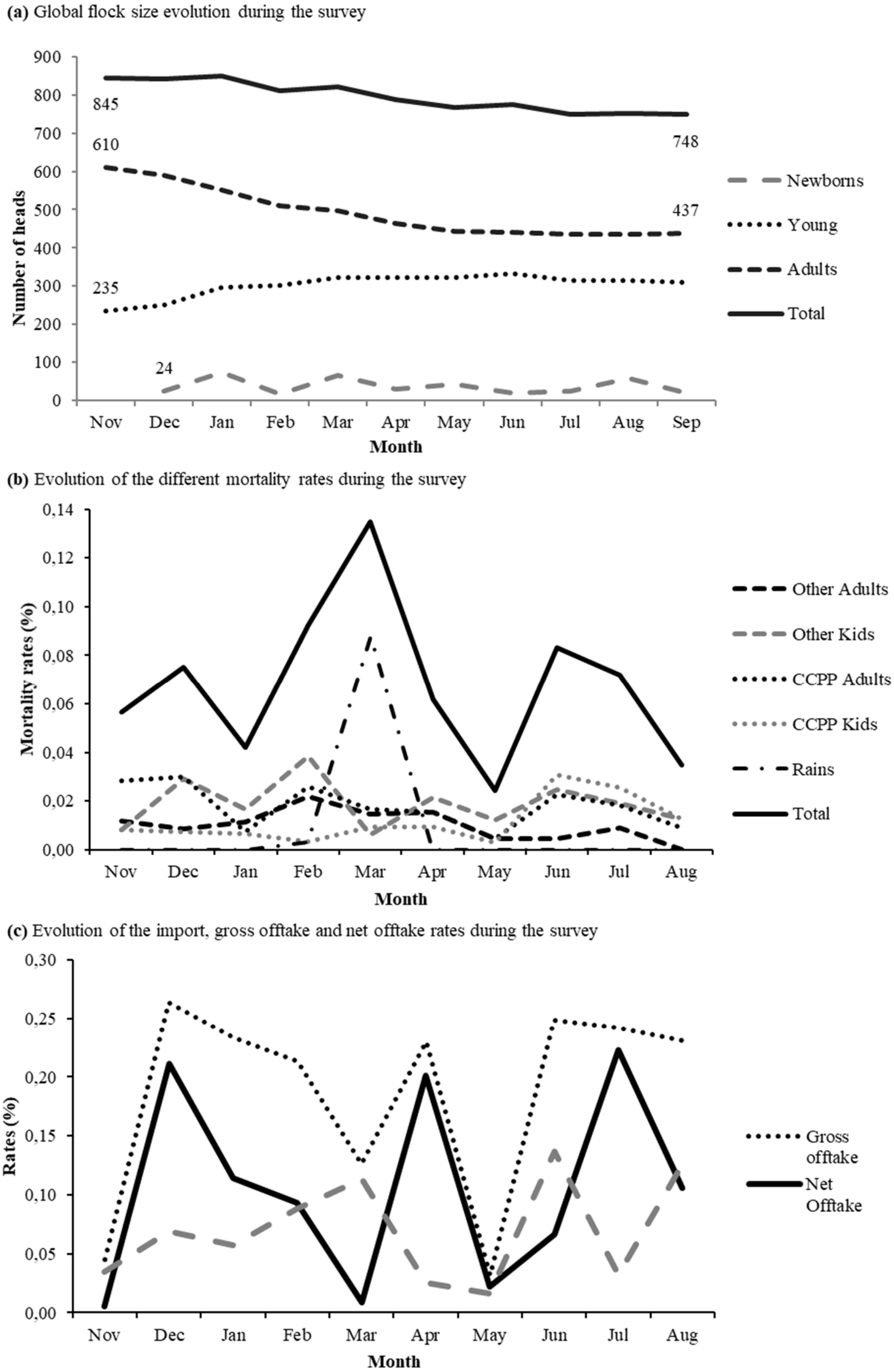

FIGURE 3 Evolution of the global flock size, mortality rates and import, gross offtake and net offtake rates during the survey. Legend: **(a)** evolution of the global flock size during the survey; **(b)** evolution of the different instantaneous mortality rates; **(c)** evolution of the import, gross offtake and net offtake rates during the survey; gross off-take is the sum of the voluntary and involuntary exits; net off-take is the difference between the gross off-take and the imports

their first kidding with a reported average age at first kidding of 15.9 up to 26 months (Wilson and Food and Agriculture Organization of the United Nations., 1991; Mtenga, Kifaro and Berhanu, 1992; Otte and Chilonda, 2002). The previous study considered kids mortalities up to the age of 6 months only.

TABLE 3 Final ouputs of the benefits-costs ratio calculation based on the three scenarios of vaccination efficiency

Outputs	Scenario 1 95% efficiency	Scenario 2 50% efficiency	Scenario 3 20% efficiency
1. Annual benefits related to the vaccination against CCPP in a herd of 100 heads			
Minimum	121.22	51.01	2.4
Maximum	6333.53	2441.42	923.16
Average	1533.25	603.07	120.19
Standard deviation	688.69	245.65	93.78
95% Confidence Interval	436 - 2973	198 - 1149	15 - 361
2. Annual cost of CCPP vaccination in a herd of 100 heads			
Minimum	18.526	14.491	13.332
Maximum	47.668	38.497	39.354
Average	24.484	21.875	20.105
Standard deviation	2.395	2.561	2.783
95% Confidence Interval	20.9 - 30.15	17.37 - 27.55	15.32 - 26.09
3. Ratio annual benefits / cost for the CCPP vaccination			
Minimum	5.47	2.459	0.176
Maximum	151.87	70.306	32.249
Average	61.87	27.201	5.715
Standard deviation	23.82	9.302	3.914
95% Confidence Interval	18.9 - 106.9	9.7 - 45.5	0.9 - 15.58

Note: costs calculated in Euros

3.2 | Stochastic model

The different rates' distribution obtained from the survey data and used in the model are presented in **Appendix S3**. The Welch test showed no significant differences between the rainy and dry season for the different inputs ($p>0.05$). Therefore, the same rates were used in the model for the 12 months of the yearly model (parsimony principle).

In the case of non-vaccination against CCPP, the annual economic losses due to CCPP for a standardized flock of 100 goats was estimated at Euros 1,712.66 in average with a minimum of 88.53, a maximum of 7,671.21 and a 95% confidence interval ranging from 476 and 3,449. These results are issued from the comparison of the final flock composition in terms of monetary value between the model run with the CCPP mortality rates observed during the survey in the absence of vaccination and the model run with no CCPP related mortalities.

The benefits, costs and the benefits-costs ratio of the CCPP bi-annual vaccination campaign are decreasing with the vaccination effectiveness (Table 3 and Appendix S5). The average benefits-costs ratio of vaccination for an initial flock of 100 heads were estimated at 61.87, 27.2 and 5.7 in average for a vaccination effectiveness of 95, 50 and 20% respectively. It is therefore decreasing with the vaccination effectiveness but remains in favor of the bi-annual vaccination (ratio >1).

3.3 | Sensibility analysis

The sensibility analysis showed that the inputs having the main influence on the benefits-costs ratio of CCPP vaccination campaign depends on the scenario (**Figure 4**). For an effectiveness of 95% (**Figure 4[A]**), the main input influencing positively the benefits-costs ratio is the mortality rate related to CCPP for the adult females (r_s = 0.83). In case of a vaccination effectiveness of 50%

(**Figure 4[B]**), the most influential input remains the CCPP related mortalities in adult females population (r_s = 0.36) with the male and female birth rates as second main influencing factor (r_s = 0.25). These 3 inputs are positively influencing the benefits-costs ratio of CCPP vaccination.

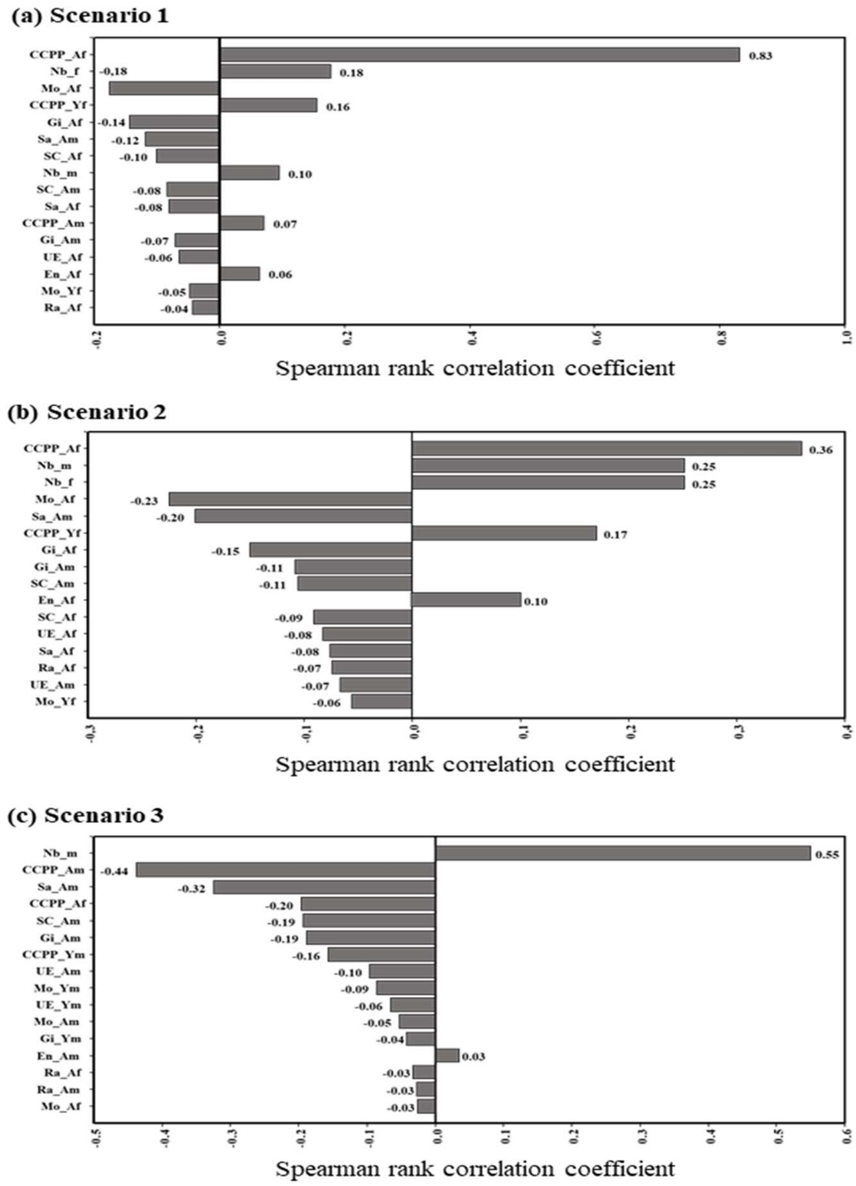

FIGURE 4 Tornado graph showing Spearman rank correlation coefficients between model input variables and the benefits-costs ratio of bi-annual CCPP vaccination for three scenarios of vaccination effectiveness . Legend: Scenario 1 (95% of vaccination effectiveness): [A]; Scenario 2 (50% of vaccination effectiveness): [B]; Scenario 3 (20% of vaccination effectiveness): [C]; CCPP_Af: CCPP mortality rate of Adult females; CCPP_Am: CCPP mortality rate of Adult males; CCPP_Yf: CCPP mortality rate of Young females; CCPP_Ym: CCPP mortality rate of Young males; En_Af: Entry rate of Adult females (purchases and gifts); En_Am: Entry rate of Adult males (purchases and gifts); Gi_Af: Exits for gifts / dowry of Adult females; Gi_Am: Exits for gifts / dowry of Adult males; Gi_Ym: Exits for gifts / dowry of Young males; Mo_Af: Mortality rate of Young females(other than CCPP); Mo_Am: Mortality rate of Adult males (other than CCPP); Mo_Yf: Mortality rate of Young females (other than CCPP); Mo_Ym: Mortality rate of Young males (other than CCPP); Nb_f: Natality rate females; Nb_m: Natality rate males; Ra_Af: Rain related mortality rates of Adult females; Ra_Am: Rain related mortality rates of Adult males; Sa_Af: Sales rate of Adult females; Sa_Am: Sales rate of Adult males; SC_Af: Self-consumption rate of Adult females; SC_Am: Self-consumption rate of Adult males; UE_Af: Unvoluntary exits (Thefts, Losses or Predation) in

Adult females; UE_Am: Unvoluntary exits (Thefts, Losses or Predation) in Adult males; UE_Ym: Unvoluntary exits (Thefts, Losses or Predation) in Young males

For a vaccination effectiveness of 20% (**Figure 4[C]**), the males birth rate (r_s = 0.55) influences the benefits-costs ratio positively and the adult males mortality rate influences it negatively (r_s = -0.44).

4 | DISCUSSION

As mentioned in a previous publication (Lipner and Brown, 1995), there are many constraints to the proper integration and implementation of CCPP vaccination in Kenya despite the official organization of the bi-annual vaccination campaigns. The constraints are mainly related to a lack of will from the institutions in terms of investments due to absence of evidences on the efficiency of this strategy. To confirm the relevance of CCPP bi-annual vaccination campaign as disease control strategy and livelihoods protection, some key questions have to be answered including: what are the actual number of CCPP cases and deaths on a yearly basis and what are the economic costs to farmers from disease outbreaks. This study is the first benefits-costs analysis study for CCPP vaccination in a pastoral set-up based on a longitudinal field survey of the flocks. It provides a partial answer to these questions.

4.1 | Longitudinal survey

After analyzing the different demographic parameters and their evolution during the survey period, several assumptions can be mentioned.

Four peaks of births are observed in February, April, July and December (Figure 3 [A]). As goats usually mate during a rainy season to give birth during the next one (King, Lawrence, et al., 2012), February and July peaks are quite surprising, but could be explained by the particularly important rainfalls and the long rainy season in the year 2012. The fertility rates reached 1.20 with a ratio of 0.6741 females and 0.5279 males, which is similar to previous findings (Wilson, 1991).

Despite the rainfalls being average to above average during the year of the survey and the previous rainy seasons, the animal population decreased over the period while it was expected to observe a herd reconstitution after the 2010-2011 drought.

The overall annual mortality rates for kids and adult animals reached 0.43 and 0.37, respectively. The main reported cause of deaths were CCPP and, in Turkana South, the heavy rains (flash floods or thermic shock on debilitated animals at the end of the dry season). Three mortality peaks were observed in December, March and June-July when analyzing the evolution of the different instantaneous mortality rates (Figure 3 [B]). Mortalities due to rains, which occurred in March in Turkana South district, explains by itself the overall peak of that month. The December and June-July peaks correspond to an increased CCPP related mortality and might be linked to local outbreaks. The number of CCPP cases in kids population showed a slight decrease in December-January, which seems in contradiction with the overall peak and the increased adult mortality due to CCPP noticed during that same period. Nevertheless, a peak in mortalities due to various reasons was observed for kids during those months. It is highly possible that kids developed acute cases and died without showing any specific clinical or post mortem signs. Such cases were reported as dead from unknown causes and accounted for in the “other” causes category. This could also explain the lower percentage of deaths related to CCPP reported in kids (32.1%) compared to adults (57%). The overall annual mortality rates related to CCPP observed in the longitudinal survey was 21 and 14% for adults and kids respectively with 65% of the herds being affected by the disease. They rates are lower when compared with an earlier study which reported an incidence of 25% and a case fatality rate of 62.5% (with 10th and 90th percentiles of 25 and 100%) (Bett et al., 2009). The reason for the variation could be related to the reporting of some CCPP related deaths in the “other” causes category (in the absence of pathognomonic lesions of the lungs).

The exploitation rate regrouping the different voluntary exits from the herd (slaughtering, sales and other exits as dowry and social payments) shows four peaks in December, February, April and July (Figure 3 [C]). The peaks of December, February and June could be explained by higher slaughtering rates during the dry season as a coping strategy (early off-take measure) and the higher prices of food in the markets. December peak for voluntary exits might also be related to higher sales rate (in order to pay the school fees due at that period) and the exits for gifts and dowry as many social events are traditionally organized during that month. The peak observed in April seems unusual (according to the known seasonal calendar (King, Lawrence, et al., 2012). It seems related to a peak in the "other exit" category and therefore dowry payments and/or gifts to relatives. It is possible that, after three above average rainy seasons, many weddings and traditional events were organized, as it is usually the case when households start to recover from a crisis during which such events are put on hold.

The involuntary exits (theft, predation or animals getting lost) were mainly reported from January to February, and in June. Those months correspond to dry seasons, when animals have to migrate on longer distances. Predation during dry seasons might also increase due to the migration of predators usual preys (wildlife) while thefts are mainly reported at the beginning of the rainy seasons as a traditional restocking strategy.

When comparing the voluntary exit rates together with the importation rates, in order to obtain the net offtake rate, three peaks, in terms of net offtake, can clearly be observed in December, April and July (Figure 3 [C]). Those peaks are closely related to the corresponding peak of voluntary exploitations made by livestock owners (sales, slaughtering and social payments or gifts).

The sample size is relatively small but the study presents the advantage of being based on a longitudinal survey and a certain representability was ensured based on the selection criteria used to guarantee the inclusion of different environmental areas and ethnic groups. As the survey year was considered as average in terms of rainfall, this survey data can also be considered as a reference for years with normal rainfalls levels. No seasonal variations of the different monthly rates were found significant, probably due to the small sample size.

4.2 | Stochastic model

Despite the seasonal trends observed in the longitudinal survey, no statistical differences were found between the dry and rainy season rates. This might be due to the small sample size of the herd monitored as seasonal differences were expected (e.g., rain related mortalities should be lower during the dry season). In the absence of seasonal variations, the same rate distribution was used over the 12 months of the model but the different exit and entry rates were kept segregate for future applications of the model.

Based on the model, the annual economic losses due to CCPP in a standard flock of 100 heads was estimated to be €1,712.66 in average. This takes into account the economic losses due to the CCPP related mortalities as well as the lower number of newborns due to adult females mortalities. This represents a daily loss of €4.7 for the livestock keeper whose poverty line sets at $1.9 (+/- €1.5) per day (last update of the World bank based on 2011 prices). The disease has therefore a large and negative impact on the Turkana population livelihoods and well-being as they mainly depend on livestock for survival. In case of high mortalities, the livestock keeper is susceptible to loose the entire flock and therefore will likely drop out of pastoralism and will need to engage into other alternative livelihoods (petty businesses such as charcoal burning and cutting of trees and shrubs for income) to survive . In some cases, he will benefit from a loan of adult females goats or sheep by the community or its relatives (locally known as "*habbanae*") in order to progressively rebuild a flock.

The monitored flocks affected by CCPP during the survey were 65% of all the target flocks. Turkana County hosts about 6,000,000 goats (KNBS, 2009), representing 60,000 flocks of 100 heads. If we consider that 65% of these herds suffer a CCPP outbreak over 1 year for an average cost of 1,712.66 euros, the losses would be estimated at €66,793,740. Considering the incidence rate of 25% reported in a previous study (Bett *et al.*, 2009), the losses would be of €25,689,900 annually.

When comparing the different outcomes of the model in the three scenario (Table 3) we can observe that the benefits are higher when the vaccination effectiveness is higher as more animals are protected from the disease and its consequences. The cost of the bi-annual vaccination campaign decreases when the vaccination effectiveness is lower as the number of heads to be vaccinated at month 6 are lower (higher number of deaths during the first 6 months). In the scenario 3 with 20% effectiveness of the vaccination, the benefits-costs ratio remains in favor of the vaccination with an average ratio of 5.7. The 95% confidence interval ranges from 0.9 up to 15.58 but it is underestimated as the benefits are restricted to direct losses. In addition, it is important to highlight the fact that the economic losses and therefore the benefits-costs ratio calculated are underestimated as the only CCPP related costs considered were the mortality cases presenting fibrinous pleuropneumonia lesions at necropsy and the reduced number of newborns. The other direct and indirect costs of the diseases (e.g., mortality cases not presenting the necropsy lesions of fibrinous pleuropneumonias, indirect losses such as abortions, decreased productions and treatment cost) were not considered in this study. Bi-annual vaccination against CCPP can therefore be considered as economically justified in the perspective of protecting the population livelihoods and ensuring food security in all cases when considering the direct and indirect costs.

A higher vaccination effectiveness (>=50%) would not only protect the population livelihoods by decreasing the mortalities but would generate longer term effect and benefits through the protection of the reproductive animals, an effective disease control and the enhancement of the livestock keepers confidence towards the vaccine to allow a better vaccination coverage. Certainly, in the actual context, CCPP control and eradication could not be reached due to the low vaccination rates in the rural areas, even when the vaccine in provided free of charge by the government. The reluctance of the livestock keepers to have their animals vaccinated is linked to several factors out of which the perceived inefficacy of the vaccine as well as its high rate of secondary effects (e.g., abortions and abscesses) (Lipner and Brown, 1995). Due to the low availability and access to animal health services in the county, disease surveillance and animal health extension to livestock keepers are not optimal and affect the effectiveness of the vaccination campaigns and the implementation of disease control programs (Bett et al., 2009).

Cognizant of these economic losses, a higher effectiveness of the vaccination campaigns is urgently required in the field in order: to ensure the protection of the livestock assets on a longer term and reverse the negative opinion of the livestock keepers affecting the vaccination coverage. This will require additional means at the level of the vaccine production unit but also a better service delivery with a proper cold chain, a good programming to vaccinate the goats during the rainy seasons (when they're in better shape), a proper training of the field practitioners. . An effective animal health extension model for the livestock keepers is also necessary to better organize timely vaccination campaigns and establish a proper disease surveillance system in the area (Lipner and Brown, 1995; Matios et al., 2014). In line with the Maputo agreement (World Bank, 2010), Governmental funds should be available locally to cover the costs of the vaccination campaigns and being independent of the international donor funds that are not always available at the right moment. Indeed, such funds usually originate from humanitarian funds and are only available in case of a prolonged drought, when the animals are debilitated.

4.3 | Sensitivity analysis

The sensitivity analysis for the benefits-costs ratio of CCPP vaccination, based on the comparison between vaccinated and non-vaccinated flocks, in terms of animal composition after one year, was significantly different based on vaccination effectiveness. When considering scenario 3 (20%-vaccine effectiveness), cost-effectiveness was mainly influenced by the male birth rate (r_s = 0.55) and by the mortality rate of adult males (r_s = -0.44). According to scenarios 1 (50%-vaccine effectiveness) and 2 (95%-vaccine effectiveness), the main factor influencing the benefits-costs ratio was CCPP-related mortality rate of adult females (r_s = 0.83 and 0.36, respectively). Such difference is probably related to the low vaccine protection in scenario 3, which generates a small difference in terms of evolution of flock size after one year. Males (young and old) having a higher economic value compared to females of the same age group, sex is thus the main factor influencing the final ratio. On the other hand, a more efficient vaccination (scenarios 1 and 2) protects adult females and thus, has a significant positive impact on the final flock composition, by preserving reproductive animal assets and consecutively allowing a larger number of births over the year.

5 | CONCLUSION

The benefits-costs ratio of CCPP vaccination is positive in the three scenarios. The economic benefits of CCPP vaccination to the livestock keepers, even with a vaccination effectiveness as low as 20%, are higher than the cost of the bi-annual vaccination of the flocks. Bi-annual vaccination campaigns are therefore economically justified as a livelihood protection measure and to increase the food security in the area. Nevertheless, on a global health perspective and in the view of having long-term effects on livestock asset protection and disease control, a higher vaccination effectiveness is required. It is therefore necessary to ensure the vaccine quality at the production level but also guarantee the integrity of the cold chain during the vaccination campaigns and good practices of the veterinarians and/or community animal health workers in charge by continuous trainings and proper guidance.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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Experimental section

Study 5

Pilot study assessing the possible benefits of a higher level of implementation of biosecurity measures on farm productivity

Transboundary and Emerging Diseases 2019, 00:1-9

Véronique Renault, Marc Lomba, Laurent Delooz, Stefaan Ribbens, Marie-France Humblet and Claude Saegerman.

Preamble

Several studies based on different methodologies assessed the cost-efficiency of disease-specific BSM or the increased risk calculated for different diseases in the absence of implementation of a given biosecurity measure. Assessing the cost-benefits of non-disease specific BSM which prevents a large number of diseases such as general hygiene, controlling visits and vehicles or applying a proper quarantine becomes more difficult and, as far as we know, has not yet been studied. Based on the methodology presented in the previous article, i.e. longitudinal herd monitoring in order to assess the CCPP-related mortality rates and converting them into a benefit-cost analysis, this pilot study tried to highlight the possible benefits of a proper level of biosecurity in a cattle farm based on the monitoring of different herd reproductive parameters and mortality rates. A biosecurity score was calculated for the farms visited during the field survey (Study 2), representing the overall implementation level of BSM. In parallel, after obtaining farmers' approval, the farm mortality data and reproductive parameters were provided by the regional animal health and identification associations, in order to investigate the potential correlation between them and biosecurity scores. The hypothesis was that a farm with a higher biosecurity level would have a better animal health status, which should be reflected through lower mortality rates and higher reproduction rates. If significant differences were observed, they could, in a second step, be converted into an economic gain (or loss) depending on the biosecurity level.

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ORIGINAL ARTICLE

Pilot study assessing the possible benefits of a higher level of implementation of biosecurity measures on farm productivity and health status in Belgian cattle farms

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Abstract

Over the last few years, the interest of decision-makers and control agencies in biosecurity (BS), aiming at preventing and controlling the introduction and spread of infectious diseases, has considerably increased. Nevertheless, previous studies highlighted a low implementation level of biosecurity measures (BSM), especially in cattle farms; different reasons were identified such as perceived costs, utility, importance, increased workload and lack of knowledge. In order to convince cattle farmers to adopt BSM, it is necessary to gather more information and evidence on their costeffectiveness and their importance or utility in terms of disease prevention and control. The objectives of this study were to determine whether the farm or farmers' profile correlated with the implementation level of BSM and if there was a positive correlation between the BSM implementation and the farm production and health parameters. Data were collected through face-to-face interviews conducted in 100 Belgian farms as part of a stratified and randomized survey. The Regional Animal Health Services provided the farm health status and production data. A general BS score and five sub-scores related to the five BS compartments (bio-exclusion, biocompartmentation, bio-containment, bio-prevention and bio-preservation) were calculated for each farm based on the implementation level of different BSM grouped in 16 domains. The study highlighted a significant and negative correlation between the mortality rates in adult cattle (over 24 months of age) and young calves (aged 0–7 days) and different BS compartment scores. The study also demonstrated that the farms having a higher general BS score were indeed more likely to have a BVDfree status. These evidence-based findings are encouraging as they demonstrate the benefits of implementing BSM and could promote their adoption by farmers.

KEYWORDS
Belgium, benefit, biosecurity, cattle, farmers, health status, implementation, measures, productivity, score

1 | INTRODUCTION

Over the last few years, the interest of decision-makers and control agencies in biosecurity (BS), aiming at controlling the introduction and spread of infectious diseases, has greatly increased. In 2007, it became a key element of the European Union Animal Health Strategy (European Commission, 2007). Biosecurity measures prevent the introduction of infectious diseases into a farm and their spread within the farm, to other farms, to humans and/or to the environment.

According to Saegerman, Dal Pozzo, and Humblet, (2012), BSM are categorized in five operational stages or compartments (a) B1, Bio-exclusion: limiting the risk of introduction onto the farm, (b) B2, Bio-compartmentation (also called bio-management): limiting the spread within the same facility (intraherd transmission), (c) B3, Biocontainment: limiting the spread to other animal facilities (inter-herd transmission), (d) B4, Bio-prevention: preventing human contamination and (e) B5, Bio-preservation: preventing environmental bio-contamination. Despite the prominence given by the livestock sector to biosecurity, previous studies demonstrated a low implementation level of BSM, especially in cattle farms (Brennan & Christley, 2012; Renault et al., 2018; Sarrazin, Cay, Laureyns, & Dewulf, 2014; Sayers et al., 2013).

Different reasons such as perceived costs, perceived utility or importance of the measure regarding disease prevention and control, increased workload and lack of knowledge were identified as responsible for such a low implementation level (Brennan & Christley, 2013; Gunn, Heffernan, Hall, McLeod, & Hovi, 2008; Hoe & Ruegg, 2006; Kristensen & Jakobsen, 2011; Kuster, Cousin, Jemmi, Schüpbach-Regula, & Magouras, 2015; Laanen et al., 2014; Moore, Merryman, Hartman, & Klingborg, 2008; Nöremark, Frössling, & Lewerin, 2010; Sarrazin et al., 2014; Sayers et al., 2013; Toma, Stott, Heffernan, Ringrose, & Gunn, 2013). A recent study conducted in Belgian cattle farms showed that the farmer's perception of a BSM not being important or useful was one of the main reasons for its non-implementation (Renault et al., 2018). The cost was never mentioned as the main reason for not implementing a BSM, as illustrated by the following farmer's quotation: 'nothing is too costly as long as it is useful and prevents losses'. Several studies investigated the factors influencing the implementation of BSM by the farmers. Most of them identified the importance of demonstrating the benefits of a measure as a key factor (Mankad, 2016; Ritter et al., 2017). This finding is in line with most behaviour change theories, such as the theory of planned behaviour (Ajzen, 1985) or the health belief model (Abraham & Sheeran, 2015; Janz & Becker, 1984). These concepts include the perception of the benefits as a key factor in terms of decision-making or as a trigger to action. Rogers's original protection motivation theory also includes the 'effectiveness of a coping response that might avert the noxious event' as one of the three key elements (Rogers, 1983). The other two elements of the original protection motivation theory are 'the magnitude of noxiousness of a depicted event' and 'the conditional probability that the event will occur provided that no adaptive activity is performed'.

Therefore, in order to convince cattle farmers to adopt BSM, it is necessary to gather more information and evidence on the cost-effectiveness of BSM implementation, importance or utility. Many studies were conducted to identify, recommend and prioritize the BSM to be implemented in dairy, beef or veal calves farms (Mee, Geraghty, O'Neill, & More, 2012). Previous works highlighted the risk ratios of several infectious diseases related to the non-implementation of BSM to justify and promote their implementation (Agger, Priou, Huda, & Aagaard, 1994; Bessell, Orton, White, Hutchings, & Kao, 2012; Bruun, Ersbøll, & Alban, 2002; Dal Pozzo et al., 2016; Giuliodori et al., 2013; Guta et al., 2014; Holzhauer, Hardenberg, Bartels, & Frankena, 2006; Kuster et al., 2015; Nusinovici, Frössling, Widgren, Beaudeau, & Lindberg, 2015; Ryan, Leonard, O'Grady, Doherty, & More, 2012). Yet, these studies are usually measure- or disease-specific and lack a more holistic approach regarding the possible benefits of BS on health and production. The cost-effectiveness of a BSM such as vaccination, footbaths and deworming related towards a specific infectious disease was previously assessed (Ali et al., 2018; Cargnel et al., 2018; Solano, Barkema, Pickel, & Orsel, 2017); nevertheless, such approach becomes more complex when considering non-specific BSM. It is therefore difficult to justify and promote measures preventing several diseases (e.g., quarantine and general hygiene), while their implementation might be more cost-effective and less time consuming for the farmers.

Consequently, the objectives of this study were to determine whether the farm or farmers' profile correlated with the implementation level of BSM and if there was a positive correlation between the BSM implementation and the farm production and health parameters.

2 | MATERIALS AND METHODS

2.1 | Data collection

For this study, the data used to assess the implementation level of different BSM by farmers was collected through a face-to-face survey previously described (Renault et al., 2018). Briefly, DGZ and ARSIA (the two Belgian regional associations of animal health and identification) provided a randomly generated list of 500 hundred farmers. This list was used to select 100 Belgian farmers (50 dairy farms and 50 beef farms) by stratified random sampling (stratification by province) in Excel 2016®. The overall response rate of the survey was 70.2% with the majority of the replacements due to the farmers being unreachable or retired at the time of the study. The selected farmers, that is 0.4% of all Belgian cattle holders, were interviewed face to face, in order to estimate their practices in terms of BSM implementation (Appendix S1).

For the farmers who gave their written consent, and as a complement to the survey data, DGZ and ARSIA provided the following holding health status and production parameters: infectious bovine rhinotracheitis (IBR) and bovine viral diarrhoea (BVD) status, mortality rates (global, 0–7 days, under the age of 24 months and over 24 months of age), calving rate, age at first calving and calving intervals.

2.2 | Development of a scoring system related to the implementation level of BSM in the farm

The different BSM assessed in the questionnaire were grouped into 16 domains: (1) purchases, (2) re-entering animals, (3) contacts with other animals, (4) vehicles and materials, (5) farmer's hygiene, (6) visitors, (7) feed and water, (8) preventive treatments, (9) health system management, (10) manure and carcasses, (11) work organization and medical materials, (12) calving management (calving season is a critical time for calves), (13) individual calf housing, (14) calf management (practices to bring up a healthy replacement stock), (15) cow stables and (16) dairy management. Each domain was assessed through specific questions and sub-questions in order to determine the level of implementation of BSM (Appendix S2). For each BSM, a score was attributed based on its implementation level (lowest score = not implemented at all and highest score = properly and systematically implemented). These scores might differ according to the possibilities of answer to questions and sub-questions, for example either 0/1, 0/2, 0–4, etc. In addition, each BSM was categorized according to its action on one of the five compartments of BS (B1 = bio-exclusion, B2 = bio-compartmentation, B3 = bio-containment, B4 = bio-prevention and B5 = bio-preservation). For example, if we consider the feed and water (FW) domain (Table 1), cleansing water troughs (i.e., question FW5) prevents a pathogen from spreading inside a same facility (i.e., B2 compartment = bio-compartmentation).

Different scores were estimated in each domain:

A domain score (5BS) was calculated by either adding or multiplying BSM individual scores, depending on the interdependence between two or more BSM. Table 1 illustrates the estimation of scores for the 'Feed and Water' domain (FW). For non-associated measures, such as FW1 to FW5, BSM individual scores were summed. For interdependent measures (e.g., using specific feeding devices and systematic disinfection of these feeding devices after use, respectively FW6 and FW7 in Table 1), the scores were multiplied. The total obtained was then divided by the maximum score possible and multiplied by 100 in order to express all the scores by a value between 0 and 100. Thus, for the FW domain, the formula estimating the 5BS is:

$$5BS \text{ for } FW = \frac{\text{Sum of FW1to FW5+FW6*FW7}}{\text{Maximum score possible}} * 100 \qquad (1)$$

B1 to B5 (compartment-specific) scores: the same calculation process was applied, but only the compartment-specific scores were considered. For example, in Table 1, FW1 to FW3 contribute to bio-exclusion (B1) and bio-containment (B3) while FW4 to FW7 measures only deal with bio-compartmentation (B2). For this domain, scores will therefore be calculated as follows:

$$\text{B1 and B3 scores for FW} = \frac{\text{Sum of FW1+FW2+FW3}}{\text{Maximum score possible}} * 100 \qquad (2)$$

$$\text{B2 score for FW} = \frac{\text{FW4+FW5+FW6*FW7}}{\text{Maximum score possible}} * 100 \qquad (3)$$

The 5BS and B1-B5 scores were calculated for each of the 16 domains (Appendix S2).
The average score of the 16 domains was then calculated in order to establish the farm general biosecurity score (G5BS) and BS compartments scores (GB1 to GB5).

2.3 | Sensitivity analysis

After estimating the scores, a sensitivity analysis was performed in R studio® in order to detect domains which influence on scores would be low (non-significant difference, $p > .05$). Indeed, these domains could possibly be deleted to simplify the scoring system. Scores (G5BS and GB1 to GB5) were recalculated after discarding one of the 16 domains and a Spearman rank correlation test allowed comparing the new scores to the initial ones. Any significant difference ($p < .05$) confirmed the influence of the domain discarded on the final score, and the importance of maintaining it in the global score calculation.
This test was performed for each domain.

2.4 | Correlation between the global biosecurity scores and the farm or farmer's profile (N = 100)

A multivariate analysis performed in Stata SE/14 allowed investigating the possible correlation between the BS scores (dependent variables) and the farmer's or farm profile (explanatory variables).
The following explanatory variables were considered (Appendix S3): (a) farm profile—region, herd type and herd size; (b) farmer's profile—gender, years of experience, education level and BS perception (composite score based on the farmer's knowledge and interest towards BS and the perception of BS in terms of importance, cost and time). A correlation matrix assessed the possible relationship between explanatory variables (Table 2).
The normality of BS scores was assessed in R studio® using a Shapiro test; different transformations (log, sin, cos, square and power transformation) were applied to the BS scores that were not normally distributed (p-value < .05). Linear regression models considering the different BS scores as continuous dependent variables were performed at the exception of the B4 scores for which a negative binomial model was used. In fact, B4 scores were generated through a few questions and not normally distributed. Their distribution showed three peaks (Figure 1).
A multivariate analysis model was tested for each BS score, that is G5BS and B1-B5 scores. The first model included all explanatory variables with a p-value ≤ .1 as assessed in the univariate model (Table 3); the non-significant variables (p > .05) were removed through a stepwise approach, starting from the least significant (highest p values). If two significantly correlated explanatory variables (Table 2) were to be included in the multivariate model, one of them was excluded at the initial step. At each step, a likelihood-ratio test comparing the two nested models allowed comparing the simplified to the more complex model. The final model was selected when the likelihood-ratio test highlighted a significant difference between the more complex and the simplified model (p < .05) or when all variables were significant (Table 4).

TABLE 1 Example of the scoring system applied for the 'Feed and Water' domain

	Question	Attributes/ score	Bio-exclusion (B1)	Bio-compartmentation (B2)	Bio-containment (B3)	Bio-prevention (B4)	Bio-preservation (B5)	Bio-security (5B)
Q1	Which of these animals have access to food storage facilities?	0: Cats/Dogs/Birds/Rodents 1: Cats/Birds/Rodents 2: Birds/Rodents 3: None	X		X			X
Q2	Do the animals have access to surface water in the pastures ?	0: Yes 1: No	X		X			X
Q3	How often is the water quality tested (per year) ?	0: Less than annualy 1: Annualy 2: More than once per year 3: City water	X		X			X
Q4	How often are the water troughs cleaned ?	4: Daily 3: 1-3 times per week 2: 1-2 times per month 1: When dirty 0: Never		X	-			X
Q5	How often are the feed troughs cleaned ?	4: Daily 3: 1-3 times per week 2: 1-2 times per month 1: When dirty 0: Never		X	-			X
Q6	Are feeding devices only used for feed (no double use for manure) ?	0: No 1: Yes		X	-			X
Q7	Are feeding devices cleaned and disinfected after each use ?	0: No 1: Cleaned 2: Cleaned and disinfected		X	-			X
Scoring formula *			=Q1+Q2 +Q3	=Q4+Q5+Q6*Q9	=Q1+Q2+Q3	-	-	=Sum(Q1-Q5) +Q6*Q7

* The scores are then divided by their maximum possible score and multiplied by 100 in order to obtain scores between 0 to 100 reflecting the level of implementation of the different biosecurity measures related to the domain

2.5 | Correlation between the biosecurity scores and the farm health status and production parameters

Out of the 100 farmers surveyed, 91 agreed for ARSIA and DGZ to provide their health status and production parameters. The following outcomes were considered: BVD and IBR status, mortality rate (global, from 0 to 7 days of age, under the age of 24 months and over 24 months of age), calving rate, age at first calving and calving intervals. The analysis was performed on 45 farms from Wallonia (southern part of the Belgium) only for the following parameters: BVD status, mortality rates from 0 to 7 days of age and the reproduction parameters, that is calving rate, age at first calving and calving interval. These parameters were not provided by DGZ as not included in their data collection system.

Linear regression models were implemented in R studio® in order to assess the possible correlation between BS scores and the production parameters provided by ARSIA and DGZ.

In the absence of an official BVD status by the time of the survey, the farm BVD status was only provided in

TABLE 2 Correlation matrix with the pairwise correlation test coefficients between the different independent variables

	Region	Biosecurity Perception	Education level	Herd Type	Experience (years)	Gender	Mixed farm	Herd size
Region	.00							
Biosecurity perception	.18	1.00						
Education level	**.58**	**0.32**	1.00					
Herd Type	.00	0.03	0.10	.00				
Experience (years)	**.21**	-0.09	-0.15	0.04	1.00			
Gender	0.12	-0.01	0.04	.12	-0.07	.00		
Mixed farm	.11	**0.23**	0.19	**.20**	-0.08	-0.10	.00	
Herd size	.12	0.05	0.012	.1	-0.07	(.00	.06	1.00

Note: In bold, pairwise correlation tests with a significant p-value (p<0.05)

Wallonia based on a veterinarian survey implemented by ARSIA. Four statutes were defined: undetermined, infected, apparently free and apparently cleared. They were further reclassified in 3 categories of outcomes: ‘0’: undetermined or infected, ‘1’: apparently cleared and ‘2’: apparently free.

3 | RESULTS

3.1 | Biosecurity scores and sensitivity analysis of the scoring system

The scoring system applied to the survey data allowed the calculation of a general BS score (G5BS) as well as BS-compartment specific scores (GB1 to GB5) for each farm. The distribution of scores is shown in Figure 1, while Table 5 summarizes the results of statistical analyses. The Spearman rank analysis performed on the 16 different sub-scores (compared to the full score) showed significant differences ($p < .001$) for each sub-score. Therefore, no domain was removed from the scoring system, as it would have affected significantly the final score.

3.2 | Correlation between the global biosecurity by power −0.2 and 0.325. For each BS score, the initial model of the score and the farm or farmer's profile (N = 100)

Two scores had to be transformed in order to appear normally distributed,that is the G5BS and the GB5 scores were respectively transformed by power −0.2 and 0.325. For each BS score, the initial model of the multivariate analysis included the explanatory variables to be used in the multivariate models ($p < .1$) (Table 3). This initial model was simplified Two scores had to be transformed in order to appear normally distrib- through a backward stepwise analysis. The multivariate analysis showed no significant variables for the G5BS, the GB2 (bio-compartmentation) and the GB5 (bio-preservation) scores. The final models and their significant variables are presented in Table 4. The bio-exclusion score (GB1) was significantly higher in beef herds and lower in large herds. The biocontainment score (GB3) was significantly higher in Wallonia compared to Flanders and the bio-prevention score (GB4) was significantly higher in Wallonia compared to Flanders and larger farms.

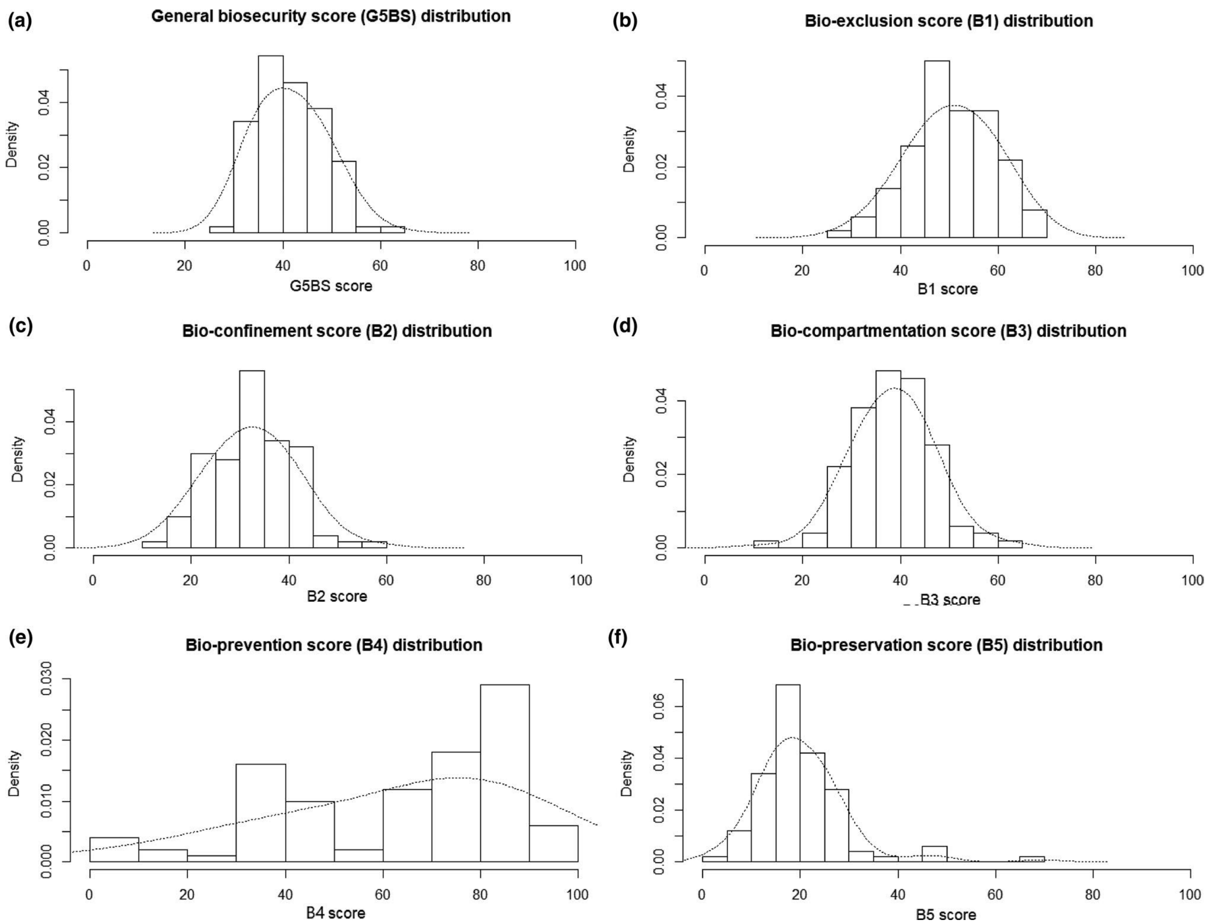

FIGURE 1 Distribution of general and compartiment biosecurity scores. General biosecurity score: G5BS; Different biosecurity compartments: B1, Bio-exclusion (limiting the risk of introduction); B2, Bio-compartmentation (limiting the spread within the same facility; intraherd transmission); B3, Bio-containment (limiting the spread to other animal facilities; inter-herd transmission); B4, Bio-prevention (preventing human contamination); B5, Bio-preservation (preventing environmental bio-contamination)

TABLE 3 Univariate linear regression model between the biosecurity scores (outcome variables) and the farm and farmers characteristics (explanatory variables) with p ≤ 1

	GB1		**GB3**		**GB4**	
	p	**Coeff**	**p**	**Coeff**	**p**	**Coeff**
Region (Ref. = Flanders)					**0.00**	).60
Herd Type (Ref = Beef)	**0.04**	3.36				
Mixt Farm (Ref = non mixt farm)					**0.01**	).47
Experience (years)						
Education Level (Ref =No superior studies)					**0.01**	).43
Herd Size	**0.09**	-0.01				
Biosecurity perception			0.06	0..53	0.01	0.07

Abbreviations: GB1, Bio-exclusion score; GB3, Bio-containment score; GB4, Bio-prevention score

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TABLE 4 Results of the multivariate linear regression model for each of the biosecurity scores (outcome variables) and the farm and farmers characteristics (explanatory variables) - Final models obtained after a backward stepwise analysis

Final model	Bio-exclusion		Bio-compartmentation		Bio-prevention	
	p	*Coeff.*	*p*	*Coeff.*	*p*	*Coeff.*
Region (Reference = Flanders)			.01	0.27	.00	0.56
Herd Type (Reference = Beef)	.02	.06				
Mixed Farm (Reference = non-mixed farm)					.01	0.04
Herd Size	.03	0.02				

TABLE 5 Summary statistics of the different biosecurity scores

	G5BS	GB1	GB2	GB3	GB4	GB5
Minimum	29.25	28.53	8.06	10.91	0	2.78
Median	42.71	50.31	27.18	38.56	50	16.67
Mean	42.64	50.72	27.77	38.50	44.27	18.93
SD	6.65	8.37	9.67	7.81	25.98	9.13
Maximum	62.36	67.8	51.69	62.6	100	66.67

Abbreviations: G5BS, General biosecurity score; GB1, Bio-exclusion score (limiting the risk of introduction); GB2, Bio-compartmentation score (limiting the spread within the same facility); GB3, Bio-containment score (limiting the spread to other animal facilities); GB4, Bio-prevention score (preventing human contamination); GB5, Bio-preservation score (preventing environmental contamination).

3.3 | Correlation between the G5BS score and the farm production parameters

Several health and production parameters were significantly correlated with BS scores; biosecurity did not influence significantly the reproduction parameters (Table 6). The farms categorized as ‘apparently BVD-free’ had a significantly higher G5B score. The mortality rates of cattle over 24 months of age were significantly but negatively correlated with a higher bio-compartmentation (GB2) and bioprevention (GB4) score. The same type of correlation was observed when considering the mortality rate of calves aged 0 to 7 days versus all BS scores, at the exception of bio-prevention (GB4).

4 | DISCUSSION

To our knowledge, this is the first attempt to assess the possible correlation between the implementation level of BSM and cattle production parameters. This approach could be a first step in assessing the cost-effectiveness of non-specific BSM in order to promote their implementation and increase their adoption rate by farmers. Even though the number of farms assessed could be considered as low (45 or 91 farms, according to the dependent variable), the farms were randomly selected and can be considered as representative of Belgian cattle holdings.

TABLE 6 Univariate linear regression assessing the correlation between the biosecurity scores (explanatory variables) and different health or production parameters (outcomes) - Models with a significant p (≤.05)

	Apparently free-BVD* status (N=45)		**Mortality rates of cattle aged above 24 months (N=91)**		**Mortality rates of calves aged from 0 to 7 days (N=45)**	
Explanatory variable	***p***	***Coeff.***	***p***	***Coeff.***	***p***	***Coeff.***
General biosecurity score	.03	- 0.02			.00	0.03
Bio-compartmentation score			.02	-17.80	.03	-21.79
Bio-containment score					.05	-13.09
Bio-prevention score			.00	-2.63		
Bio-preservation score					.05	-14.38

Abbreviation: BVD, Bovine Viral Diarrhoea.

4.1 | Scoring system

Different biosecurity scoring systems have been developed and documented in the literature for poultry and pig production systems (Gelaude, Schlepers, Verlinden, Laanen, & Dewulf, 2014; Rodrigues da Costa et al., 2019; Silva, Corbellini, Linhares, Baker, & Holtkamp, 2018; Silva et al., 2019; Van Limbergen et al., 2018) but, from the authors' knowledge, there is only one study documenting as biosecurity scoring system in dairy farms (Can & Altuğ, 2014). An on-line self-assessment system (Biocheck cattle[1]) provides an evaluation of a farm biosecurity level and also delivers prioritized recommendations but its scoring system is not yet described in the scientific literature. Scoring systems differ through the number of BSM assessed, the BS sub-categories (none or two categories, i.e., external and internal BSM) and the absence or presence of a weighting system. None of these systems considers the five compartments of biosecurity (5 B') and their specific scoring. The scoring system applied in this study includes the same BSM as the Biocheck bovine on-line self-assessment tool, but their classification, as well as the scores calculated, is different. Indeed, Biocheck bovine regroups the BSM into five categories for external biosecurity and six categories for internal biosecurity. The scoring system applied in the present study classifies BSM into 16 categories (or domains) and considers their possible contribution to the five BS compartments (5 B's). The analysis is therefore believed to be more accurate in the estimation of the correlation of the different domains or B1 to B5 compartments with health and production parameters.

4.2 | Correlation between the biosecurity scores and the farm or farmer's profile

The bio-exclusion score (B1) was significantly higher in dairy farms compared to beef holdings. Indeed, dairy farms must comply with specific requirements for milk quality control (QFL) and register less animal movements. Furthermore, natural mating is still prevailing in beef farms and therefore, bull purchases are frequent (Renault et al., 2018). Keeping a closed herd is a major component of bio-exclusion. Another significant variable explaining the B1 was the herd size. The farms accounting more cattle heads implement significantly less bio-exclusion measures, despite the higher possible impact if an infectious disease is introduced into the herd. A higher proportion of large herds purchase cattle (USDA, 2009). Furthermore, in dairy herds, the proportion of heifers raised on-site decreases as herd size increases (USDA, 2014, 2014).

The bio-compartmentation (B3) and bio-prevention (B4) scores were significantly influenced by the region, that is higher in Wallonia. The survey was conducted by two different researchers, one in Flanders and another one in Wallonia, which could have biased the survey methodology despite standardization and the use of closed questions. Nevertheless, previous studies also highlighted regional disparities (Sayers et al., 2013). The possible factors deserving further investigation could be the culture, the climate, the predominant farming systems and a different training and technical support between regions, as suggested by a similar study in pig farming (Costard et al., 2015). The bio-prevention scores (B4) were also significantly higher in larger herds, for inexplicable reason, and thus require further investigations.

4.3 | Correlation between the global biosecurity score and the farm health and production parameters

Despite the small sample, several significant differences were highlighted between some BS scores and the farm health and production parameters.

The farms declared as apparently BVD-free by their veterinarian had a higher general BS score, corresponding to a higher implementation level. This suggests a possible correlation between the general BSM implementation level and BVD control.

The mortality rates of animals over 24 months of age were significantly lower when the bio-compartmentation and bio-prevention scores were higher. The calf mortality rates (age: 0–7 days) were significantly lower when the general BS score as well as the bio-compartmentation, bio-containment and bio-preservation scores were higher. These findings demonstrate a possible economic benefit for the farms, as the mortality rates are lower in farms implementing more BSM to prevent the spread of diseases. Examples of such measures include animal health management (detection and management of disease carriers and sick animals), work organization, calving and calf management as well as the general hygiene of stables. Although previous disease-specific studies reported that those measures, or their related risks, influence the disease incidence, their cost-effectiveness have not been assessed so far. Indeed, such measures contribute to the prevention and/or control of several diseases and cannot be analysed individually as they are part of a global disease prevention and control approach. These observations highlight a correlation between the implementation of such measures, farm productivity and the possible economic benefits of their implementation, as they seem to reduce direct losses on farm.

5 | CONCLUSION

From the author's knowledge, this is the first evidence-based study highlighting the possible economic benefits through better disease prevention and control and mortality reduction related to the appropriate implementation of measures aiming at controlling the spread of diseases within and from the farm. In the future, a study including a larger number of farms should be implemented, in the context of a more powerful analysis. It would allow assessing more accurately the cost-benefits ratio of BSM and potentially linking other sets of BSM to the farm production parameters and health status.

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ETHICAL APPROVAL

Ethical statement is not applicable to this study as the data were gathered through questionnaire survey without any animal experimentation.

ENDNOTE

1 https ://www.bioch eck.ugent.be/bioch eck_cattle.php

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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Experimental section

Study 6

Rural veterinarian's perception and practices in terms of biosecurity across three European countries

Transboundary and Emerging Diseases 2018, 65:e183-e199

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Preamble

Several studies mentioned the professional visitors as a major risk of disease introduction in a farm. In addition, the farm survey in Study 2 highlighted the lack of control perceived by the farmers when it comes to hygiene of visitors as illustrated by the following citation “we need them so it is difficult for us to impose any access conditions”. Among the professional visitors, the veterinary practitioners are professional visitors at high risk of introducing or spreading infectious diseases from one farm to another. Besides they are also supposed to set an example in terms of biosecurity when visiting a farm. Nevertheless, the implementation level of BSM by rural practitioners has not been studied yet at the exception of a few studies mentioning a poor implementation level. This study presents a survey implemented in different European countries in order to gather data on reported BSM implemented in the field by veterinarians and the different constraints they face.

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ORIGINAL ARTICLE

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Rural veterinarian's perception and practices in terms of biosecurity across three European countries

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Summary

The implementation of biosecurity measures in the animal health and production context is quite broad and aims at limiting the risk of introduction and spread of diseases. Veterinarians play a major role in biosecurity as key informants on the subject for cattle holders, key players in terms of disease prevention/control and eradication programs, as well as key risk factor in terms of disease dissemination. Many biosecurity studies have highlighted professional visitors such as veterinary practitioners as representing a high-risk factor in terms of disease introduction in animal facilities but, to date, very few studies have focused on the implementation level of biosecurity measures by veterinarians. An online survey was implemented in three European countries (Belgium, France and Spain) to assess the behaviour of rural veterinarians towards biosecurity, as well as their implementation level of the biosecurity measures. A descriptive analysis of data and a scoring system were applied to assess the implementation level of measures. The influence of different factors on the implementation level of biosecurity measures was investigated through a negative binomial regression model. The study identified different strengths, weaknesses, possible constraints and solutions in terms of veterinary perspectives. Veterinarians are considered as key informants by the farmers and could therefore play a more active role in terms of guidance and improvement of biosecurity at farm level. Based on the survey outcomes, two factors seemed to influence significantly the implementation level of measures: the country where he/she practices and the veterinarian's perception level of biosecurity. The biosecurity stages with the lowest application level, therefore representing the biggest threats, were bio-exclusion (increasing the risk of disease introduction) and biocontainment (increasing the risk of inter-herd transmission).

KEYWORDS
Belgium, biosecurity, cattle, France, perception, Spain, survey, veterinarians

1 | INTRODUCTION

Biosecurity (BS) is defined by the Food and Agricultural Organization as “A strategic and integrated approach to analysing and managing relevant risks to human, animal and plant life and health and associated risks to the environment” (FAO, 2007). Over the last decades, the importance of BS in animal production systems has increased due to the large economic impact of animal diseases and increasing awareness on the One Health concept and zoonotic risks. It has been previously reported that 75% of the emerging diseases were originating from domestic or wild animals and 60% of existing human infectious diseases were zoonotic (Taylor, Latham, & Woolhouse, 2001). The World Health Organization (WHO) has recently listed the top 10 emerging pathogens based on outbreaks risks and lack of non-existence medical countermeasures (Pizzi, 2015). Based on this analysis, an initial list of eight diseases needs urgent attention, as they are all zoonotic: Crimean Congo haemorrhagic fever, Ebola virus disease, Marburg haemorrhagic fever, Lassa fever, Middle East respiratory syndrome (MERS), severe acute respiratory syndrome (SARS), Nipah virus disease and Rift Valley Fever.

The infectious nature of pathogens combined with poor biosecurity practices may contribute to disease transmission within and between farms (e.g., Chenais et al., 2017; Fretin et al., 2013; Kylie et al., 2017). The implementation of biosecurity measures (BSMs) in the animal health and production context is quite broad (Mai, 2014) and includes proper implementation of measures to reduce the risk of introduction and spread of the pathogens.

In any animal facility, BSMs rely on five stages (Saegerman, Dal Pozzo, & Humblet, 2012): (i) B1, Bio-exclusion: limiting the risk of introduction; (ii) B2, Biocompartmentation: limiting the spread within the same facility; (iii) B3, Biocontainment: limiting the spread to other animal facilities (inter-herd transmission); (iv) B4, Bioprevention: preventing human contamination; and (v) B5, Biopreservation: preventing environmental biocontamination.

In this context, and for these five stages, the role and responsibility of veterinarians are key elements to ensure an early detection and control of disease outbreaks. Veterinarians play a major role as key informants on the BS for cattle holders; indeed, they consider their veterinary practitioner as the main source of information and adopt BSM based on veterinary advices (Gunn, Heffernan, Hall, McLeod, & Hovi, 2008; Heffernan, Nielsen, Thomson, & Gunn, 2008; Sayers et al., 2013). On the other hand, veterinarians also represent an important risk factor in terms of disease spread, as many studies have listed visitors, and more specifically professional visitors such as veterinarians, as a key risk factor in terms of bio-exclusion (Anderson, 2009; Brennan & Christley, 2013; Canadian Food Inspection Agency, 2013; Maunsell & Donovan, 2008; Mee, Geraghty, O’Neill, & More, 2012; NADIS, 2015; Noremark, Fr€ ossling, & Lew-€ erin, 2010; Sayers et al., 2013; van Schaik et al., 2002; van Winsen et al., 2016). Meanwhile, an ongoing survey implemented in Belgian cattle farms (unpublished data) confirmed that most cattle holders were not feeling comfortable in asking their veterinarians to wear clean and/or specific work clothes or boots when visiting their premises; they prefer relying on their professionalism in that regard. Nevertheless, only few studies have assessed the proper implementation of BSM by veterinarians in rural practice. Their perception of the role they play and the responsibilities they have with regard to that aspect remains unclear. Based on a PubMed search with “biosecurity,” “veterinarians” and “cattle OR cow OR bovine” used as keywords, the level of awareness, understanding and/or implementation of BSM by veterinarians has only been studied in the following countries: Sweden (Noremark & Sternberg-Lewerin, 2014), Great Bri-€ tain (Gunn et al., 2008; Pritchard, Wapenaar, & Brennan, 2015; Shortall et al., 2016), Ireland (Sayers, Good, & Sayers, 2014) and Spain (Simon-Grife et al., 2013).

This survey aimed at assessing the perception and interest of rural veterinarians towards BS, as well as the implementation level of BSM through an online survey implemented in Belgium, France and Spain. It consisted in identifying strengths and weaknesses in terms of BSM in various cattle production systems from the veterinary perspective. The study also assessed the possible influence of different contextual factors on the implementation level of BSM by veterinarians.

2 | MATERIALS AND METHODS

2.1 | Questionnaire design

The questionnaire was elaborated based on a literature review of questionnaires used in other studies related to biosecurity practices among veterinarians (Anderson, 2012; Gunn et al., 2008; Hoe & Ruegg, 2006; Kristensen & Jakobsen, 2011; Maunsell & Donovan, 2008; Noremark & Sternberg-Lewerin, 2014; Pritchard et al., 2015;€ Sayers et al., 2014; Shortall et al., 2016; Simon-Grife et al., 2013), and a working session gathering 10 rural veterinarians from the three countries, held to identify the problems they faced in their daily practice in relation with BSM. The questionnaire (Appendix S1) was initially divided into 11 categories: clothes, boots, material, organization of visits, hand hygiene, vehicle, management of medical waste, biosecurity of the veterinarian, advices to farmers, veterinary training and veterinary profile. It was pretested with six veterinarians from the three countries before final validation and launching.

It included multiple choice and open questions and was designed as an online survey hosted in Google Drive™ to reach a maximum of veterinarians and ease data collection. It was opened for 3 months, and different channels were used to invite veterinarians to participate:

1. In Belgium, invitations were sent to 2,850 private veterinarians by the Professional Union of Veterinarians (U.P.V), through their monthly booklet. This exhaustive list included 500 veterinarians with a rural or mixed practice.
2. In France, invitations were sent by the National Society of Veterinary Technical Groups (SNGTV), based on their mailing list of 2,000 members; 1,300 of them were included, whatever animal species and type of practice.
3. In Spain, the questionnaire was hosted on the Spanish Association of Bovine Veterinarians website (http://www.anembe.com/). The association's membership is 1,000.

2.2 | Analysis of descriptive data

The answers provided were standardized and recategorized.

Regarding the questions on work environment, veterinarians were asked to mention the application level of some key BSM by cattle holders, such as: (i) operational footbaths; (ii) separated/isolated calving boxes; (iii) adequate quarantine for incoming animals; and (iv) consideration of the veterinarian as the most appropriate adviser on BSM. These answers described the farm environment in which veterinary practitioners were working and the possible influence they could have on farmer practices. The last two questions concerned the main points the cattle holder, and the veterinarian her/himself, could improve, as well as the BS stage they considered as the most important. The possible areas of improvements for cattle holders and veterinarians were asked in an open question with a list of three measures to improve in decreasing order of importance. A score of 3 to 1 was assigned to each listed measure: 3 for the first measure listed, 2 for the second one and 1 for the third one. The total score per measure was calculated (e.g.,: a measure listed twice in first position, five times in second position and only once in third position would obtain a total score of 17 (sum of (2*3) + (5*2) + 1). Finally, a ranking of all measures was carried out, based on such total score.

A scoring system was applied to data in order to estimate different types of scores in relation with implementation of BSM by veterinarians (Appendix S2). In case of no answer, the lowest score was imputed, assuming the absence of answer was masking poor BS practices. Subquestions with a ≤ 30% answer rate were not considered. First of all, seven categories of BSM were created as follows: (i) work clothes; (ii) boots; (iii) hands; (iv) material; (v) risk consideration; (vi) management of medical waste; and (vii) advices on purchase.

For each category, a specific score was generated per BS stage (B1-5) based on the answers provided. A general biosecurity score (5B score) was then calculated for each category, based on the formula below:

$$[5B\ score]_x = 100 * \frac{\sum_{i=1}^{5} B(i)_x}{[Maximum\ score]_x}$$

with x = 1 to 7 for the category of measures concerned; i = 1 to 5 for the biosecurity stages B1 to B5. Maximum score = sum of maximum scores possible for B1 to B5.

After calculating the 5B scores of each category, a global 5B score was obtained by summing the 5B scores of each category. Global scores for each biosecurity stages (B1 to B5) were also calculated based on the formula below:

$$Global\ scoreB_x = \sum_{i=1}^{7} B_x{*}\ of\ category\ (i)$$

With x= biosecurity stage concerned; i = 1 to 7 for each measure category

* expressed as a score of 0 to 100, with 100 as the maximum score obtainable.

A descriptive analysis of data was performed in order to estimate the application level of BSM by veterinarians, per category of measures and BS stage (bio-exclusion, biocompartmentation, biocontainment, bioprevention and biopreservation), as well as to assess the farm environment and identify possible ways or areas of improvements.

2.3 | Regression analysis

Some variables were selected as possible explanatory variables: country, years of experience, type of practice, number of herds managed, main type of herds and perception of biosecurity

(Appendix S3), while the others contributed to the calculation of different BS scores (Appendix S2).

A negative binomial regression model was built-in Stata SE 14.1 (StataCorp LP, College Station, TX, USA), using the global 5B score as dependent variable and different explanatory variables (Appendix S3). The negative binomial regression method was applied due to extrabinomial variability. A p-value of .05 was considered as significant.

The first model included all explanatory variables (Appendix S3), and the non-significant variables ($p > .05$) were removed in a step-by-step approach (starting from the least significant variable, i.e., the variable with the highest p-values). Interactions between "country" and "BSM perception" were considered in the initial model. At each step, a likelihood ratio test comparing two nested models allowed comparing the simplified to the more complex model. When the likelihood ratio test gives a $p > .05$, the exploratory variable was discarded. The final model was selected when the likelihood ratio test stated a significant difference between the more complex and the simplified model ($p < .05$). In this case, the more complex model was retained.

The same procedure was followed using the specific BS scores (from B1 to B5) as dependent variables and the same initial explanatory variables. It aimed at assessing eventual differences in terms of considerations given by the veterinarians to each BS stages.

3 | RESULTS

A total of 205 surveys were properly completed by the rural veterinarians. Based on the number of veterinarians reached in the different countries, the global answer rate is of 7.3% with rates of 19.4%, 4.8% and 4.6% in Belgium (N = 97), France (N = 62) and Spain (N = 46), respectively. The global, French and Spanish answer rates **(a)** Do you consider biosecurity as a priority for the veterinarians? Are underestimated as the veterinary practitioners invited to participate were not only rural or mixed practitioners.

3.1 | Descriptive analysis of the veterinary survey

Profiles of respondents are presented in Table 1 while Appendix S4 (A-G) summarizes the dependent variables used in the negative binomial regression model.

TABLE 1 Overview of the number of respondents per country (N = 205)

	Belgium	France	Spain	Total
Type of practice (%)				
100 Rural	39	13	39	91
>50 rural	48	39	6	93
<50 rural	10	10	1	21
Years of experience				
0–13	38	18	9	65
14–24	18	15	16	49
24–31	20	12	16	48
>31	21	17	5	43
Perception of Biosecurity Measures				
Very high	30	14	3	47
High	13	14	7	34
Average	25	12	9	46
Low	20	14	17	51
Very low	9	8	10	27
Number of farms in the practice				
1–40	2	12	61	75*
41–80	8	11	53	72*
81–150	18	13	45	76*
>150	34	10	46	90*
Type of herds				
Dairy	12	18	33	63
Mixed	25	0	0	25
Suckling	33	31	10	74
Varied	27	13	3	43
Total	97	62	46	205

**Typo error in the original article corrected in this version*

Regarding the perception of veterinarians concerning BSM (Figure 1), most of them considered it as a priority for the profession, while 2% did not answer, as shown in Figure 1a. The majority of the veterinarians (80%) do not consider to be usually at risk, from the safety point of view, while 1.5% perceived they were systematically at risk (Figure 1b). For what professional training in terms of biosecurity was concerned, 23% mentioned not having followed any training after graduating, either due to lack of interest (2.5%) or to the lack of time (20.5%); 13.7% of participants mentioned biosecurity trainings as being part of their veterinary curriculum while postgraduation studies or readings on the topic were specified by 36.1% of them (Figure 1c).

In terms of farm environment (Figure 2) facilities required in terms of BS are rather poorly present. Less than 10% of farms have functional footbath(s) as mentioned by 89% of participants. Specific boxes for calving are mentioned for less than 25% of farms by 87% of veterinarians. More than 90% of cattle holders do not apply an appropriate quarantine period for incoming animals, as specified by 63% of veterinarians. The majority of veterinarians (67%) mention being considered by farmers as their privileged interlocutor in terms of biosecurity advices.

From the veterinarians' perspective, the most important measures to improve in cattle holdings are as follows: (i) make functional footbaths and cleaning facilities (e.g., boot and hand washing stations) available for visitors; (ii) apply control measures and quarantine upon purchasing animals; and (iii) have an appropriate attitude towards BSM in terms of awareness, understanding and behaviour change (Table 2). Small differences were noticed between countries. In Spain, the lack of cleaning facilities and footbaths was not seen as a priority while the control of visitors seemed a more important issue. In France, the absence of an isolation area was mentioned as the third most important measure to improve.

After calculating specific scores for each of the five BSM stages (B1 to B5) and the general 5B score for each category of measures, it was possible to assess the implementation level of BSM per category and stage, as well as the possible improvements (Figure 3a,b). In terms of proportion of BSM implementation per category, "management of medical waste" was the category with the highest implementation level (79%), followed by the category "materials" (63%), "hands" (47%), "work clothes" (45%), "risk consideration" (35%), "Advices on purchase" (34%) and "boots" (24%).

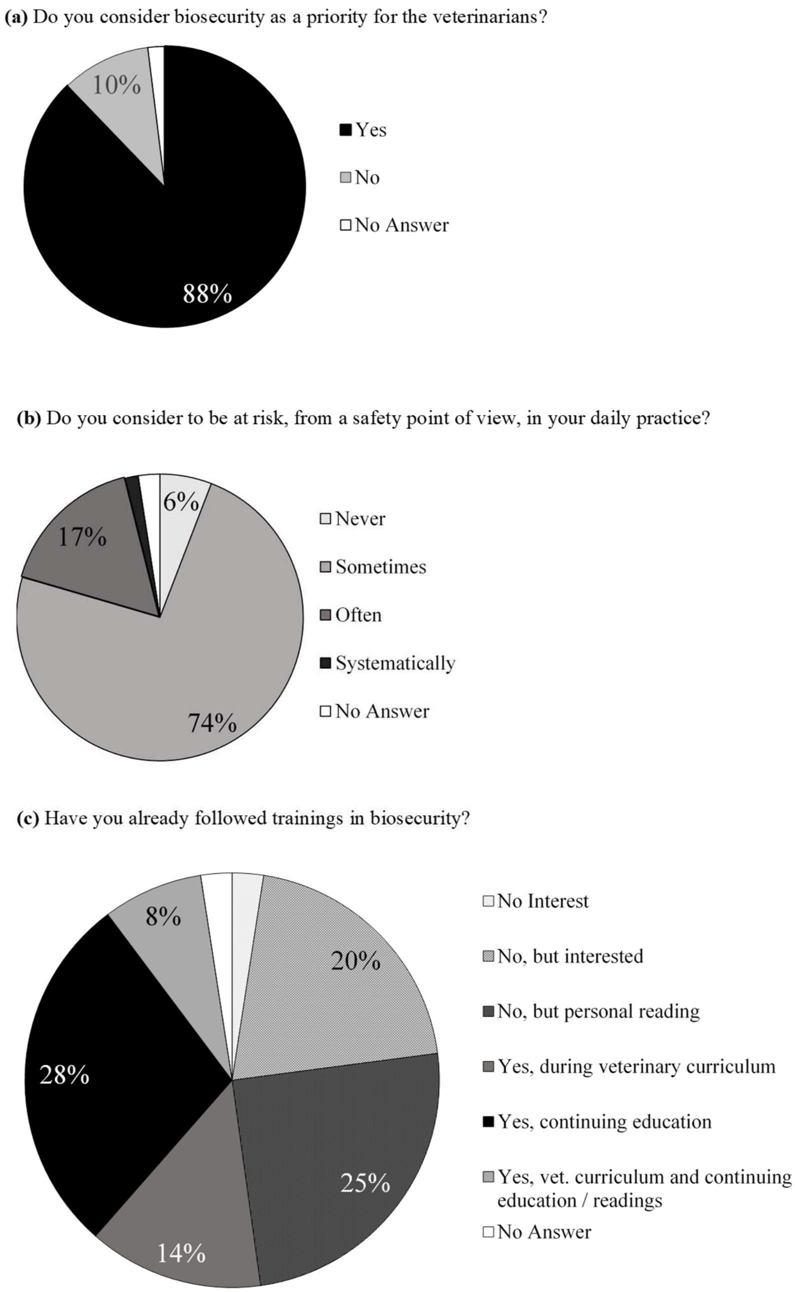

FIGURE 1 Veterinary perception and attitude towards biosecurity (N=205)

Hygiene measures related to hand, work clothes and boots reached a score generally low. For boots measures (Appendix S4B), 63% of the veterinarians never wear cover boots, while 89% of them do not wash their boots under the water jet upon entering premises; they usually wash and brush boots only when exiting farms (94%). Veterinarians using cover boots (but not systematically; N = 65) report doing it mainly in the following situations: outbreaks, high risk or suspicion of infection, expertise visits or trainings and in offland rearing facilities. On the contrary, they do not use cover boots if they need to enter the boxes or walk in the litter: indeed, cover boots are not considered as practical in such cases.

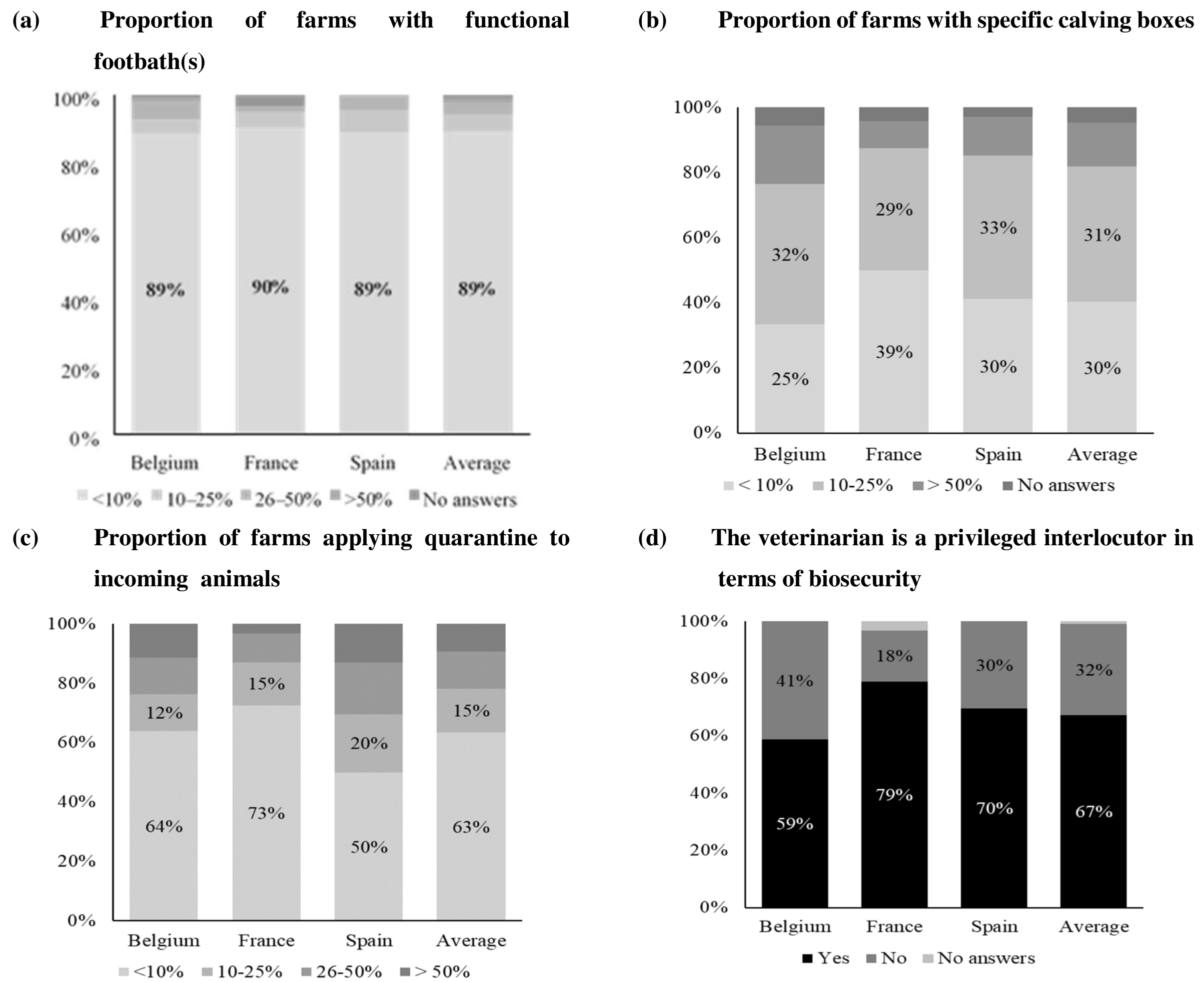

FIGURE 2 Farm environment of the veterinary practitioners. (a) Proportion of farms with functional footbath(s). (b) Proportion of farms with specific calving boxes. (c) Proportion of farms applying quarantine to incoming animals. (d) The veterinarian is a privileged interlocutor in terms of biosecurity

For what work clothes are concerned (Appendix S4A), 58% of veterinarians only change clothes when they look dirty or less often than daily. Disposable calving gowns are used by 60% of participants in case of surgery. Regarding hand hygiene (Appendix S4D), 66% of the veterinarians wash their hands after each farm but only 25% of them use antibacterial soap (65% of them use soap and 9% clear water).

Only 30% of the veterinarians always wear disposable examination gloves during their visits, while 29% use them often, 32%, sometimes and 8%, never.

For purchase advices provided to cattle holders (Appendix S4G), most veterinarians advocate for risk mitigation by suggesting to limit or avoid purchases (69%), test animals (79%) and/or apply quarantine (1%). Nevertheless, advices seem limited, in terms of diseases to test for: those that are not targeted by a disease control or eradication programs are usually not suggested (e.g., the proportion of veterinarians who never mention bluetongue, Schmallenberg disease, Mortellaro disease and mastitis reached 63%, 66%, 55% and 42%, respectively).

Regarding risk considerations for organizing work (Appendix S4F), 65% of the veterinarians do not organize

TABLE 2 Veterinarians' ranking of biosecurity measures to be improved by cattle holders (N = 205)

Measure to be improved by cattle holders	Belgium	France	Spain	Total
Lack of functional footbaths/cleaning facilities for visitors	***213***	***232***	36	481
Purchases: no quarantine	***191***	***82***	***63***	336
Purchases: no control	***131***	58	***88***	277
Behaviour of cattle holders towards BSM: lack of awareness, understanding and behaviour change	***86***	***45***	***51***	182
Prevent contact between domestic animals and wildlife	42	41	43	126
Control of visitors	34	27	***63***	124
Isolation of sick animals/having an isolation area	29	***75***	15	119
General hygiene of the cattle holder	59	43	11	113
Unfitted infrastructures for implementation of BSM	31	19	47	97
Appropriate and regular cleaning and disinfection of stables	27	30	19	76
Limited time or possible investments	33	10	22	65
General hygiene of materials and equipment	18	14	10	42
Calving boxes/area	18	20	1	39
Provide specific clothes/boots for visitors	26	4	6	36
Bio-exclusion measures	0	31	4	35
Appropriate disease control and management system at farm level	20	1	7	28
Improve national system in terms of control, regulation and communication	13	4	4	21
Bioconfinement measures	13	2	0	15
Control of vector and rodents	9	0	6	15
Appropriate animal grouping system	6	1	5	12
Other	9	1	5	15

BSM, biosecurity measures; in bold and italic: the four most important measures, ranked per country.

their farm visits based on risks. Furthermore, within a same cattle farm, 25% of them do not visit the animals in an order based on contamination risk. Most veterinarians are aware of the risk linked to necropsies and, either they refuse to perform them on site (20%), or they take specific measures to limit the number of necropsies or the risk of contamination (65%). The vehicle is parked inside the farm for 47% of participants and 8% of them bring their dog in the car during the visits.

Hygiene of medical materials (Appendix S4E) and management of medical waste (Appendix S4C) are generally well implemented. The large majority of veterinarians do not use domestic trash to dispose of their empty flasks (82%), out of date medicine flasks (88%), needles and scalpel blades (88%). A yellow container for medical waste is present in the vehicle of 71% of veterinarians. Regarding medical equipment (needles, etc.), the majority of participants (>50%) change after each animal, and a large majority change at least after each farm, except for syringes; indeed, 33% of veterinarians change them daily (or less often) and only 32% of them change after each animal. Reusable material is mainly sterilized

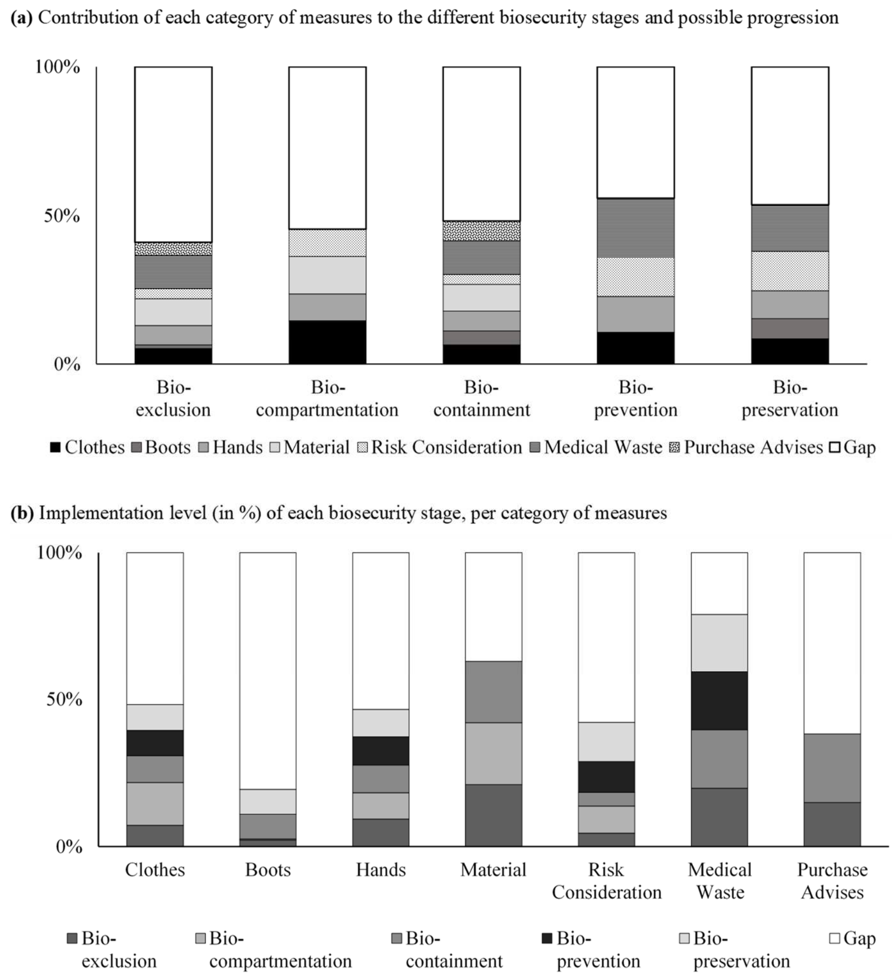

FIGURE 3 Implementation level of biosecurity measures per category and biosecurity stage (N = 205)

after each animal (67%), and the sterilization process seems fully effective for only 28% of veterinarians, while not fully effective for 64% and ineffective for 5%.

Based on the veterinary perception of their work practices, the biosecurity stage they consider to implement the best is bio-exclusion (B1) for 56% of participants and biocontainment (B3) for 21% of them (Figure 4a). When considering specific scores per biosecurity stage (Figure 4b), it appears that 54% of the veterinarians obtained the highest score for bioprevention (B4), 22% for biopreservation (B5) and 15% for biocompartmentation (B2). Their lowest score was obtained for the concept/pillars they thought to manage correctly (Figure 4a,b). After ranking the most important measures to be improved in their practice (Table 3), the five most important were as follows: (i) improve disinfection of clothes and boots between farms; (ii) provide more technical guidance/advices to farmers in terms of biosecurity; (iii) require minimal cleaning facilities and equipment at farm level (for Belgian and French veterinarians); (iv) cleaning and disinfection of medical materials; and (v) the use of disposable clothes and/or gloves. In Spain, an appropriate vehicle hygiene by increasing the cleaning frequency appeared in the top five measures to be improved.

3.2 | Negative binomial regression model

The first model using the general 5B score as dependent variable showed significant differences between countries and BSM perception level by veterinarians. The score was significantly higher for France ($p = .011$, coeff. = .0565 and

(a) Which biosecurity concept/pillar do the veterinarians consider to manage as best?

(b) Best biosecurity concept/pillar score obtained

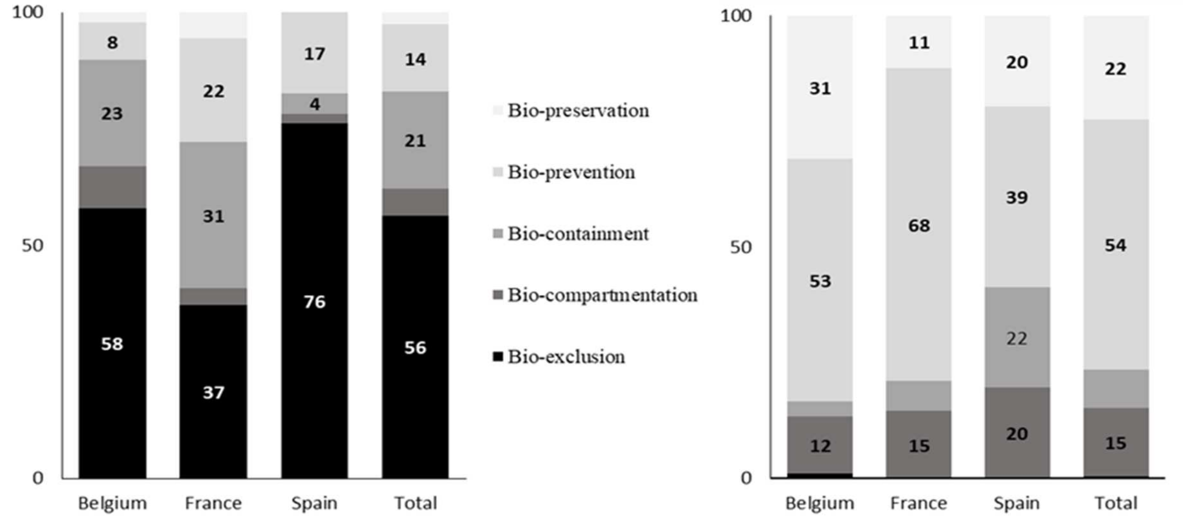

FIGURE 4 Biosecurity concept/pillar best implemented, based on the veterinarian's perspective (N = 205)

TABLE 3 Veterinarians' ranking of measures to be improved in their own practice (N = 205)

Measures to be improved by the veterinarians	Belgium	France	Spain	Total
Cleaning and disinfection between farms (clothes and/or boots)	***76***	***77***	***43***	***196***
Provide technical advices to cattle holders	***49***	***21***	***31***	***101***
Require minimal cleaning facilities and equipment at the farm level such as dedicated boots, clothes and surgical materials	***62***	***28***	10	***100***
Appropriate cleaning and disinfection of surgical materials	***38***	***29***	***20***	***87***
The use of disposable clothes and/or gloves	***30***	***27***	12	***69***
Hygiene of professional vehicle	13	14	***19***	46
Technical advices provided to the farmer regarding purchases of animals	17	7	***14***	38
Better time and stress management and risk-based planning	19	10	12	41
Hand hygiene	9	8	2	19
Other	4	8	6	18
General hygiene	8	8	0	16
Disposable clothes and/or gloves for surgeries	8	5	0	13
Technical advices in terms of animal grouping system	6	6	1	13
The use of disposable cover boots	4	4	3	11
Management of medical waste	8	0	3	11
Hygiene measures between animals	0	1	8	9
Technical advices on control of visitors	6	0	3	9
Not depend on the farmer for hands and boots disinfection	3	3	0	6

In bold and italic, the five most important ranks by country.

TABLE 4 List of significant explanatory variables in the final models, using the different scores of biosecurity measures as dependent variables (N total= 205, Belgium: N = 97, France: N = 62, Spain: N = 46)

	Significant explanatory variables				95% confidence interval	
Dependent variable	**Variable**	**Variable category**	***p*-value**	**Coefficient**		
5B	Country	France	0.011	0.087	0.020	0.153
		Spain	<0.001	0.143	0.067	0.219
	BSM perception	BSM perception 5	0.005	0.146	0.045	0.247
B1-Bioexclusion	Country	France	0.002	0.148	0.055	0.241
		Spain	<0.001	0.209	0.124	0.293
	BSM perception	BSM perception 5	0.006	0.150	0.043	0.258
B2- Biocontainment	Country	France	<0.001	0.225	0.124	0.326
		Spain	0.001	0.195	0.084	0.306
B3- Bioconfinement	Country	France	0.008	0.087	0.023	0.151
		Spain	<0.001	0.164	0.092	0.236
	BSM perception	BSM perception 5	0.006	0.135	0.039	0.230
B4- Bio prevention	Country	France	0.011	0.120	0.028	0.213
	BSM perception	BSM perception 5	<0.001	0.178	0.038	0.318
B5-Bio preservation	Country	France	0.046	0.070	0.001	0.138
		Spain	0.068	0.072	-0.005	0.150
	BSM perception	BSM perception 5	0.005	0.148	0.045	0.251

BSM perception 5 = very high level of perception of biosecurity

95% CI = 0.0197–0.1531) and Spain ($p < .001$, coeff. = .1432 and 95% CI = 0.0675–0.2191) compared to Belgium; no significant difference was observed between France and Spain. The score was also significantly higher for veterinarians with the highest BSM perception level ($p = .005$, coeff. = .1455 and 95% CI = 0.0446–0.2465). No significant difference was highlighted when considering other explanatory variables and/or interaction between country and BSM perception level.

When the models using specific BS stage scores as dependent variable were applied, significant explaining variables were similar, with two exceptions: no significant differences between Belgium and Spain for B4 score, and no significant difference due to BSM perception for B2 score (Table 4).

4 | DISCUSSION

The present online survey provides a useful analysis of the current level of implementation of BSM by rural veterinarians, which is in line with the general outcomes of previous biosecurity studies implemented in Europe (Anderson, 2012; Brennan & Christley, 2013; Gunn et al., 2008; Heffernan et al., 2008; Laanen et al., 2014; Mee et al., 2012b; Noremark et al., 2010; Noremark & Sternberg-Lewerin, 2014; Sarrazin, Cay, Laureyns, & Dewulf, 2014; Sayers et al., 2014,2013; Toma, Stott, Heffernan, Ringrose, & Gunn, 2013; Villarroel, Dargatz, Lane, MacCliskey,& Salman, 2007). It also highlighted the areas of improvements. Moreover, the present scoring system allowed a more specific analysis per biosecurity pillar/concept and category of measures. The main factors influencing significantly the application level of BSM were identified to facilitate decisionmaking.

The scoring system gave the same weight to each category of measures in the calculation of the global 5B score. This could generate a bias if some category of measures represents a higher biosecurity risk. This was taken into account, as the method assigned a higher weight to measures affecting all concept/pillars of biosecurity, compared to measures influencing only one of them.

This survey analysed mainly BSM practices of veterinarians in terms of role and responsibilities on: (i) technical guidance of cattle holders to improve BS at farm level; and (ii) their possible role as mechanical vector of diseases.

Biosecurity infrastructures (e.g., calving areas, isolation stall) are rarely available in farms. The main weaknesses that should be corrected, as a matter of priority, are linked to bio-exclusion and biocontainment (footbath and cleaning facilities for visitors, quarantine for newcomers, control of visitors and contacts with other domestic species and wildlife). The survey also confirmed that cattle holders do consider the veterinarian as a key informant on the biosecurity topic. Therefore, veterinarians could and should play an active role in terms of guidance and BSM improvements at farm level.

Regarding the veterinary practices, the current implementation level is quite low, which leaves, except for management of medical waste and material, a large place for improvement. These findings are in line with the most important improvements the veterinarians consider as a priority to implement in their practice. Hygiene of boots and clothes between farms is probably conditioned by the lack of cleaning facilities in farms, which was reported as the main weakness in French and Belgian farms. Another improvement suggested by some veterinarians was the possibility to have their own cleaning and disinfection system in their vehicle. From the comments reported in the survey, organizing the visits on the basis of contamination risks is not always possible as most visits are set up on last minute phone calls. Nevertheless, it is taken into account whenever possible, and within a same farm, if several operations are planned. Improvement of time and stress management is also seen as a priority; it is perceived as an important obstacle to an appropriate implementation of BSM by veterinarians.

It appears clearly that veterinarians do not self-evaluate themselves adequately, in terms of BSM implementation. They generally overestimate their degree of BSM implementation, especially for bioexclusion (B1) and biocontainment (B3). Indeed, they consider they implement these stages the best while the lowest scores were reached for both of them and the analysis of priority measures to be improved shows mainly measures related to these stages. They also consider they should play a more active role in terms of advising cattle holders to increase biosecurity at farm level.

Even though trends are generally similar for the three countries surveyed, biosecurity scores were significantly higher in France and Spain compared to Belgium, both for global and specific biosecurity stage scores. This seems contradictory, as the percentage of veterinarians with a very high perception level is higher in Belgium (30.9%) compared to France (22%) and Spain (6%). Reasons might be found in the level of awareness, the usual practices of veterinarians in those countries and/or different working environments, which could better enable the adequate implementation of BSM by veterinarians. As an example, the lack of cleaning facilities in farms was a priority to address for Belgian and French veterinarians, while this constraint did not appear to be major in Spain (low ranking by the veterinarians).

5 | CONCLUSION

The large majority of veterinarians consider biosecurity as a priority for their profession, although they do not consider their own safety to be at risk in their daily practice. This could represent a threat in terms of public health as seroprevalence for zoonotic diseases is usually significantly higher among rural veterinarians (Bernard et al., 2012; Dal Pozzo et al., 2017; Luce et al., 2012; Molineri, Signorini, Perez, & Tarabla, 2013). The survey highlighted weaknesses and margin for improvements, especially regarding bio-exclusion (related to the risk of disease introduction) and biocontainment (related to the risk of inter-herd disease transmission). Therefore, in case they do not adopt good practices, veterinarians might fail in one of their main responsibilities, that is limit the spread of a disease in case of outbreak. They can also be a high risk for farmers by playing the role of unintentional mechanical vector of diseases in premises. Although veterinarians expressed different constraints, possible solutions exist and have already been implemented by some veterinarians, such as an autonomous and mobile decontamination system or farm-dedicated clothes, boots and/or surgical material boxes that are left on premises.

The perception level of BSM by the veterinarians influences significantly the adequate implementation of good practices. Therefore, and to improve veterinary good practices, it is essential to allow biosecurity a greater role in veterinary training programs and curriculum, and to ensure an appropriate and ongoing awareness raising on the issue as part of continuing education proposed to veterinarians.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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Experimental section

Study 7

Factors Determining the Implementation of Measures Aimed at Preventing Zoonotic Diseases in Veterinary Practices

Pathogens 2021, 10, 436

Véronique Renault, Sébastien Fontaine and Claude Saegerman.

Preamble

If the professional responsibility of a veterinary professional could be engaged if she/he introduces an infectious disease in a farm by negligence, her/his own health could also be compromised as the non-implementation of BSM exposes the veterinarian to the risk of contracting a zoonosis. The previous survey showed us a large room for improvement in terms of BSM implementation by the veterinarians. Among the measures studied, some of them such as wearing gloves and hand hygiene, were useful to prevent zoonoses. This study focuses on the BSM that should be implemented by the veterinarians in order to preserve themselves from contracting zoonotic diseases, as well on the factors determining their adoption. The targeted population were veterinary practitioners as well as the veterinary students in their last years of training (masters 2 and 3).

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Article

Factors Determining the Implementation of Measures Aimed at Preventing Zoonotic Diseases in Veterinary Practices

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Abstract: Background: Zoonoses prevention relies mainly on the implementation of different biosecurity measures. This study aimed to assess the level of implementation of biosecurity measures by veterinary practitioners and students and to identify the possible behaviour change determinants. Methods: The data was collected through a cross-sectional survey (N = 382). Statistical analyses were implemented based on the Health Belief Model to identify the possible determinant of the behaviours and the explanatory variables of the perceptions. Results: The survey showed a good level of implementation of the biosecurity measures (median of 81%). The implementation was associated with a higher perception of the zoonoses' susceptibility and the measures' benefits, and with a lower perception of the zoonoses' severity. The study also revealed that the decision to implement a measure was mainly taken on a case-by-case basis depending on the perceived risk of exposure related to a specific context or intervention. Conclusion: The main determining factors identified for the implementation of biosecurity measures (BSMs) were the risk susceptibility and the benefits of the biosecurity measures, which could be influenced by evidence-based communication. The methodology developed can be applied regularly and in other countries to better capture these changes in perceptions over time.

Keywords: one health; biosecurity; veterinarians; students; Health Belief Model; perception; risk; behaviour

1 . Introduction

Biosecurity (BS) includes all the measures aiming at preventing the introduction of pathogen agents and/or reducing their transmission. As part of the "One Health" approach, BS is particularly important as it includes measures preventing animal, human and environmental contaminations. As more than 75% of emerging diseases and 60% of the infectious diseases affecting humans are zoonotic [1], BS in public health needs to address the issue of animal–human contaminations. In that regard, veterinarians represent a population at greater risk of infection by zoonotic pathogens and can play a role in their transmission [2]. Despite this accrued risk, the level of implementation of biosecurity measures (BSMs) by veterinarians was reported as generally low in several studies [3–10]. Therefore, it would be worth investigating the reasons for this low implementation despite the risks.

According to the Health Belief Model (HBM), health-related behaviours are influenced by different beliefs and perceptions which can be influenced by different psychosocial determinants, as described in Figure 1 [11]. The perceptions listed, also called HBM constructs, are: (i) the risk susceptibility (perceived likelihood of the risk of occurrence), (ii) the risk severity (perceived impact of the risk if it occurs), (iii) the benefits (perceived positive outcomes related to a given behaviour), (iv) the barriers (perceived barriers to the behaviour implementation or outcomes) and (v) the health responsibility (perceived responsibility towards animal, public and environmental health). The determinants of good behaviours must be identified to better promote the necessary changes and to better mitigate the zoonotic risks. Nevertheless, such studies have not yet been conducted for the veterinary profession.

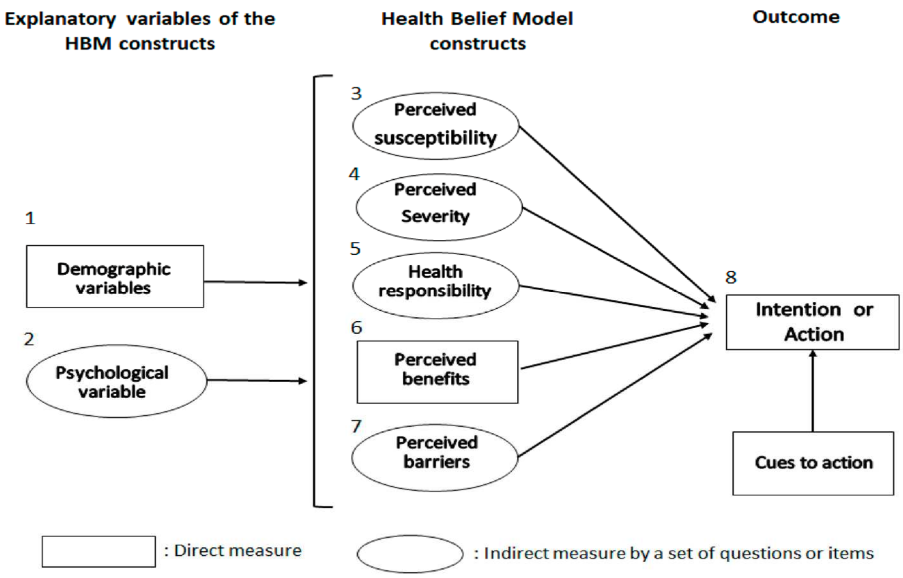

Figure 1. The Health Belief Model.

The objective of this study was to assess the level of implementation of BSMs by veterinary practitioners and senior students in veterinary medicine (years 5 and 6 of the veterinary course at Liege) and to identify the main determinants of the adoption of BSMs. The outcomes of the study make it possible to better communicate with veterinarians and to increase the implementation level of BSMs in their practices.

2. Results

2.1. Survey Results and Respondents Profiles

The answer rates were 35% for the students (N = 227) and 13% for the veterinary practitioners (N = 114) (Table 1).

The proportion of males and females among the student respondents was 22% and 78% respectively and a large majority (93%) reported having practical experience through various internships. The veterinary practitioners were 51% male and 49% female.

Among the respondents, 52% were practicing on or had experience with small animals only, 10% with large animals only, 32% had mixed practices (including equine) and 6% had no practical experience (students) or were practicing in other fields, such as wildlife and consultancies (Table 1). Fifteen per cent of the students and 39% of the veterinary practitioners who answered the survey reported having been personally affected by a zoonosis in the past. Thirty per cent of the students and 71% of the practitioners reported knowing someone that had been affected by a zoonosis in the past.

Table 1. Demographics of the respondents.

Responders	**Year of Study or Graduation**	**N**	**Gender**			**Kind of Practice**		
			Female	**Male**	**None/ Other**	**Large Animals**	**Small Animals**	**Mixed**
Veterinary students	Total students	960	76.35%	23.65%	-	-	-	-
	Total respondents	227	78.41%	21.59%	7.49%	3.96%	48.90%	39.65%
	2nd year Master's	162	75.31%	24.69%	9.88%	3.09%	50.00%	37.04%
	3rd year Master's	65	86.15%	13.85%	1.54%	6.15%	46.15%	46.15%
Veterinary practitioners	Total UPV members solicited	848	38.92%	61.08%	0.00%	11.79%	26.42%	61.79%
	Total respondents	114	49.12%	50.88%	3.51%	21.05%	58.77%	16.67%
	Before 1986	28	3.57%	96.43%	7.14%	17.86%	57.14%	17.86%
	1986 to 1995	38	52.63%	47.37%	5.26%	23.68%	57.89%	13.16%
	1996 to 2005	25	68.00%	32.00%	0.00%	20.00%	68.00%	12.00%
	2006 to now	23	78.26%	21.74%	0.00%	21.74%	52.17%	26.09%
TOTAL		341	68.62%	31.38%	6.16%	9.68%	52.20%	31.96%

The chi-square tests to compare the proportion of men and women and the proportion of veterinarians in the different types of practices did not demonstrate any statistical differences ($p > 0.05$). We can therefore consider the samples as representatives of the overall population.

2.2. *Implementation Level of the Biosecurity Measures*

As reported by the respondents, most of the BSMs were implemented either always or most of the time (Figure 2). Overall, the BS score reflecting the percentage of implementation of the different biosecurity measures ranged from 46% to 100%, with a median of 81% (quartile 1: 69%, and quartile 3: 92%). Some measures—such as disinfecting the hands after each consultation, ensuring proper containment of the animals, proceeding to an immediate disinfection if dealing with a wounded animal and, for rural practitioners, cleaning boots when exiting a holding—were always implemented or implemented most of the time by more than 95% of the respondents. Three BSMs had a lower implementation rate (45–53%): (i) wearing protective glasses, (ii) being vaccinated against rabies and (iii) using disposable coats (for rural practitioners).

The conditions for a measure to be implemented (when not done systematically) or adopted (when a measure was reported as never implemented) varied among the respondents (Table 2). Nevertheless, overall as well as for the large majority of the BSMs (8 out of 13), risk-based decisions or the low perception of the risk exposure was the main reason justifying non-implementation.

Table 2. List of most frequent conditions under which a given biosecurity measure was or would be implemented (N = 341).

Condition of Implementation	OVERALL	BSM 1	BSM 2	BSM 3	BSM 4	BSM 5	BSM 6	BSM 7	BSM 8	BSM 9	BSM 10	BSM 11	BSM 12	BSM 13
Numbers of answers	1059	96	127	62	123	143	74	78	78	43	17	72	127	19
Risk-based (increased risk/evidence-based risk)	**37%**	**34%**	**77%**	**56%**	**34%**	**29%**	**11%**	**27%**	**62%**	**14%**	**24%**	**1%**	**42%**	**11%**
Relevance	**10%**	0%	1%	2%	**23%**	**15%**	3%	5%	**13%**	0%	0%	0%	**29%**	0%
Materials (or infrastructure) availability	**7%**	4%	0%	3%	2%	4%	**30%**	1%	1%	2%	**24%**	**26%**	1%	**79%**
Feasibility	7%	**19%**	0%	0%	**9%**	8%	3%	6%	3%	**53%**	6%	1%	0%	0%
Not specified/I do not know	7%	**23%**	6%	6%	7%	3%	7%	4%	3%	2%	12%	6%	4%	**5%**
Sufficient time	5%	10%	1%	**8%**	2%	3%	1%	4%	0%	5%	**35%**	**31%**	0%	0%
More practical/comfortable	5%	3%	0%	**8%**	7%	**22%**	1%	1%	1%	0%	0%	1%	0%	0%
More discipline (negligence)	5%	6%	**7%**	2%	**9%**	7%	5%	5%	**5%**	2%	0%	0%	0%	0%
Recyclable (ecological concern)	3%	0%	0%	2%	0%	0%	0%	**17%**	0%	0%	0%	0%	**18%**	0%
Knowledge/information	3%	0%	0%	0%	1%	0%	**22%**	1%	0%	0%	0%	**19%**	0%	0%
Financial sustainability and/or justification	2%	0%	0%	6%	0%	1%	0%	**18%**	0%	0%	0%	6%	2%	0%
Willingness to do it	2%	0%	0%	0%	0%	5%	**16%**	1%	**5%**	0%	0%	0%	1%	0%
Good acceptance/usual practice	2%	0%	**7%**	5%	6%	2%	0%	0%	0%	0%	0%	0%	0%	0%
Proven to be efficient/needed	2%	0%	0%	0%	1%	0%	0%	4%	1%	**21%**	0%	1%	1%	**5%**

Legend: grey cells: most frequent reasons; bold numbers: among the three most listed reasons. BSM1: hands disinfection; BSM2: asking about the country of origin of the animal; BSM3: wearing gloves adapted to needs; BSM4: wearing a mask (if there is a risk of projections); BSM5: wearing protective goggles (if there is a risk of projections); BM6: throwing away the needles without replacing the cap; BM7: washing dirty clothing separately; BM8: being vaccinated against rabies; BM9: ensuring proper containment; BM10: proceeding to an immediate disinfection if dealing with a wounded animal; BM11: attending continuous training; BM12: using a disposable coat; BM13: cleaning boots when exiting the holdings.

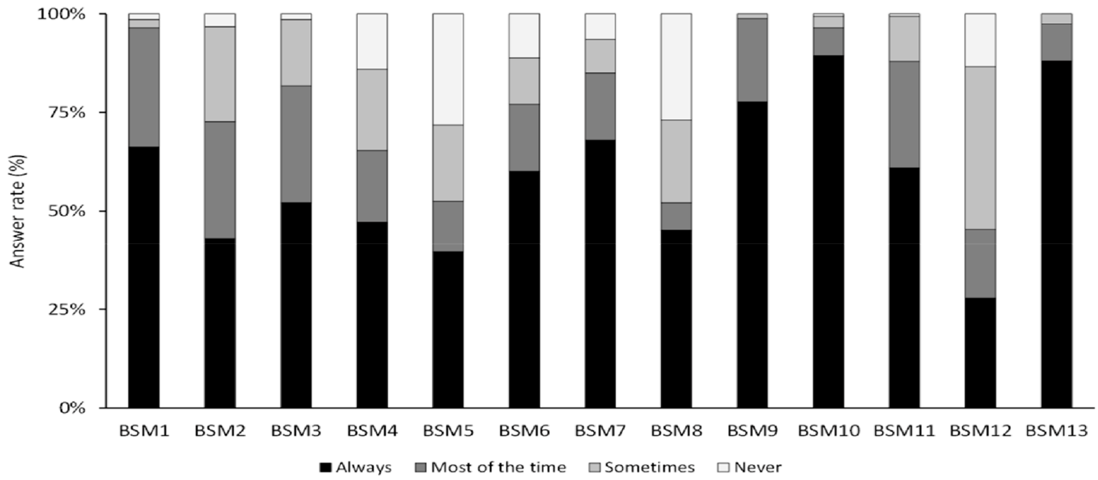

Figure 2. Implementation level of the different biosecurity measures by the respondents (N = 341). Legend: biosecurity measure(BSM) 1: hands disinfection; BSM2: asking about the country of origin; BSM3: wearing gloves; BSM4: wearing a mask; BSM5: wearing protective goggles; BSM6: throwing the needles directly into a specific container without replacing the cap; BSM7: washing dirty clothing separately with a proper cleaning cycle; BSM8: being vaccinated against rabies; BSM9: ensuring a proper containment; BSM10: proceeding to an immediate disinfection if wounded; BSM11: continuous training; BSM12: using a disposable coat; BSM13: cleaning boots when exiting the holdings.

2.3. Assessment of the Reliability of the Items Used to Indirectly Determine the Psychological Variable and the Health Belief Model Constructs

The Cronbach's alpha standardised coefficient calculated for the "risk aversion" as well as the perception of "risk susceptibility" and the "health motivation" showed a good reliability (coefficient > 0.7) while the reliability of "risk severity" and "barriers" seemed poor (coefficient = 0.52 and 0.53, respectively) (Table 3). The exploratory factor analysis (EFA) nevertheless confirmed "barriers" as a factor build based on three items despite this poor Cronbach's alpha coefficient. The final scores of each construct were therefore calculated considering the items providing the highest Cronbach's alpha (Table 3).

The median scores obtained for the psychological variable and the different HBM constructs were generally high, with the median values being above 67%, with the exception of the scores for perceived "barriers", which were generally low, with a median value of 30% (Figure 3).

Table 3. Cronbach's alpha coefficient, factor loadings and scoring formulas used to determine the scores of the respective components.

Component	Cronbach's α	Item Code	α if Item Deleted	Factor Loadings (EFA Analysis)	Component Score Calculation
Risk aversion	0.8	RA1	0.6	0.8	Risk aversion score = (RA1 + RA2)/2
		RA2	0.6	0.9	
		RA3	0.8	0.5	
Risk susceptibility	0.8	Su1	0.8	0.6	Risk susceptibility score = SUM Su1 to Su4/4
		Su2	0.7	0.8	
		Su3	0.7	0.7	
		Su4	0.8	0.6	
Risk severity	0.6	Se1	0.4	0.7	Risk severity score = (Se1 + Se2)/2
		Se2	0.2	0.8	
		Se3	0.7	0.0	
Health responsibility	0.7	HR1	0.5	0.8	Health responsibility score = (HR1 + HR2)/2
		HR2	0.5	0.9	
		HR3	0.9	0.2	
Barriers	0.5	Ba1	0.3	0.6	Barriers score = (Ba1 + (100 − Ba2) + Ba3)/3
		Ba2	0.5	0.3	
		Ba3	0.5	0.5	

Legend: EFA: exploratory factor analysis; item code description provided in Appendix A.

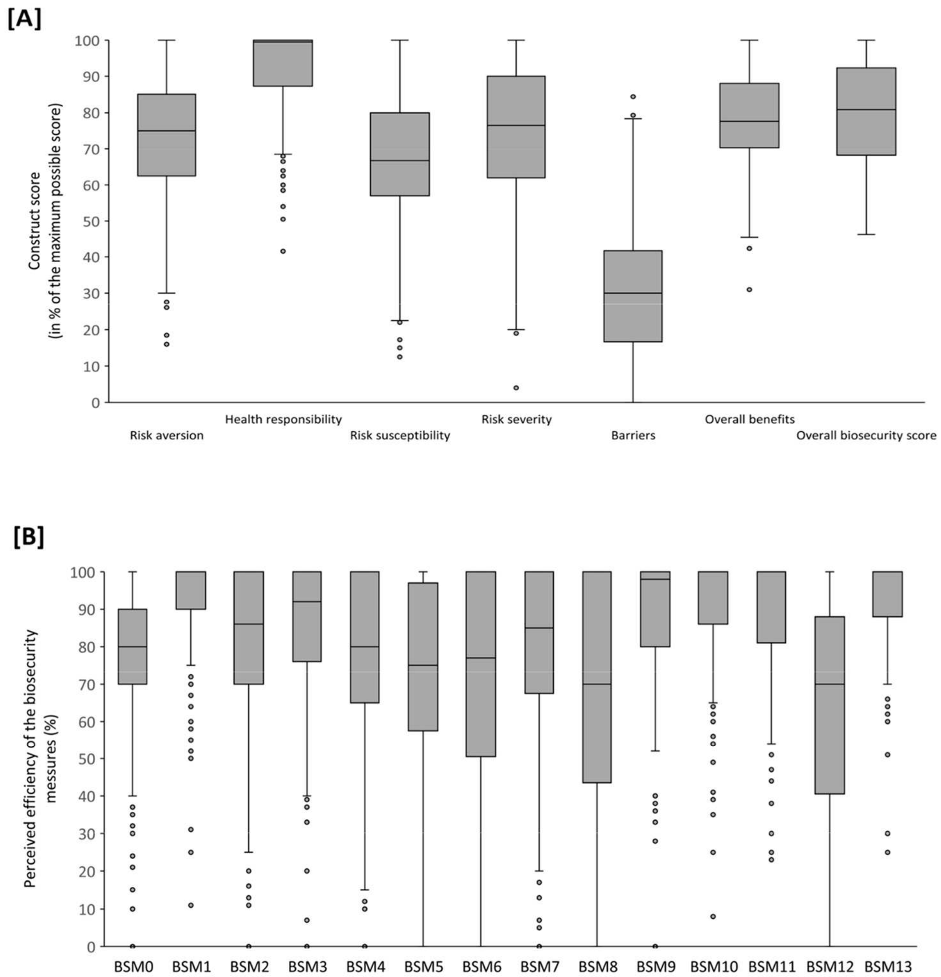

Figure 3. Perceptions of the different Health Belief Model constructs (**A**) and of the perceived benefits of the specific biosecurity measures (**B**). Legend: BSM0: overall efficiency of the different preventive measures; BSM1: hands disinfection; BSM2: asking about the country of origin; BSM3: wearing gloves adapted to needs; BSM4: wearing a mask (if there is a risk of projections); BSM5: wearing protective goggles (if there is a risk of projections); BSM6: throwing the needles away directly without replacing the cap; BSM7: washing dirty clothing separately; BSM8: being vaccinated against rabies; BSM9: ensuring a proper containment; BSM10: proceeding to an immediate disinfection if dealing with a wounded animal; BSM11: attending continuous training; BSM12: using a disposable coat; BSM13: cleaning boots when exiting the holdings.

2.4. Regression Models

The Spearman rank correlation test and the Kruskal–Wallis H Test showed no significant associations between the different explanatory variables of the HBM constructs.

When considering the overall BSM implementation score as the final output and the overall BSM benefits perception, the final multivariable model showed that the overall BS implementation was significantly and positively associated with the perception of the disease susceptibility and the perceived benefits, while it was negatively and significantly associated with the perception of the disease severity (Figure 4 and Appendix B). The HBM constructs were significantly associated with three explanatory variables (Figure 4). The seniority of the veterinary practitioner, type of practice, risk aversion profile and workload had no significant effects on the different perceptions. A high-risk aversion profile was associated with a higher perception of the five HBM constructs, and the perception of the zoonoses' severity was significantly higher for males. The veterinary practitioners had a significantly higher perception of the diseases' severity and barriers while they had a lower perception of their health responsibility and of the overall benefits of the BSM implementation regarding the prevention of zoonoses.

Regression models were also developed for each of the specific BSMs listed in the survey relating to the factors affecting the perception of their benefits (Figure 5A) and their actual implementation (Figure 5B). With regard to the perceived benefits of the different BSMs, and with the exception of BSM6 (throwing away needles without replacing the cap), respondents with a higher "risk aversion" level had a significantly higher perception of the benefits. Male respondents had a significantly lower perception of the benefits of hands disinfection, asking about the country of origin and wearing masks. Compared to veterinary students, veterinary practitioners had a significantly lower perception of the following BSMs: asking about the country of origin, washing working clothes separately and being vaccinated against rabies. The type of practice also seemed to significantly influence the perceptions of some BSM benefits. Compared to rural practitioners, the veterinarians working with small animals (or in mixed practices) seemed to have a higher perception of the benefits of hands disinfection, asking about the country of origin and wearing masks. The workload seemed to negatively influence the perceived benefits of ensuring proper containment of the animals.

With regard to the factors determining the BSMs' implementation, the perception of the benefits was significantly and positively associated with the implementation level of all the BSMs, with the exception of three (wearing a mask, ensuring proper containment and cleaning boots when exiting an animal holding) for which no association was found with any of the HBM constructs. Respondents with higher "health responsibility" were also more likely to be vaccinated against rabies.

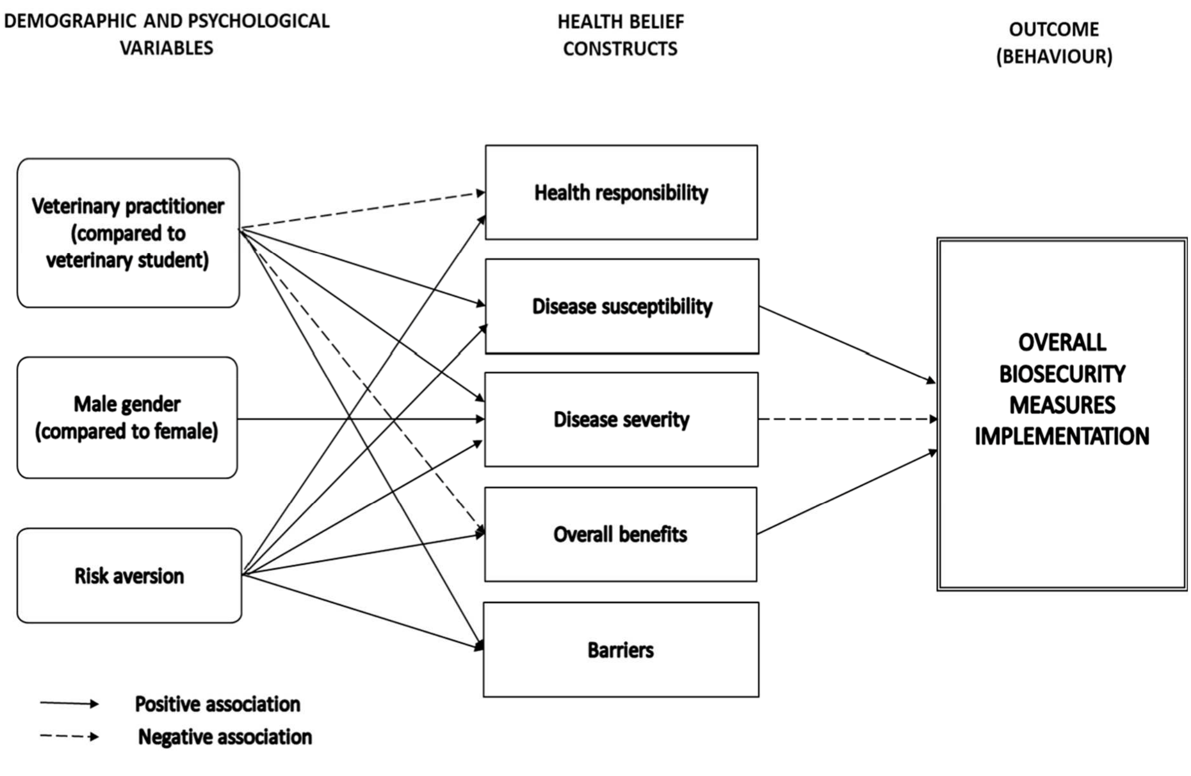

Figure 4. Identification of significant associations based on the multivariable regression model using the overall benefits perception and the overall biosecurity score (for the veterinary practitioners and students).

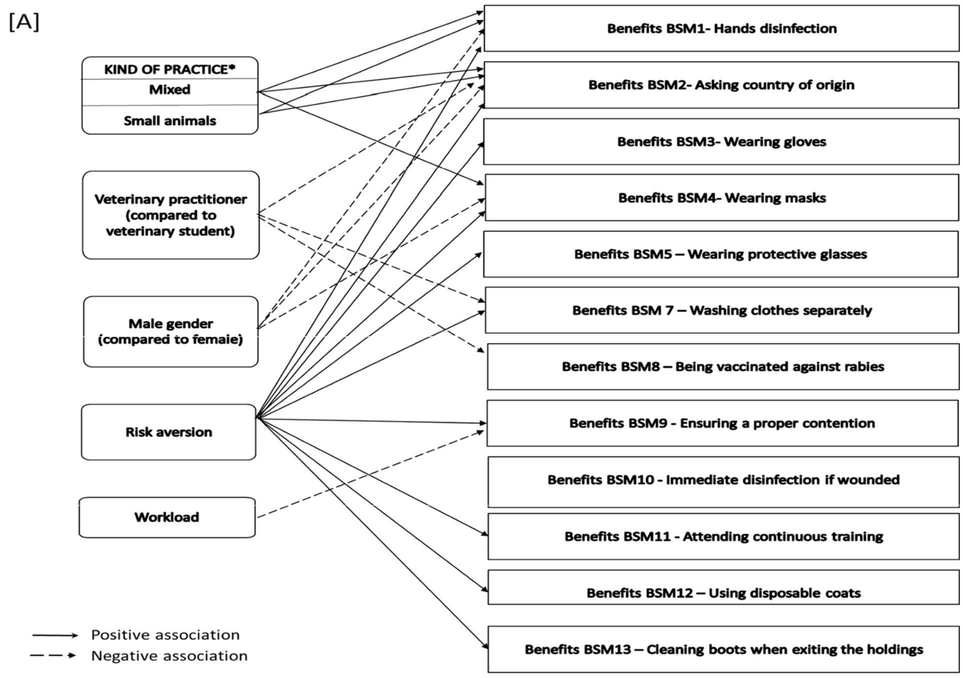

Figure 5. *Cont.*

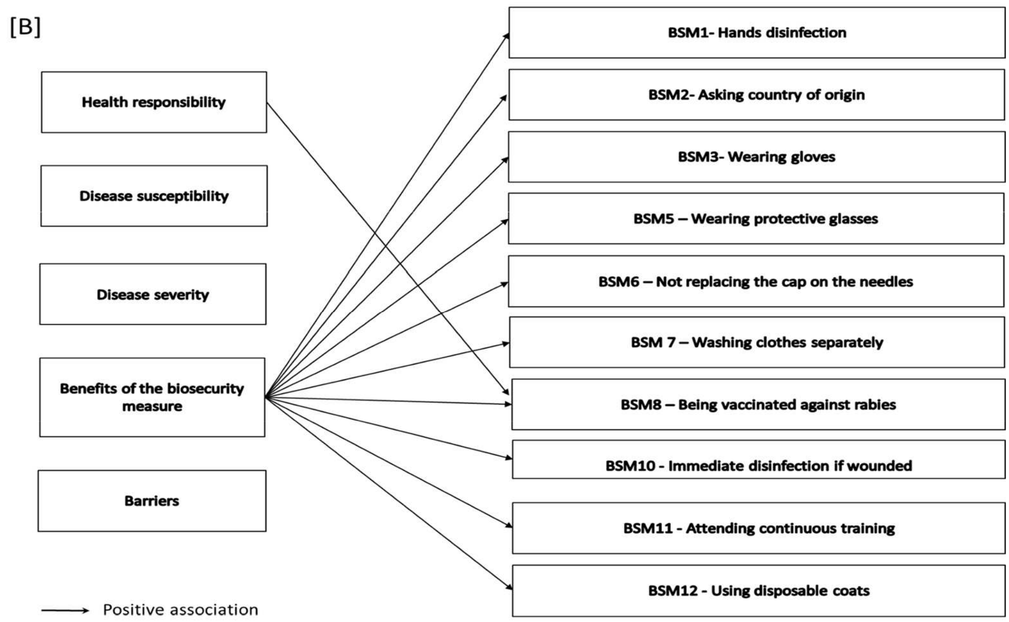

Figure 5. Identification of significant associations identified based on the multivariable regression model for the different biosecurity measures (for veterinary practitioners and students). (**A**) Variables significantly associated with the perceived benefits of the biosecurity measures and (**B**) HBM constructs significantly associated with the implementation of the different biosecurity measures. Legend: * mixed and small animal practices compared to large animal practices.

3. Discussion

This is the first study evaluating the level of implementation of BSMs by Belgian veterinarians and veterinary students with regard to zoonosis prevention. It also identified the possible influence of personal beliefs and perceptions on the adoption of BSMs, as well as possible cues to action, in order to influence the decision-making process. To reduce the volunteer and the social desirability biases the anonymity of the respondent was guaranteed, the questions were oriented around the respondents' daily practices and several reminders were sent in order to increase the response rate. The answer rates seemed to be acceptable, as it was more efficient than the reported response rate of 4.7% for personalised internet surveys [12]. The samples were considered representative of the overall population, as the proportion of males and females as well as the proportions of different type of practices were not significantly different among the target populations and the respondents.

The reported level of implementation of the BSMs by the veterinary practitioners was generally good, with 8 out of the 13 BSMs being systematically implemented by more than 50% of the respondents. If this situation is comforting, it seems in conflict with the results of previous studies mentioning lower implementation rates, including in a Belgian study targeting rural practitioners [8]. These differences could be explained by the difference in the respondents' profiles (the previous study was addressed to rural practitioners only) or differences in the formulation of the questions, which might lead to different answers. It is therefore difficult to compare the outcomes of the different studies.

For most BSMs, and overall, the main reason for non-implementation was the perceived low exposure to the risk. The second most listed reason, "relevance of the measure based on the type of practice or intervention", can also be assimilated to a perceived exposure to the risk, which is considered higher or lower based on the kind of practice or intervention and determines the decision to implement a given BSM or not. This means that most veterinarians will decide to implement a given BSM on a case-by-case basis, which requires going through a systematic risk analysis. This is in line with the findings of other studies [5,6] and represents a major concern as this risk analysis is mainly based on individual perceptions and might not reflect the actual level of risk. An ecological concern appears to prevent the implementation of two BSMs: washing clothes separately and wearing disposable coats. The negative ecological impact of these BSM is perceived by the respondents as more important than the actual risk of being infected by a zoonosis. This concern should be addressed by finding some efficient, adapted and ecological friendly solutions and properly considered in any communication messages.

The HBM constructs were significantly different among the student and veterinarian populations. The fact that veterinary students had a higher perception of their health responsibility and of the overall benefits of the BSM and a lower perception of zoonoses' susceptibility and severity, as well as a lower perception of the barriers, is an interesting finding which would be worth investigating further. It might be related to personal experiences with zoonoses, as the percentage of respondents who were affected by a zoonosis in the past was higher for the practitioners compared to the veterinary students (39% and 15% respectively). Small animal practitioners and mixed practitioners had a significantly higher perception of the benefits of several BSMs: hands disinfection, asking about the country of origin and wearing masks. The lower perception of the benefits of asking about the country of origin (for rabies prevention) was lower in the rural practitioners; it can be explained by the lower risk of exposure for veterinarians not working with carnivores. For hands washing and wearing a mask, the lower perception of the measures' benefits could not be associated with any logical explanation, although it appears from the comments that several rural practitioners mentioned that wearing a mask was not well-received by farmers and that water facilities were not always available on the field. Therefore, the perceptions of the benefits for these two measures might have been lowered by these inconveniences being perceived as important and giving a "negative balance" to the benefits.

The overall biosecurity measures implementation was significantly higher for the respondents with a higher perception of susceptibility to zoonoses and of BSM benefits. This is in line with the analysis of the reasons for non-implementation of the measures, for which the majority were based on a perceived low risk of exposure, in the cases of respondents never implementing a measure, or, in cases of respondents only implementing a measure in some cases, a higher perception of risk (e.g., suspicion of a zoonosis). The implementation level was also significantly lower when the perception of the severity of the zoonoses was higher, which is surprising as we assumed that the perception of the zoonoses' severity would positively influence the behaviour implementation. Indeed, a previous meta-analysis based on vaccination examples proved "the consistent relationships between risk perceptions and behaviour" and considered risk perceptions as a key concept in different theories of health behaviour [13]. The perceptions of barriers did not have a significant influence on the studied behaviour but other studies based on the HBM identified barriers as a significant component [14,15]. This difference could be linked to what were defined as "barriers" in the different studies. In the present study, "barriers" were defined as the perceived level of control over the diseases while, in some other studies, barriers were defined as constraints, such as the cost or burden of the measure.

The main limitation of the cross-sectional studies applied to behaviour change analysis is that perceptions might also be influenced by existing behaviour (e.g., a respondent vaccinated against rabies might have a lower perception of the susceptibility to infection than a non-vaccinated respondent) [11]. This is why the best approach would be a prospective interventional study where the behaviour changes are evaluated instead of the actual behaviours and compared between a control group and a group who benefitted from interventions [11]. These kinds of experimental studies have been reviewed in a metaanalysis [16] which concluded that “the impact of risk appraisals on behaviour is moderated by efficacy appraisals”. Therefore, the risk appraisal, which includes the risk susceptibility and severity, generally has a significant effect on the behaviour change but this effect is mitigated by the efficacy approval, defined as “people’s judgment of their ability to manage a focal hazard” based on the efficacy of the possible measures or behaviours. The logic behind this finding is that, if an individual has a high perception of the efficacy of a preventive measure, they will be more likely to adopt the behaviour when their risk perception increases, and, if the individual believes they have no control over the risk (low efficacy approval), the risk perception will not affect the behaviour change.

4. Materials and Methods

4.1. Survey Design and Implementation

The data were collected in two online surveys developed with LimeSurvey, an opensource web application. One questionnaire targeted the veterinary practitioners in Wallonia (Appendix C) and the other was directed to the veterinary students of the University of Liege in the second or third years of the Master’s degree (Appendix D). The study was based on the HBM and different questions were asked to assess HBM constructs and the level of implementation of the BSMs by the respondent.

The demographic variables considered in the survey were gender, the year of education or the year of graduation, the type of practice (large animals, equine, small animals, mixed or other) and the workload. One psychological variable, “risk aversion”, was assessed indirectly by asking the respondents their degree of agreement (from 0: fully disagree to 100: fully agree) to three different statements, formulated as questions provided in the form a validated risk attitude scale [17].

The questions used to assess the five HBM constructs were formulated based on existing guidelines [18,19] and questionnaires used in previous studies [20–24]. The constructs were assessed indirectly by asking the respondents their degree of agreement (from 0: fully disagree to 100: fully agree) to different statements (Table 4), with the exception of the perceived benefits of the different BSMs, which were assessed through a direct question (Table 2). The risk of infection by a zoonotic pathogen was assessed in terms of susceptibility (perceived likelihood to occur) and severity (perceived impact of the risk if it occurs). For “benefits”, the perceived efficiency of the BSM implementation regarding the prevention of zoonoses was assessed both globally and individually for the 13 BSMs listed as good practices in veterinary medicine [25]. The “barriers” were defined as the perceived level of control the respondent had on the risk management measures and their ability to perform them. The last construct, “health responsibility”, referred to the sense of responsibility perceived by the respondent regarding their health, public health and animal health.

Table 4. List of statements used to assess the different Health Belief Model constructs by asking the respondent their degree of agreement through a visual analogue scale.

HBM Construct	Statements Used for the Indirect Assessment of the Constructs
Susceptibility	- In my view, veterinary practitioners are very frequently exposed to zoonotic infectious diseases. - In my view, zoonotic infectious diseases represent a major risk for veterinary practitioners. - As a veterinary practitioner, I could easily and unwillingly be responsible for the spread of a zoonotic disease to my relatives or to other persons. - My future professional practice represents a significant risk to my health.
Severity	- If I were to contract a major zoonotic disease, my income would be heavily impacted. - If I were to contract a major zoonotic disease, my life quality would be severely affected. - If I were to contract a major zoonotic disease, I might contaminate my relatives and other persons.
Health responsibility	- Veterinary practitioners have an important responsibility towards public health. - It is important for veterinary practitioners to respect and apply preventive and control measures while practicing in order to prevent the spread of infectious diseases. - Staying healthy is important for both my private and professional life.
Benefits	In your view, what is the efficiency of the following biosecurity measures in preventing your own possible contamination? (0: useless, 100: very effective (full protection)) - BSM0. The different preventive measures which can be taken by veterinarians. - BSM1. Disinfecting hands after each manipulation. - BSM2. Asking the owner about the country of origin of the animal in consultation. - BSM3. Protecting hands by wearing gloves adapted to the needs. - BSM4. Protecting oneself from oro-nasal contaminations by wearing a mask in case of interventions likely to cause projections (e.g., abscess puncture, wound cleaning, descaling, autopsy). - BSM5. Protecting oneself against ocular contaminations by wearing protective glasses during interventions likely to cause projections (e.g., descaling, autopsy). - BSM6. Throwing needles directly into a specific container without replacing the cap. - BSM7. Washing dirty clothing separately with a proper cleaning cycle. - BSM8. Being vaccinated against rabies. - BSM9. Ensuring proper containment in order to avoid being wounded (bites, scratches, etc.). - BSM10. In cases of wounds, proceeding to immediate cleaning with an antiseptic soap or solution. - BSM11. Keeping oneself updated on the new developments in terms of zoonosis and their prevention. - BSM12. Using a disposable coat a single time. - BSM13. Cleaning one's boots when exiting the holdings.
Barriers	- No measure is really effective; I am exposed to zoonotic infections anyway. - Due to my practices, I am able to considerably lower the risks of exposure to and contamination by a zoonotic disease. - Undertaking hygienic measures (e.g., hands, boots, etc.) is only possible if the holdings are equipped with proper cleaning infrastructures. If there are no cleaning spots on the holdings, we cannot perform these measures).

Legend: BSM: biosecurity measure.

The last component of the HBM model is "intention or action". For the veterinary students, the questions asked whether their intention would be to perform the BSM in their future practice, while for the veterinary practitioners, the questions asked if they applied the BSM in their daily practice. In both cases, the respondents were asked if the BSM would be implemented, or was implemented: always, most of the time, sometimes or never.

The question was asked for each of the 13 BSMs used to measure the "benefit" construct (Table 1). "Cues to action" are defined in the HBM model as a "stimulus necessary to trigger the decision-making process" [14]. These elements are various and could not be clearly defined prior to the survey. In order to identify the possible factors that could trigger the decision-making process, whenever a respondent stated that a BSM was not always implemented, they were asked: (i) in which specific circumstances they were implementing the BSM and (ii) the main reason for not implementing the BSM (if they perceived it to be efficient but reported not implementing it).

Before validation, the questionnaires were pre-tested by four veterinarians (two rural practitioners and two small animal practitioners) and six veterinary students, respectively. Invitations to answer the survey were sent to the students through the mailing lists of the Students' Office and to the veterinary practitioners by the Professional Union of Veterinarians in Wallonia. The questionnaire was available from 15 September 2019 to 15 May 2020, with monthly reminders sent between 26 September 2019 and April 2020.

4.2. Statistical Analysis

The data from the completed questionnaires were extracted to Microsoft Excel© and the responses given by the participants were coded in accordance with Appendix A.

The representativeness of the samples was tested with a chi-square test performed in Stata SE/14 (StataCorp, College Station, TX, USA) by comparing the proportion of men and women in both populations and, for the veterinary practitioners, the representation of the different type of practices in both groups.

4.3. Scoring of the Health Belief Model Components

The psychological variable "risk aversion" and the four HBM constructs were determined indirectly through a set of questions or items. The items to be included in the construction of the construct were confirmed with an exploratory factor analysis performed with the lavaan package in R studio© (version 3.6.1 2019-07-05) and the Cronbach's alpha coefficient (α) using the psych package in R studio© (version 3.6.1 2019-07-05). For the EFA, items with a factor loading equal or superior to 0.3 [26] were considered as important, a Cronbach's alpha coefficient equal to or above 0.7 was considered to demonstrate a good reliability and coefficients above 0.6 were considered to demonstrate an acceptable reliability [27]. For each construct, a mean score ranging from 0 to 100 was calculated after the identification of the items to be included. The scores of the reverse-worded questions in which the component was negatively formulated were recalculated to ensure uniformity across questions and facilitate the analysis (a higher score therefore always represented a higher perception of the construct measured).

The other components of the HBM, the perceived benefits and the intention or action, were assessed directly with a single question. The perceived benefits were assessed through an efficiency score ranging from 0 to 100. An overall score for the perception of benefits was also determined by calculating the average score of all the BSM benefits (13 in total). In terms of intention or action, an overall BS score was calculated and expressed as a percentage of the maximum score possible.

$$Overall\ BS\ score = \frac{\sum_{x=1}^{13} Implementation\ level\ of\ BSM(x)}{\sum_{x=1}^{13} Maximum\ score\ of\ BSM(x)} \times 100 \quad (1)$$

4.4. Negative Binomial Regression Models

In order to identify the main determinants of the adoption of BSMs, different multivariable regression models were used in order to assess: (i) the influence of the different demographic and psychological variables (explanatory variables) on each of the HBM constructs (outcomes) and (ii) the influence of the different HBM constructs (explanatory variables) on the "intention or action" (outcome). The HBM constructs and the "BS score" were considered as a count ranging from 0 to 100. A Poisson regression was therefore used initially but the goodness of fit of the Poisson regression appeared insufficient due to extra-binomial variability. A negative binomial regression was therefore used for the different analyses.

Prior to the model testing, possible correlations between the exploratory variables to be used were tested using a Spearman rank correlation test for the continuous variables and a Kruskal–Wallis H Test for comparisons between continuous and categorical variables. At first, univariable negative binomial regressions were implemented to assess the possible effect of the explanatory variables on the outcome variable. All the explanatory variables for which a significant difference was identified (p-value < 0.1, in order to be more conservative) were included in the multivariable negative binomial regression model. A backwards stepwise procedure was then applied in Stata SE/14 (StataCorp LP, College Station, TX, USA). The model was progressively simplified by removing the less significant variables with a p-value > 0.05 one by one. The model was considered as final when all variables had a significant p-value (<0.05), or when no further simplification was possible without having a significant difference between the most complex and the simpler model (likelihood ratio test with a p-value < 0.05).

5. Conclusions

Based on the findings of this study, it appears that the main factors that can positively influence the actual implementation of BSMs are the perception of the risk susceptibility and the perception of the BSM benefits or their relevance. In order to facilitate this implementation it would be necessary to deploy a different kind of evidence-based study, which could support the different communication message and convince the veterinarians of the relevance and efficacy of the measure. Nevertheless, due to the complexity of the interrelations between the different beliefs, perceptions and the behaviours and their specificity to a given context, the outcomes of this study should not be generalised to other countries and might change over time based on the national context. Prospective and observational studies assessing the evolution and duration of all these elements over time might help better predict and influence behaviours in a broader context, as well as increase the efficiency of the awareness raising campaigns.

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Chap. 4 - Discussion and Perspectives

Representativity and studies biases

Most of the surveys implemented as part of this thesis were done on-line with the link made available through the mailing list of professional associations. This survey methodology presents the risk of volunteer bias as “the participants volunteering to take part in a study intrinsically have different characteristics from the general population of interest” (Brassey et al., 2017). In order to assess and limit this bias, several reminders were sent in order to increase the answer rate and, whenever possible, the representativity of the different samples were compared to the overall target population of the survey. These comparisons showed no significant differences. Another limitation of the studies is due to a possible social desirability bias and an information bias as the behaviours are mainly self-reported and not based on actual observations. To reduce these biases, the information message at the beginning of the surveys guaranteed the anonymity of the respondent and several reminders were sent in order to increase the response rate. The answer rates of the different surveys conducted seem to be acceptable as they are similar to the average reported response rate of 4.7% for personalised internet survey (Sinclair et al., 2012). The questions were focused on daily practices and, for the face-to face-interview, the data collector clearly informed the respondents that this survey was not part on any control program but based on a desire to better understand their actual practices and field constraints. The percentage of mandatory measures reported as not implemented by the respondents are in favour of a majority of responses reflecting the reality. As an example, 30% of the farmers mentioned not respecting the mandatory abortion notification, which seems in line with the ARSIA report mentioning that 22% of the farmers did not report any abortion in their herd over the last 3 years (ARSIA, 2020). In addition, some triangulation of the reported behaviours was performed by two mechanisms. A farm visit was organised after the face-to-face interviews (study 2) to observe some of the reported facilities and practices (e.g. existence of calving pens, separated stables, quarantine area, litter hygiene, and footbaths). The second mechanism consisted in comparing some behaviours reported by the farmers in the study 2 and the veterinarian in study 6 such as the veterinarians’ hygiene practices when entering and exiting a farm. The results were therefore triangulated between surveys and the reported trends were similar.

Belgian cattle farming

Belgium agriculture has been in crisis for several years with reported imported products often pricing lower than fair market value than local products in most supermarkets. In the current globalized market, Belgian local producers are competing with foreign producers who have lower production costs and less quality assurance and control regulations. Often time this forces Belgian producers to sell products and sub-products of animal origin at less than fair market value. For example, in 2017, Belgian locally produced milk price was 0.29 €, while the production costs were estimated at 0.46 € per litre (Olbrich, 2017). The beef market is not favourable either to European cattle farmers with a reported marginal profit and a decreasing ratio between the meat value and the input costs (Hocquette *et al.*, 2018). This little to no profit margin agricultural crisis cycle need to be considered when developing production regulation and policy that ensure a good quality of animal food and food products to answer the consumers' demand and the public health challenges.

A survey (study 2) found that Belgian cattle farmers recognize the importance and benefit of biosecurity and preventive measures in comparison to mitigation and crisis management. Most farmers interviewed considered their biosecurity level as satisfactory. Nevertheless, the overall implementation level of BSM in farms remains low and challenging Farmers expressed several constraints. Study 2 identified the measure feasibility (26%), a relevance perceived as low in the actual context (19%) or an efficacy perceived as poor (19%) as the main reasons for not implementing a specific BSM. The study on determining factors (study 3) also identified the perceived benefits of BSM as one the main factors determining their implementation. As documented by several researchers (Moore *et al.*, 2008; Brennan and Christley, 2012), the variations and contradictions in biosecurity recommendations and regulation by the different actors and ,regulation bodies coupled to a lack of easy access to publication of these regulations, makes it difficult for farmers to be in compliance. The Belgian farming context does not make an exception as several farmers mentioned receiving contradictory information from agents of the same authority. A lack of consensus on the importance and/or priority of BSM to be implemented also prevails among rural veterinarians. Another example of the impact of confusing and contradictory information is also illustrated by a 2014-study which highlighted several contradictions in the epidemiological surveillance system in Belgium. Indeed, an exhaustive list of infectious animal and zoonotic diseases is lacking, and there are differences between the list of diseases effectively monitored and the diseases which should be monitored, based on advises of the FASFC scientific committee or documented cost-benefits analysis (Cardoen *et al.*, 2014). The actual level of information of animal health professionals in Belgium is not sufficient to provide a uniformed and proper level of information to cattle farmers. For example, unlike for pig and poultry intensive farming, there is no official website or overall legislation mentioning an exhaustive list of mandatory measures that farmers should implement in their cattle farm. Mandatory measures are only mentioned in some disease specific laws and ministerial or royal decrees such as the royal decree related to foot and mouth disease (Royal Decree, 2005). The same issues have been raised by an analysis performed on the EU legislative framework on animal health which highlighted (European Comission, 2013):

- The lack of clear links with other legislations such as public health, food safety and environmental protection and lack consistency among the different animal health legislations
- The lack of overall strategy and need to focus on increased biosecurity
- The lack of horizontal law with the obligations being spelled out in different legal acts

As mentioned in previous studies (Moore *et al.*, 2008; Brennan and Christley, 2012) and confirmed by study 2 and 3 , it is necessary to clarify the priority diseases to be targeted by surveillance and control programs. It is also essential to identify the priority BSM recommended for animal health professionals in order to harmonise and uniform communication to cattle farmers. Ideally, such clarification and harmonisation should be done through a participatory process including animal health experts, as well as cattle farmers, to ensure the acceptability of recommendations.

The new European Union animal health law provide a legal framework to biosecurity actions and measures (European Union, 2016). It emphasize that “biosecurity is a key prevention tool” and clarifies that “the biosecurity measures adopted should be sufficiently flexible, suit the type of production and the species or categories of animals involved and take account of the local circumstances and technical developments”. Nevertheless, this text does not provide any specific recommendation in terms of biosecurity measures to be prioritized and/or be made mandatory. Unfortunately defines biosecurity as “the sum of management and physical measures designed to reduce the risk of the introduction, development and spread of diseases to, from and within animal population or an establishment, zone, compartment, means of transport or any other facilities, premises or location” which does not reflect the importance of public and environmental health and might lead to the omission of these important aspects in any future document or policy.

Priority diseases and biosecurity measures for the Belgian cattle farming sector

As shown by study 2 and 3, as well as through previous sociological studies, the reasons for the low adoption of recommended BSM might come from the difference of perspective and objectives prevailing between authorities, veterinarians and cattle farmers (Nöremark, Frössling and Lewerin, 2010; Sayers, Good and Sayers, 2014). These differences often lead to a perception of insufficient or inadequate biosecurity policies (Gunn *et al.*, 2008). Due to the difference of objectives in communication messages, cattle farmers might not be interested by communication and will therefore not seek additional information. Study 1 showed major differences between the priority diseases listed by the OIE, the priority zoonosis listed by ECDC and/or the priority diseases listed by the Belgian authorities, and some of the most frequent diseases encountered in cattle farms (on-line veterinary survey). The latter are more likely to be the farmers’ priority but were not always listed in the previous prioritization studies (e.g. multifactorial diseases such as mastitis, interdigital dermatitis and diarrhoea). When considering the six priority diseases for Belgian authorities and cattle farmers (study 1), it appears that their transmission pathways (based on the diseases typology) illustrate all possible pathways. Their related BSM will therefore include all BSM. Therefore, trying to emphasize the BSM related to these six diseases will not permit the prioritization of any BSM. Althought this is negative finding, this could encourage the sanitary authorities to improve prevention efforts of potential introduction and spread of other notifiable diseases important to the national or international animal and public health authorities but not considered as a priority by the cattle farmers. Indeed, the adoption of new practices by the cattle farmers could be increased if the sensitization messages are focusing on the BSM aimed at controlling diseases considered as important by cattle farmers. Therefore, despite the different disease control objectives, animal health authorities and cattle farmers could reach to an agreement on the determination of priority BSM. A table designed thanks to the literature review shows which diseases are addressed by each BSM (Appendix 2). It is an operational tool which can facilitate easy identification of BSM in order to timely and effectively control and prevent targeted diseases.

The benefits or outcomes of BSM are the most important elements to consider in any effort to motivate farmers be uptake recommendations(Study 3). Farmers identified these factors according to 10 out of 14 studies reviewed that examined factors associated with implementation of BSM . Although labelled differently, e.g. benefits, perceived importance, attitude towards BSM or positive outcome of behaviour, 'benefits' should be considered more as a ratio rather than an absolute number. Indeed, the perceived 'benefits' of a BSM will be high when its perceived positive outcomes are considered higher than perceived constraints or related costs. The positive outcomes could be related to herd health and productivity as well as to public health, environmental health or animal welfare. Indeed, the general public have shown more interests in cattle farming and their health responsibility as shown in study 3 and other studies (Gauly *et al.*, 2013; Toma *et al.*, 2013; Hocquette *et al.*, 2018; Denis-Robichaud *et al.*, 2019).

The benefits could also be measured in terms of cattle farmers' resilience to infectious diseases. Proper knowledge of the actual level of implementation and the possible improvements to be adopted in case of outbreaks could help mitigate different disease outbreaks and increase the capacity of the farmer to mitigate the impact of disease outbreaks in the country or surroundings either by preventing the contamination of his herd or by better containing the disease. Studying the effect of different BSM implementation resilience towards infectious diseases could effectively convince them to adapt their behaviour based on risk levels.

As mentioned by some cattle holders during the field interviews, "no *BSM is too costly as long as it is useful and effective. It depends of the positive economic impact of the measure*". This highlights the need for evidence-based and cost-effectiveness studies, as mentioned also in previous studies (Garforth *et al.*, 2006; Rehman *et al.*, 2007; Brennan *et al.*, 2016) and the recognised lack of knowledge to identify worthwhile BSM to recommend (Sanderson, Dargatz and Garry, 2000). Most studies recommending biosecurity practices do not provide strong evidence of their efficacy or cost-effectiveness. Besides, the existing studies on disease cost-efficiency usually target a single practice or focus on the prevention of specific diseases (Brennan and Christley, 2012). Study 5 is specific to the CCPP vaccination but provides a methodology to estimate the benefits in terms of overall herd productivity. It was tested in study 6, on a small sample of farms, as a possible way to estimate the overall benefits of a higher biosecurity. It showed interesting results, as a higher biosecurity level was significantly correlated with a BVD free-status, a lower mortality rate in adult cattle (over 24 months) and young calves (0-7 days). With strong evidence, reproduced on a larger scale with additional steps to convert cattle heads preserved or gained (through higher reproductive parameters) in farms with high biosecurity levels could bring the needed evidence and support the communications by providing clear cost-effectiveness evidence.

Guidance and technical advices to cattle farmers

With reported multiple and sometimes conflicting recommendations, it is necessary to improve the technical guidance offered to cattle farmers in terms of biosecurity. In the absence of evidence-based cost-effectiveness analysis, the farmers might be tempted to adopt BSM easy to implement while they are not always the most effective or relevant in their case (Moore *et al.*, 2008). There is a need for a standardized and improved communication among animal health authorities and the different providers of animal health services to prevent any further confusion of farmers and harmonise the message (Sayers, Good and Sayers, 2014). The cattle farmers' level of trust towards national authorities and control instances is described as low in many studies and thus needs to be improved (Heffernan *et al.*, 2008b; Moya *et al.*, 2019) for proper adhesion of farmers to disease control programs and legislations. It also appears from several studies that the recommendations should be provided on a case by case basis, considering the specific farm environment and context in order to better address the farmers' priorities.

The role of veterinarians in providing such advises is essential as they are considered as the main references for biosecurity as well as a trustful source on information (Rehman *et al.*, 2007; Heffernan *et al.*, 2008a; Brennan and Christley, 2013; Garforth, 2015; Moya *et al.*, 2019). Nevertheless, as mentioned in the introduction, it requires a shift from rural veterinary practitioners, which is not easy for several reasons including the unproven efficacy of BSM, the absence of common understanding and agreement on the key recommendations, and inadequate biosecurity public policies (Gunn *et al.*, 2008). Study 6 showed that most veterinarians do consider biosecurity as a priority (88%), but less than 50% have attended continuous trainings on biosecurity and/or got informed on the topic by personal readings. In addition, among the things to improve, the study highlighted the need for technical advices on biosecurity. For example, the recommendation regarding animal purchase, is often restricted to the mandatory test and does not include other important diseases in the Belgian context such as Mortellaro disease or mastitis.

Resources on relationship between the different BSM and infectious diseases can be useful to rural veterinarians (Appendix 2). It is also the case for the chapter 14 of the book on biosecurity in animal producer and veterinary medicine entitled, Transmission of cattle diseases and biosecurity in cattle farm" (Sarrazin *et al.*, 2018). Nevertheless, these tools are not sufficient. As part of the BOBIOSEC project funded by the Federal Public Service (FPS) Health, Food Chain Safety and Environment, an on-line risk-based scoring system to quantify biosecurity in cattle production was jointly developed[5] by the University of Liège and the University of Ghent: Biocheck cattle (Damiaans *et al.*, 2020). More specifically, the Biocheck cattle relies on a questionnaire that was developed based on the outcomes of Study 2. That study identified the BSM to be included in the scoring systems, but also the measures to be exclude, in order to shorten the questionnaire (e.g. questions without a clear score, questions correlated within a same category or questions with less than 15% variation in the application and not stressed by multiple sources in the literature review). All BSM categories and sub-categories were weighted, based on experts' opinion, in order to elaborate a risk-based scoring system accessible to all farmers and veterinarians, free of charge. After completing the survey, the user obtains an overall biosecurity score and scores per category; that score can be compared to the average score of her/his country. Charged additional functions are provided by the system such as personalized and automatically generated feedback, continuous monitoring of the farm BS level with downloadable reports, comparisons and sharing as well as on-line training. The basic Biocheck application, free of charge, allows the user to identify weaknesses and the main areas of improvements. It also provide a benmarking system that permit the camparison of their situate to her/his peers. Such aspects could promote the adoption of new BSM by cattle farmers and help the veterinary users to perform a standardized and reproductible risk assessment with personalized recommendations. Nevertheless, the system still has some limitations. The weighting system remains subjective, as it is based on experts' opinion, but it is also a general weight provided while the weights usually depend of the targeted diseases. That could be a major bias for farmers who have a disease specific-objective. The list of BSM used in the questionnaire was reduced, but is still quite extensive as it includes between 69 and 214 questions, depending on the type of farm (veal, beef or dairy). This takes time to complete and can deter its use , especially if assessments need to be repeated over time.

Other tools in relation with biosecurity were developed in different countries; they might be of interest in Belgium, if we consider the findings of studies 2 and 3 that highlighted the farmers' interest for specific and technical guidance to achieve personal animal health objectives. Veterinary herd health management is becoming increasingly important but needs to be based on the farmers' main goal and a cooperative strategy, defined commonly with the farmer, to ensure the implementation of recommendations and a long-term success (Derks *et al.*, 2013). In Australia, for example, a smartphone application was developed to help farmers to develop their own biosecurity plan (https://www.farmbiosecurity.com.au/toolkit/farmbiosecurity-app/): they can select different actions in a list of suggested BSM and monitor their progress. Such tools are interesting and should be looked into more details to better promote biosecurity in cattle farms.

[5] On-line website for the Biocheck: https://biocheck.ugent.be/fr

Other biosecurity stakeholders who should be considered and sensitized

Professional visitors (e.g., veterinarians and artificial inseminators) represent another group of key stakeholders in biosecurity risk, as highlighted by several studies. Study 2 highlighted the fact that who farmers are aware of this risk but d do not act on it, it is due the fact they place trust the professionalism of the visitor or they do not feel in position to impose restrictive measures upon them as they do need their services (for cattle salesmen). In the actual Belgian context, it is clear that the risk of introduction of infectious diseases in a farm by professional visitors is high, as cattle farmers perceive it, either lack of responsibility or control over the visitors action. Study 6 shows that if rural veterinarians consider they properly manage the risk of disease introduction in the farms they visit, there is still a large room of improvement as they tend to overestimate their implementation of bio-exclusion and bio-containment measures. It appears from the studies 2 and 6 that the misunderstanding between the veterinarians and cattle farmers goes beyond the animal health objectives discussed above, but also relies in their shared responsibility to ensure a correct bio-exclusion. When considering, for example, the poor implementation of hygienic measures upon entering the farms (e.g. cleaning boots and changing clothes), most veterinarians mention the absence of cleaning facilities in the farm as well as the farmers' responsibility to provide farm-specific clothing while farmers consider it is the veterinarian's professional responsibility. There is a need of a better communication between veterinarians and farmers to clearly understand the respective expectations and agree on a common way forward, as solutions are applied by some farmers (farm-dedicated clothing) or veterinarians (own mobile disinfection unit). Cattle farmers should also be empowered and feel in position to impose restrictive measures to visitors without any negative repercussion.

The attitude and beliefs of other professional visitors should be study as well, in order to better identify the risks and possible mitigation measures to be established. Among them, cattle salesmen represent a major risk as according to the farmers survey, most of them do not take specific hygiene measures and, as it is the case for veterinarians, cattle farmers are reluctant to condition their access to the stables as they depend on them. A survey aimed at determining level of awareness regarding biosecurity and BSM among other professionals working with famers' would strengthen the biosecurity levels in cattle farms.

Perspectives and recommendations to improve biosecurity in Belgian cattle farms

According to the different studies implemented in Belgium, several factors negatively affect the implementation of BSM in cattle farms (Figure 18). These factors are either linked to the farmer's characteristics, attitudes and beliefs, the farming context and the administrative and legal context. Based on this analysis, several recommendations can be made to the different actors in order to improve the biosecurity level in cattle farms.

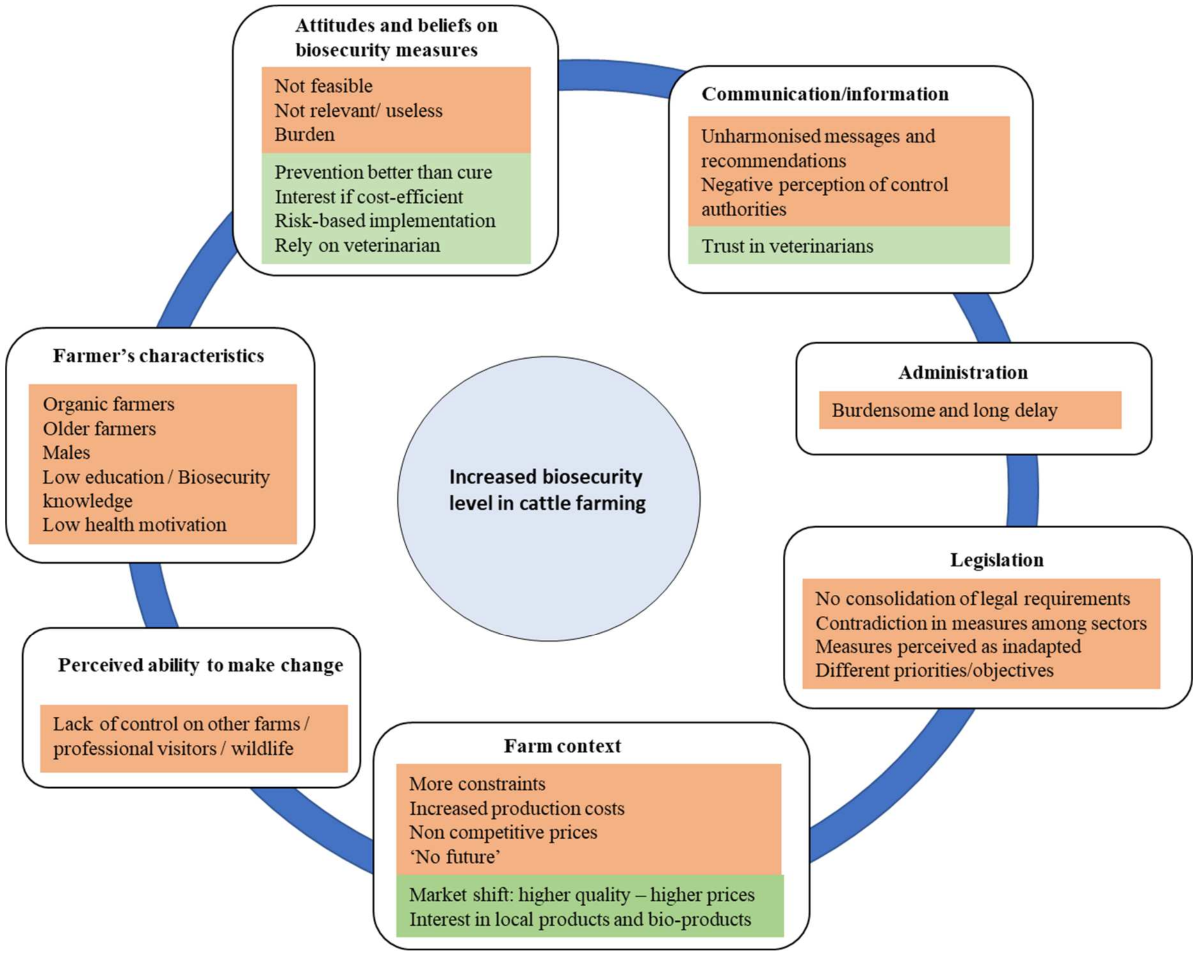

Figure 18 – Proposed conceptual model explaining factors affecting the implementation of biosecurity measures in Belgian cattle farms. In orange, factors affecting negatively; in green, factors affecting positively

In terms of research, there is an urgent need for evidence-based cost-efficiency studies to identify the priority BSM and to convince the farmers of their cost-efficiency. As mentioned previously, the actual knowledge does not allow the identification of worthwhile BSM and leads to a general confusion as different actors will recommend different measures (Moore *et al.*, 2008). It appears from previous studies that even the veterinarians, considered as the main informants on technical guidance, have mentioned the lack of information on BSM efficiency. This finding was confirmed through the exchanges with cattle farmers during study 1, as many of them reporting receiving contradictory information from the different entities (e.g. FASFC agents vs. veterinarians). In addition, the absence of a common goal and objective among the national authorities adds to the cattle famers negative perception towards the national control and eradication programs, often considered as irrelevant (Moore *et al.*, 2008; Derks *et al.*, 2013; Cardoen *et al.*, 2014; Sayers, Good and Sayers, 2014). Based on the Transtheoretical Model of Behaviour Change, any information considered as irrelevant or not answering a specific need of the recipient will not be processed and used. In order for any communication to be effective in changing behaviour, it should raise the interest of the target group by answering their needs.

To ensure the adequacy of the recommended national control and eradication programs and mandatory BSM, a proper analysis should be performed by a group gathering experts from different sectors, including cattle farmers, in order to identify jointly the priorities to be addressed and related BSM. It is indeed essential to agree on common objectives in terms of animal, public and environmental health. If not, the measures will be perceived as irrelevant or not important by cattle farmers or might end up in contradiction with recommended measures from other sectors. The identified measures should be relevant to needs of cattle farmers, acceptable, feasible and shared with other sectors in order to avoid possible contradictions (e.g. need to remove bushes and vegetation for vector control while environmental rules promote natural hedges and, in some areas, forbid vegetation clearing). As for the One Health approach, BSM should be considered in a holistic approach and, as suggested by a recent study, as “a unified concept to integrate human, animal, plant and environmental health” (Hulme, 2020). Negative impact of some preventive treatments on the environment or human health have been documented in the past. Some examples are: the development of (multi)drug resistance linked to the preventive use of antibiotics in some intensive farming system (Robinson *et al.*, 2016), the contamination of the environment related to treatments of animals with acaricides (Santos *et al.*, 2018) and the negative effects on beneficial insects consecutive to the use of chemical larvicides in the control of vector breeding sites (Milam, Farris and Wilhide, 2000). Such negative impacts could be avoided in the future, showing the importance of having a One Health approach and build interconnections among health, agriculture and environmental sectors and considering the natural and social sciences which can facilitate the adoption of BSM by the population (Hulme, 2020). These aspects are clearly taken into consideration by the European green deal which policy areas include, among other things, biodiversity (measures to protect the ecosystem) and food safety under the terminology “from farm to fork”.

The identification of common goals and objectives through a participatory and intersectoral approach should also help farmers to regain some trust towards national control authorities. Indeed, it seems to be an issue. It is also essential to define the roles and responsibilities of the different stakeholders in order to improve the farmers’ perception of their health responsibility and their ability to make change.

Effective training and communication to farmers should be implemented by trustful sources such as veterinary practitioners or farmers’ associations, in order to promote biosecurity and the major BSM. Such communications should focus on the factors determining the implementation of BSM, which were identified as: BSM benefits and cost-effectiveness, as well as responsibility of cattle farmers towards animal, public and environmental health. Special attention should be brought to organic farmers, as their perception of BSM benefits and health motivation are lower, while these two constructs are key factors determining the implementation of BSM. The development of on-line and mobile applications for farmers to perform self-evaluations and get personalised feedback on biosecurity are also of major interest and should be promoted as the actual tool, Biocheck cattle, is promising but has several constraints and limitations. As demonstrated by studies 6 and 7, as well as other studies, the shift from curative to preventive medicine implies a repositioning of the rural veterinarian and a much needed different approach that is currently not in place. If more consultants and private counsellors provide paid herd management and biosecurity advices, veterinarians still perceive that farmers are reluctant to pay for such services. Furthermore, even if these services are provided free to charge, the investment in time and resources for such advices should be considered . There is an urgent need to change the rural veterinarians' and cattle farmers' perceptions on that issue in order to pursue the shift from curative to preventive medicine. Indeed, most biosecurity advices provided by the veterinarians are still an answer to animal health problems reported on the farm and/or restricted to mandatory measures.

In addition, two major macro challenges remain and will have an important impact on the farmers' behaviour regarding BSM. The actual farming context is not favourable for cattle farmers as imported animal products and sub-products coming from countries with lower production costs and constraints compete with local products. Nevertheless, the shift in the consumers' profile, with an increasing demand in local products and an apparent willingness to purchase quality products at higher prices, is encouraging and might change the negative opinion on the future of cattle farming. National and international initiatives supporting local product consumptions and promoting a fair price to the producers should be encouraged. The last challenge is the apparent lack of control of farmers on some bio-exclusion measures as no measure seems to be totally efficient in preventing interactions of cattle with wildlife and cattle farmers perceive as difficult the control the professional visitors. Regular monitoring and surveillance programs should be implemented to mitigate the risk of disease introduction through wildlife as the environmental and demographic changes will certainly increase contacts between domestic animals and wildlife in the future. Furthermore professional visitors have a professional responsibility to prevent any disease transmission and should be targeted in future research and interventions. The situation is most likely similar or even worse with other professional visitors such as the cattle salesmen, feed suppliers, etc. Further studies should be implemented to clearly identify the risk related to each professional visitor as well as different workshops and training in order to make them aware of biosecurity issues and the risk they represent. Such workshops and training should be the responsibility of the national authorities or farmers' associations.

Conclusion

As illustrated by the current COVID-19 pandemic caused by zoonic transmission, the interest for biosecurity has increased over the years, and its concept is becoming more important due to the multiple threats and increased risk related to the demographic changes, environmental changes, globalization and increased international exchanges and travels. Biosecurity level can be been strengthened in the Belgian intensive production systems (e.g. pig and poultry industry), with clear mandatory measures and recommendations integrated in a common legislative document. Biosecurity level improvement will require the different stakeholders to take actions as recommended above and a clear legal framework providing the list of obligations and recommendations in terms of biosecurity in cattle farms. Further, obtaining strong evidences demonstrating BSM cost-efficiency and to identify the priority BSM to recommend can convince the stakeholders of their utility and benefits. These above measures outlined should also be implemented in order to serve as a basis for the decision making of the different actors.

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Appendixes

Appendix 1- Overview of the transmission pathways for cattle diseases of relevance to Belgium (from Sarrazin *et al.*, 2018)

Disease	Species affected and asymptomatic carriers				Direct contact			Indirect contact													References
	Zoonotic	Other reservoirs	Asymptomatic carriers	Wild reservoirs	Animal to animal	Transplacental	Venereal	General	People	Animals (other than rodents)	Rodents	Fomites	Syringes/needles	Ingestion: Feed	Ingestion: Water	Inhalation: General	Inhalation: Droplet	Inhalation: Aerosol	Soil/Manure	Arthropod Vector	
Anaplasmosis		Mammals, birds	X	X		X		X					X							X	[1-4]
Anthrax	X	Mammals, birds	X		X			X				X		X	X	X			X	X	[5, 6]
Aujeszky's Disease		Pigs, sheep, dogs, cats, rodents, etc	X	X	X	X	X	X				X			X	X		X	X		[4, 7]
Babesiosis (bovine)	X	Buffalos, deer	X	X																X	[4]
Bluetongue		Ruminants, carnivores	X	X	X	X	X	X					X							X	[4, 7, 8]
Botulism	X	Most animals	X	X	X			X	X	X	X	X	X	X	X	X		X	X		[9-19]
Bovine enzootic leukosis			X		X	X		X					X							X	[20-23]
Bovine herpesvirus 4 associated disease		Ruminants	X				X							X	X	X					[24]
Bovine respiratory disease[6]		Ruminants	X	X	X			X	X	X	X	X		X	X	X	X	X			[25-123]
Bovine spongiform encephalopathy	X	Sheep, goats	X	X		X								X							[4, 7, 124, 125]
Bovine viral diarrhoea			X		X	X	X	X	X	X	X	X		X		X		X	X		[48, 65, 126-137]
Brucellosis	X	Ruminants, pigs, dogs, rodents, etc	X	X	X	X	X							X	X	X			X		[4, 7, 138-144]
Campylobacteriosis	X	Vertebrates	X	X	X		X	X				X		X	X				X		[4, 8]
Coccidiosis			X		X			X	X		X	X		X	X				X		[145-160]
Cryptosporidiosis	X	Mammals	X	X	X			X	X	X	X	X		X	X				X		[148, 150, 161-176]

[6] The bovine respiratory disease complex includes the bovine respiratory syncytial virus, parainfluenza virus 3, *Mannheimia haemolytica, Pasteurella multocida, Histophilus somni and Mycoplasma bovis.*

Disease	Species affected and asymptomatic carriers				Direct contact			Indirect contact													References
	Zoonotic	Other reservoirs	Asymptomatic carriers	Wild reservoirs	Animal to animal	Transplacental	Venereal	General	People	Animals (other than rodents)	Rodents	Fomites	Syringes/needles	Ingestion		Inhalation			Soil/Manure	Arthropod Vector	
														Feed	Water	General	Droplet	Aerosol			
Cysticercosis	X		X	X										X	X						[4, 177, 178]
Dermatophytosis	X	Mammals, birds	X	X	X			X				X								X	[4, 179]
Diarrhoea / enteritis (coronavirus, rotavirus, *E. coli*)	X	Mammals	X	X	X			X	X	X	X	X		X	X				X		[56, 59, 66, 67, 161, 165, 167, 170, 176, 180-199]
Distomatosis	X	Ruminants	X	X										X							[21, 200, 201]
*E. coli (*verotoxic)	X	Mammals			X			X	X	X	X	X		X	X				X		[202-212]
Echinococcosis	X	Mammals, birds	X	X										X	X						[4, 213, 214]
Enterotoxemia (*Clostridium* spp.)		Humans	X	X	X			X	X	X	X	X		X	X				X		[215-225]
Foot and Mouth Disease		Cloven-hooved livestock, wildlife	X	X	X			X	X	X	X	X	X	X		X		X			[4, 226-232]
Giardiasis	X	Mammals	X	X	X			X	X	X	X	X		X	X				X		[168, 173, 233]
Infectious bovine keratoconjunctivitis			X		X			X	X	X		X								x	[234-244]
Infectious bovine rhinotracheitis (IBR)			X		X	X	X	X	X			X				X		X			[48, 65, 68, 120, 245-268]
(Inter)digital infections		All			X			X											X		[21]
Intestinal parasitism	X	Ruminants	X	X				X	X	X		X		X	X				X	x	[269-291]
Leptospirosis	X	Mammals			X		X	X				X		X	X	X			X		[4, 292]
Pediculosis and ectoparasitism	X				X			X		X	X	X									[293-308]
Listeriosis	X	Mammals, birds	X	X	X	X		X	X	X	X	X		X							[309-333]
(Sub)clinical mastitis	X		X		X			X	X			X				X		X	X		[21, 334-338]
Metritis: trichomoniasis (T) + chlamydiosis(C)					T		T+C	T						C	C	C					[8, 339-342]
Necrobacillosis (laryngitis)			X		X			X				X									[343-361]
Neosporosis	X	Mammals	X			X								X	X						[362-366]

Disease	Species affected and asymptomatic carriers				Direct contact			Indirect contact														References
	Zoonotic	Other reservoirs	Asymptomatic carriers	Wild reservoirs	Animal to animal	Transplacental	Venereal	General	People	Animals (other than rodents)	Rodents	Fomites	Syringes/needles	Ingestion		Inhalation			Soil/Manure	Arthropod Vector	
														Feed	Water	General	Droplet	Aerosol			
Papillomatosis			X		X	X		X				X								X	[8, 21, 367-369]
Paratuberculosis		Mammals	X	X		X	X					X		X	X						[4, 370-374]
Q Fever / Coxiellosis	X	Vertebrates	X	X	X	X	X	X				X		X	X	X			X		[4, 375-377]
Rabies	X	Mammals		X	X			X		X		X	X	X	X						[378-393]
Salmonellosis	X		X	X	X			X	X	X	X	X		X	X	X		x	X		[161, 394-410]
Scabies					X			X				X									[411-425]
Schmallenberg disease		Ruminants	X	X		X	X													X	[8, 426-430]
Tuberculosis (bovine)	X	Mammals	X	X		X		X				X		X	X	X	X		X		[4, 431, 432]

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Appendix 2 – List of cattle diseases and the biosecurity measures efficient to prevent their introduction or spread

DISEASE CODE	Tot.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
BIOSECURITY MEASURES																																																
1. Related to animal movements																																																
Closed herd / No movements	27	1			1		1	1		1						1		1	1	1	1			1		1	1			1		1	1	1	1	1	1		1	1	1		1			1	1	1
No taking part in cattle exhibitions	18	1			1		1	1		1									1							1	1			1		1	1	1	1	1	1		1	1	1							
All in/all out system of each age group and each separate stable	22	1			1		1	1		1									1	1						1	1			1		1	1	1	1	1	1		1	1	1		1				1	1
Ensuring free source or origin / no importation of infected animals	29	1	1		1		1	1	1	1		1				1		1	1	1	1			1		1	1			1		1	1		1	1	1		1	1	1		1			1	1	1
Pre movement testing (against specific diseases)	26	1	1		1		1	1		1						1		1	1	1	1			1		1	1			1		1	1		1	1			1	1	1		1			1	1	1
Quarantine (3 weeks, separate area or building (3m distances) and testing for entering or re-entering animals	29	1	1	1	1	1	1	1		1		1						1	1		1			1		1	1			1		1	1		1	1	1		1	1	1	1	1			1	1	1
Testing for entering or re-entering animals	24	1	1		1		1	1		1		1						1	1					1		1	1			1		1	1		1	1			1	1	1		1			1	1	1
Separate area or building (3m distances) for quarantine	26	1		1	1		1	1		1								1	1		1			1		1	1			1		1	1	1	1	1	1		1	1	1		1			1	1	1
Reducing commingling when purchasing	19	1		1	1		1	1		1									1	1	1					1	1			1		1	1	1		1		1		1							1	
Divide calves in high and low risk groups based on veal calves risk classification	11				1		1											1		1						1				1		1	1	1						1							1	
Good transport conditions, safely, in a clean truck, decent loading ramp, no overcrowding, calm handling, as short as possible, not passing through a sorting center	20	1			1		1			1					1				1	1										1		1	1	1	1	1		1	1	1			1	1			1	1
2. Related to vertical or venereal transmissions																																																
No breeding animals shared with other farms	11						1	1		1	1							1			1					1	1			1			1							1								
Check semen status before insemination	4						1			1								1								1																						
Artificial insemination	8						1			1	1							1			1					1							1							1								
3. Prophylactic measures																																																
Vaccination	12						1												1								1				1	1	1			1	1	1		1	1					1		
Deworming strategies	3													1		1																										1						
Preventive treatments	10		1			1															1						1					1			1	1			1		1		1					
Regular hoof trimming by professionals (twice/ year)	1																			1																												
Regular foot bathing	1																			1																												
4. Vector control: prevent introduction of contaminated vectors / environment contamination																																																
Ticks control	6		1			1						1						1				1					1																					
Mosquitoes / biting flies control	9		1				1											1							1			1	1												1		1					1
Identification of contaminated soils/ pastures and prevent their usage	2			1										1																																		
Rodents control program	7																				1						1					1			1				1					1			1	
Destroy snail habitats / prevent access to snail habitats	1															1																																
5. Prevent direct contact with eventual external shedders/carriers																																																
Prevent contact in pastures with animals of neighbouring farms and wildlife (pigs and ruminants) (simple or doubles fences)	24		1		1	1		1		1									1		1					1				1		1	1	1	1	1	1		1	1	1	1	1	1		1	1	1
Closed housing / locked doors (prevent contact with pets, carnivores, rodents,… in stables)	18									1							1				1			1		1				1		1	1	1	1	1	1		1	1		1		1		1	1	
Proper carcass disposal, avoid exposure to scavengers	7			1						1							1		1					1							1										1							
Prevent dispersion of biological fluids during sample collection	6			1			1			1		1						1	1																													
6. Prevent contamination of food and water from external shedders/carriers																																																
Storage of food in clean and closed structures to prevent their contamination	14				1				1	1			1	1			1				1			1		1					1	1					1							1			1	
Clean water and feed troughs regularly	19							1		1				1			1				1					1				1	1	1	1	1	1	1	1		1	1		1		1			1	
No access to surface water/ Prevent access to running or stagnant water in pastures	9													1		1	1				1			1		1					1			1													1	
Equipment for handling of manure should not be used for feed	12																				1					1						1	1	1	1	1	1		1	1		1					1	
Cleaning and disinfection of feeding utensils	18									1				1			1				1			1		1				1		1	1	1	1	1	1		1	1		1		1			1	
Identification and proper disposal of contaminated feed	9			1	1				1				1	1			1									1					1													1				

DISEASE CODE	Tot.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
7. Prevent contamination by visitors																																																
Access restriction for visitors + Visitors control and register	19	1			1					1								1	1								1			1		1	1	1	1	1	1		1	1			1	1			1	1
In-house or clean boots and clothes for visitors (availed by farmer)	21	1			1					1									1						1		1		1	1		1	1	1	1	1	1		1	1		1	1	1			1	1
Personal working hygiene of professional visitors (hands hygiene, visitor own boots/clothes, etc)	22	1						1		1				1					1						1		1		1	1		1	1	1	1	1	1		1	1		1	1	1			1	1
Usage of disinfection footbath	21	1						1		1									1						1		1		1	1		1	1	1	1	1	1		1	1		1	1	1			1	1
Deny access to stables to cattle salesmen	6	1						1		1									1								1			1																		
Vehicle access restriction / no vehicles in areas where animals are kept/ passing by, separate access routes	16	1			1					1									1								1			1		1	1	1	1		1		1	1		1		1			1	
Footbaths and hand washing facilities between compartments	20	1						1		1				1					1						1		1		1	1		1	1	1	1	1	1		1	1		1		1			1	
8. General management																																																
Monitoring and recording.	33	1	1	1	1	1	1		1	1	1			1		1	1	1	1	1	1		1	1	1	1	1	1		1		1	1	1	1	1	1		1	1				1			1	
Keep an up to date animal identification and record keeping register with animal health data	32	1	1	1	1	1	1		1	1	1			1		1	1	1	1	1	1		1	1	1	1	1	1		1		1	1	1	1	1	1		1	1							1	
Constant surveillance and monitoring	34	1	1	1	1	1	1		1	1	1			1		1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1	1	1	1	1		1	1				1			1	
Systematic control 5-6 weeks after parturition in high risk farms(for metritis)	2																						1		1																							
Identification and elimination/segregation of carriers/ infected animals by regular testing	24	1	1			1	1	1	1	1	1							1	1		1			1	1	1	1			1		1	1		1	1			1	1	1						1	
Maintain resistant breeds or endemic stability	12		1			1										1									1							1			1	1		1	1					1	1			1
Work organization	6	1								1					1				1						1					1																		
Working from young to old animals	13	1													1										1	1						1	1	1	1	1	1		1	1							1	
Individual daily calf checks	8														1										1							1		1	1	1			1								1	
Avoid excessive stress or stressful events	15	1													1										1				1	1		1		1	1	1		1	1	1				1	1		1	
No equipment or vehicles shared with other farms	9									1									1						1		1			1			1							1		1					1	
Bedding and flooring	16	1								1	1									1					1	1	1					1	1	1	1	1	1		1	1							1	
Bedding/ litter removal; keeping fresh and clean beddings	21	1						1		1	1				1					1					1	1	1		1			1	1	1	1	1	1		1	1		1		1			1	
No recycling of bedding	18	1								1	1									1					1	1	1		1			1	1	1	1	1	1		1	1		1					1	
Cemented floors / concrete flooring	14									1	1									1					1	1			1			1		1	1	1	1		1			1		1				
Presence of rubber mat on the floor	4																			1					1				1															1				
Proper disposal of manure from other farms within 500 meters	9																								1	1					1		1		1		1		1			1					1	
Avoid piling manure	4																								1	1						1					1											
Housing	17	1								1	1				1	1		1	1	1			1		1	1	1		1	1						1	1			1								
Housing density	28	1								1	1				1	1		1	1	1			1		1	1	1		1	1		1	1	1	1	1	1	1	1	1	1	1	1				1	1
Good ventilation and air quality (positive pressure ventilation of >15 cubic ft. per minute per calf	15	1													1					1					1				1	1		1	1	1	1	1		1	1	1					1			
Maintaining a dry environment where possible	9	1													1					1					1	1	1		1	1																	1	
Tie stall or stanchion facilities	7														1										1		1		1			1				1											1	
House the animals per sex, no mixed groups	5																								1				1			1						1		1								
Proper feeding	15	1													1								1		1				1	1	1	1	1	1		1		1				1		1	1			
Well-balanced ration	16	1						1							1								1		1				1	1		1	1	1		1		1				1		1	1		1	
Good feeding procedures	16	1						1							1										1				1	1	1	1	1	1		1		1				1		1	1		1	
Control of adequate feed intake	16	1						1							1								1		1				1	1		1	1	1		1		1				1		1	1		1	
Grazing practices	8													1		1					1				1	1	1			1												1						
Integrated grazing management: shifting the animals every 7-14 days, no regrazing before 60 days, dose and move-system	3															1									1																	1						
Extensive grazing(beef)	3																								1					1												1						
Zero grazing(dairy)	6													1											1													1		1		1		1				
Pasture drainage	3															1									1																	1						
Avoid sharing or renting pastures	6																				1				1	1	1													1		1						
Mowing	2																								1																	1						
Ploughing under manure before animals go on pasture	3																								1						1											1						
Biological control of helminths	4													1			1								1																	1						

DISEASE CODE	Tot.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
9. General hygiene practices																																																
Cleaning/disinfection of all possibly contaminated equipment	31	1			1		1	1		1	1			1	1		1	1	1	1	1		1	1	1	1	1		1	1		1	1	1	1	1	1		1	1		1		1			1	
Cleaning stables before introduction of new calves, steam or hot water, thorough drying of multiple days,	25	1						1		1	1				1				1	1	1					1	1		1	1		1	1	1	1	1	1		1	1		1	1	1			1	1
Sanitary vacancy ("vide sanitaire")	23	1						1			1				1				1	1	1					1	1		1			1	1	1	1	1	1		1	1		1	1	1			1	1
Cleaning and disinfection of equipment after each usage (calving, milking,…)	27	1					1	1		1	1				1			1	1	1	1		1		1	1	1		1	1		1	1	1	1	1	1		1	1		1		1			1	
Regular hands cleaning and disinfection (especially between age groups)	25	1						1		1	1				1				1	1	1		1		1	1	1		1	1		1	1	1	1	1	1		1	1		1		1			1	
Proper cleaning and disinfection of surgical instruments and needles between animals	21	1	1			1	1	1		1	1	1			1			1	1	1	1		1		1	1	1		1	1			1							1								
Animal transport vehicle and other vehicles leak proof and cleaned and disinfected before entry, through separate access routes.	20				1					1									1		1					1	1			1		1	1	1	1	1	1		1	1		1	1	1			1	1
10. Management of sick or quarantined animals																																																
Only allow healthy animals on common pastures (testing)	8		1			1													1							1							1									1	1					1
Quick recognition, isolation and treatment of sick animals	30	1	1			1		1		1	1				1	1		1	1	1	1		1	1	1	1	1	1		1		1	1	1	1	1	1		1	1		1		1			1	
Sick animals treated last	19	1						1		1					1					1					1	1	1			1		1	1	1	1	1	1		1	1				1			1	
Quarantine facilities and work organization	19	1								1					1			1	1						1	1	1			1		1	1	1	1	1	1		1	1				1			1	
Separate quarantine stable-building, capacity at least 2% of the farm	19	1								1					1			1	1						1	1	1			1		1	1	1	1	1	1		1	1				1			1	
Separate boots and impermeable clothing for the quarantine stable	19	1								1					1			1	1						1	1	1			1		1	1	1	1	1	1		1	1				1			1	
A washing installation for the quarantine stable	17	1								1					1				1						1	1	1			1		1	1	1	1	1	1		1	1				1				
Changing gloves for each sick animal	17	1								1					1				1						1	1	1			1		1	1	1	1	1	1		1	1				1				
Daily observation	14									1															1	1	1			1		1	1	1	1	1	1		1	1				1				
Separate housing of relapses and chronic cases	6									1																1	1			1		1	1															
Injectable medication instead of oral (to control the actual uptake and dosage)	2																										1					1																
Effective and applicable treatment protocols and evaluation of the protocols	9																										1				1	1		1		1				1	1			1	1			
Hospital ration with water and hay ad libitum, high level of protein and energy, vitamins and minerals	6																										1					1		1		1				1				1				
Frequent and thorough cleaning of quarantine and hospital pens and their feed and water places	12																										1			1		1	1	1	1	1	1		1	1		1		1				
11. Parturition																																																
Testing all cases of abortion	5									1											1			1			1						1															
Maternity pen	15	1								1	1									1			1				1		1			1	1		1	1	1		1	1							1	
Maternity pen separated from other animals	15	1								1	1									1			1				1		1			1	1		1	1	1		1	1							1	
Existence of maternity area with enough individual calving pens	15	1								1	1									1			1				1		1			1	1		1	1	1		1	1							1	
Maternity pen designed for easy cleaning and drainage	15	1								1	1									1			1				1		1			1	1		1	1	1		1	1							1	
Not using maternity pens for sick animals	14	1								1	1												1				1		1			1	1		1	1	1		1	1							1	
Always someone present at the moment of calving	8	1								1	1												1						1			1				1	1											
Cleaning and disinfection	14	1								1	1										1		1		1		1		1			1	1			1	1			1							1	
Cleaning of calving/abortion area (maternity pen/stables/box) before and after each calving/abortion	15	1								1	1										1		1		1		1		1			1	1	1		1	1			1							1	
Cleaning and disinfection of udder and vulva	14	1								1	1										1		1		1				1			1	1	1		1	1			1							1	
Cleaning and disinfection of hands before and after abortion and/or calving	15	1								1	1										1		1		1		1		1			1	1	1		1	1			1							1	
Cleaning and disinfection of obstetric material before and after abortion and/or calving	15	1								1	1										1		1		1		1		1			1	1	1		1	1			1							1	
Immediate calf care	4	1																											1			1				1												
Immediate clearing of airways	3																												1			1				1												
Immediate separation of the calf from the mother <--> Keep the calf with cow for 24 hours (oldest)	9	1																							1							1			1	1	1		1	1							1	
Navel dipping, in a clean vessel with fresh disinfectant	4																												1			1				1				1								
Immediate and proper disposal of fetal membranes and tissues after abortion and/or calving	7							1		1											1			1			1		1				1															

DISEASE CODE	Tot.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
12. Calves management																																																
Calves feeding	9									1								1								1						1	1	1		1	1								1			
Good quality and quantity colostrum, within first 6 hours	17	1					1			1								1								1			1	1		1	1	1	1	1	1	1	1						1		1	
Proper supply of milk (quantity and quality)	10	1																1														1	1	1	1	1		1	1						1			
Avoid feeding of infected milk / pasteurization of fed milk	15	1								1								1								1			1	1	1	1	1		1	1		1	1					1	1			
Temperature control of milk given	4																														1	1				1		1										
Gradual supply of concentrates and hay to adapt to new diet	6																															1			1	1		1							1		1	
Hutches / calves pen	10																	1								1			1			1	1		1	1	1		1						1			
Hutches should be placed in an outdoor environment, situated to minimize weather impact	9																												1			1	1		1	1	1		1						1		1	
Hutches should be placed 1,25m apart	10																									1			1			1	1		1	1	1		1						1		1	
Hutches should be cleaned, preferably steamed, disinfected and thoroughly dried before housing new calves (also underneath)	11																									1			1			1	1	1	1	1	1		1						1		1	
Daily cleaning of bedding and housing of calves (stress-free, dust-free)	12																												1			1	1		1	1	1	1	1	1				1	1		1	
Specific equipment's	7																									1						1	1		1	1			1						1			
Use of one bucket per calf with a teat	7																																1	1	1	1			1						1		1	
Cleaning the buckets after each feeding	7																									1							1		1	1			1						1		1	
Use of oesophageal feeder only when necessary	1																															1																
Calves groups management	14	1																1								1			1	1		1	1	1	1	1	1	1	1								1	
Calves and young stock separated from older animals and other age groups	12																	1								1			1			1	1	1	1	1	1		1	1							1	
Temperature and humidity control <15° in the calf stable	14																	1								1			1			1	1	1	1	1	1	1	1			1			1		1	
13. Dairy management																																																
Equipment	3	1								1																	1																					
Regular control and maintenance	1	1																																														
Immediate replacements of broken or cracked milk tubes.	1	1																																														
Wash and sanitize equipment after each milking.	3	1								1															1																							
Automatic milking system	2	1																									1																					
Milking operations	3	1								1															1																							
Teats clean and dry	2	1																							1																							
Eventual teats disinfection before milking (dipping)	2	1																							1																							
Examine foremilk	2	1																							1																							
Teat disinfection after teat cups removal (dipping)	3	1								1															1																							
Healthy young cow first, then older cows and infected cows last.	3	1								1															1																							
Ensure cows remain standing after milking (fresh feed and water)	1	1																																														
Establish goals for udder health and monitor their achievement	1	1																																														
If purchase of a lactating cow: isolation, separate/last milking and bacteriological culture	1	1																																														
Separate first calf heifers from multiparous animals	1	1																																														
Good and balanced nutrition	1	1																																														
Clip flanks and udder	1	1																																														
Preventive treatments	1	1																																														
Monitoring of SCC	1	1																																														
Dry period < 4 days	1	1																																														
Appropriate management of clinical mastitis	1	1																																														
Culling of cows with chronic / non responsive intramammary infections	1	1																																														

DISEASE CODE	Tot.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
14. Animal workers from the farm																																																
Prevent contact of farmer or worker with cloven hoofed animals from other farms	5									1									1							1	1																				1	
Personal working hygiene of worker/farmer (boots, clothes, hands,…)	21	1								1		1							1						1	1	1			1		1	1	1	1	1	1		1	1		1	1	1			1	1
Regular training of animal keepers,	38	1	1	1	1	1	1		1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1		1	1	1				1	1	1	1	
Animal per person ratio as low as possible	9	1																	1											1		1	1	1		1				1							1	
15. Prevent human contamination (zoonosis)																																																
Raw milk/milk products only from certified farms	4	1								1																	1			1																		
Meat inspection / properly cook meat before consumption	2													1			1																															
16. Prevent environmental contamination																																																
Manure treatments or spreading in the absence of wind only	1																										1																					
Number of measures adressing the disease		**103**	**17**	**11**	**23**	**13**	**26**		**8**	**82**	**31**	**8**	**2**	**21**		**17**	**14**	**36**	**50**	**34**	**39**	**2**	**26**	**20**		**68**	**76**	**6**		**66**	**14**	**103**	**92**	**70**	**77**	**97**	**72**	**22**	**77**	**79**	**16**	**45**	**21**	**50**	**23**	**10**	**82**	**21**

Legend: code of diseases

Code	Disease
Tot.	Total number of diseases adressed
1	Acute and subclinical mammitis
2	Anaplasmosis/ Ehrlichiosis
3	Anthrax
4	Aujeszky's Disease
5	Babesiosis (bovine)
6	Bluetongue / Fievre catharrale ovine
7	Bovine herpesvirus 4
8	Bovine Spongiform Encephalopathy
9	Brucellosis
10	Campylobacteriosis
11	Crimean-Congo Hemorrhagic Fever
12	Cryptococcosis
1	Cysticercosis
14	Dermatophytosis/ mycosis
15	Distomatosis
16	Echinococcosis

Code	Disease
17	Enzootic bovine leucosis
18	Foot and Mouth Disease
19	Interdigital and digital dermatitis
20	Leptospirosis
21	Lyme disease / Borreliosis
22	Metritis (non specific path)
23	Neosporosis
24	Papillomatosis
25	Paratuberculosis
26	Q Fever / Coxiellosis
27	Schmallenberg disease
28	Secondary infections
29	Tuberculosis (bovine)
30	Botulism
31	Bovine respiratory diseases
32	BVD
33	Coccidiosis

Code	Disease
34	Cryptosporidiosis
35	Diarrhea / enteritis
36	E. Coli verotoxic
37	Enterotoxemia (*Clostridium* spp)
38	Giardiasis
39	Infectious Bovine Rhinotracheitis(IBR)
40	Infectious Bovine Keratoconjunctivitis
41	Intestinal parasites
42	Lice and ectoparasites
43	Listeriosis
44	Necrobacillosis (laryngitis)
45	Rabies
46	Salmonellosis (non typhoidal)
47	Scabies

Appendix 3- Results on a longitudinal study assessing the effects of a specific workhop on the veterinary students beliefs and perceptions on zoonosis

Short Communication

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Effects of a Specific Workshop on the Beliefs and Perceptions on Zoonosis of the Veterinary students: A First Pilot Longitudinal Study

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ABSTRACT

Background: Zoonoses represent a major threat and an occupational health hazard for the veterinary practitioners. Their prevention relies mainly on the implementation of different biosecurity measures (BSM). Nevertheless, the existing studies demonstrate a low level of implementation of BSM by the veterinary professionals. The objective of this study is to assess the level of implementation or intention to implement the BSM by the veterinary students before and after a specific workshop on zoonosis in order to evaluate the efficacy of such training activities on the adoption of the proper behaviour. Methods and principal findings: The data was collected through a longitudinal survey (N = 41). The different beliefs and perceptions of the respondents as well as their level of implementation or intention to implement the different biosecurity measures were assessed before and after the survey and compared in order to evaluate the possible effect of the workshop on these different elements.

Conclusion and Significance: The workshop did not have any significant influence on the intention to adopt a proper behaviour. In the future, it is recommended to increase the duration of training sessions on this topic throughout the cursus as well as to pursue such communications towards the veterinary professionals.

Short Communication

Zoonoses represent 60% of the diseases affecting humans and 75% of emerging diseases [1]. They represent a major threat in public health and their socio-economic impact are important as illustrated by the 2020 pandemic of COVID-19 which has severely affected the economy and the social lives of the population worldwide. Zoonoses prevention relies mainly on biosecurity measures which should be emphasized at the interface of animals, humans and environment. The veterinary professionals are more likely to be exposed to these pathogen agents [2] and the veterinary students appear to be exposed early in their education [3,4]. Despite these findings, different studies reported a generally low level of implementation of the biosecurity measures (BSM) by the veterinary professionals [5,6]. According to the Health Belief Model (HBM), the intention to implement a given behaviour is determined by 5 mental constructs:

a. The risk susceptibility (perceived likelihood of the risk occurrence),
b. The risk severity (perceived impact of the risk if it occurs),
c. The benefits of the behaviour,
d. The barriers to the behaviour implementation or outcomes
e. The health responsibility (perceived responsibility towards animal, public and environmental health) [7].

These constructs can be influenced through proper communication and awareness raising. Nevertheless, the training received in terms of zoonotic risks and biosecurity is judged insufficient by 28% of the students at the Faculty of Veterinary Medicine of Liege (Renault V., 2020, unpublished data). Such training sessions could easily be developed and included in the professional training of the veterinary students. The objective of this pilot study was to assess the actual impact of a two-hours workshop on the zoonotic risks on the different constructs of the HBM and on the intention of the veterinary students to implement the BSM in their future practices.

Materials and Methods

Survey Design and Implementation

In order to raise awareness of the veterinary students on the zoonotic risks and the biosecurity measures to implement, a specific workshop on zoonosis was developed. It was designed as case studies to be presented by the student on different zoonotic diseases affecting different species in order to promote self-reflection and exchanges among small groups of 10 to 16 students from end of September 2019 to April 2020. A longitudinal study was carried on and the data was collected by an on-line survey developed with Lime Survey, an open-source web application. The questionnaire was directed to veterinary students in Master two or three (Appendix A) registered for the paraclinics seminars under which the workshop on zoonoses was to be delivered. The students' survey was conducted twice: once before the workshops (from September 2019 up to end of May 2020) and a second time at the end of the academic year (from June up to end of July 2020). The invitations to fill in the first survey were sent on a monthly basis to the students through the mailing lists of the Students' Office after approval of the Dean of the Faculty of Veterinary Medicine. Specific reminders were also sent to the different student groups about 10 days before their workshop on the zoonosis in order to increase the answer rate for the first survey. For the second survey, the invitations were sent in May, June and July (just after the examination session).

In the first survey, different questions were asked to assess the different components of the different HBM constructs and the level of implementation of the BSMs by the respondent [8]. Existing HBM guidelines [9,10] and questionnaires [11-15] were used in order to develop the different questions related to the HBM constructs which were mainly assessed indirectly by asking the respondents their degree of agreement (0: fully disagree and 100: fully agree) with different statements at the exception of the perceived benefits of the different BSMs which were assessed by a direct question [8]. The second survey included only the questions related to the HBM constructs as well as some questions related to the eventual practical experience acquired in between (Table 1). The construct called 'health responsibility' was not assessed and compared as the workshop emphasized mainly on the zoonotic risk and their preventive measures. No effect on the 'Health responsibility' perception was therefore expected. The student's identification number was used to pair the data and to control that the student did benefits from the workshop on zoonosis between the 2 surveys and to analyze whether the training workshops that they attended did change their beliefs and perceptions regarding the zoonotic risks and the ways to prevent them.

Table 1: List of statements used to assess the different Health Belief Model constructs by asking the respondent their degree of agreement through a visual analogue scale [8].

HBM construct	Statements used for the indirect assessment of the construct
Susceptibility	According to me, veterinary practitioners are very frequently exposed to zoonotic infectious diseases
	According to me, zoonotic infectious diseases represent a major risk for veterinary practitioners
	As a veterinary practitioner, I could easily and unwillingly be responsible of the spread of a zoonotic disease to my relatives or to other persons
	My future professional practice represents an important risk for my health
Severity	If I were to contract a major zoonotic disease, my incomes would be heavily impacted
	If I were to contract a major zoonotic disease, my life quality would be severely affected
	If I were to contract a major zoonotic disease, I might contaminate my relatives and other persons
Benefits	According to you, what is the efficiency of the following biosecurity measures to prevent yourself from a possible contamination (0: useless, 100: very effective (full protection):
	BSM0. The different preventive measures which can be taken by the veterinarians
	BSM 1. Disinfecting your hands after each manipulation (or cleaning them with an antibacterial soap or solution)
	BSM 2. Inquiring from the owner about the country of origin of the animal in consultation
	BSM 3. Protecting my hands by wearing gloves adapted to the need(s)
	BSM 4. Protecting myself from oro-nasal contaminations by wearing a mask in case of interventions likely to cause projections (e.g. abscess puncture, wound cleaning, descaling, autopsy)
	BSM 5. Protecting myself against ocular contaminations by wearing protective glasses during interventions likely to cause projections (e.g. descaling, autopsy)
	BSM 6. Throwing the needles directly into a specific container without replacing the cap
	BSM 7. Washing dirty clothing separately with a proper cleaning cycle
	BSM 8. Being vaccinated against rabies
	BSM 9. Ensuring a proper contention in order to avoid being wounded (bites, scratches,
	BSM 10. In case of wound (bites, scratches ,..), proceeding to the immediate cleaning with an antiseptic soap or solution (a few minutes after the event maximum)
	BSM 11. Keeping myself updated of the new evolutions in terms of zoonoses and their prevention (continuous training)
	BSM 12. Using disposable coat for single use
	BSM 13. Cleaning my boots when exiting the holdings
Barriers	No measure is really effective; I am exposed to zoonotic infections anyway

	By my practices, I am able to considerably lower the exposure and contamination risks to a zoonotic disease
	Performing hygienic measures (e.g. hands, boots) is only possible if the holdings are equipped with proper cleaning infrastructures. If there are no cleaning spots on the holdings, we cannot perform these measures

Statistical Analysis

The data originating from completed questionnaires were extracted to Microsoft Excel© and the responses given by the participants were coded in accordance with Appendix 1. The longitudinal study only included the students who did answered to the first survey prior to the workshop, attended the workshop and answered the second survey after the workshop. The representability of the sample used in the longitudinal study to compare the perceptions before and after the workshop was tested by comparing the gender, year of education and practical experiences of the respondents compared to the general master student population. The different comparisons were based on a chi-square test performed in Stata SE/14. The scoring of the four HBM constructs was done as described in a previous study which analysed the determining factors of the biosecurity measures by the veterinary professionals based on the results of the first survey [8]. The perceived benefits of BSMs were assessed through a single question generating a BSM efficiency score ranging from 0 to 100. The average score of all the BSM efficiency score (13 in total) was also calculated and called “Overall score” for the benefits’ perceptions. The other HBM constructs, were determined indirectly by asking a set of questions or items. The scores of each construct were calculated as the mean score of each of the items and range from 0 to 100. The level of intention to implement a BSM or the actual level of implementation were graded from 0 (Never implemented) to 4 (Always implemented) and an overall BS score was calculated by estimating the overall level of implementation of the individual BSM in percentage of the maximum score possible obtained (if all the BSM are always implemented). The perception scores related to the risk susceptibility, risk severity, barriers and benefits as well as the different BS implementation scores were calculated in the first and second survey and paired based on the student’s identification number. The perceptions before and after the workshop were then compared by a Wilcoxon signed-rank test (for paired data) using Stata SE/14.

Results

The longitudinal study was implemented as planned in order to capture the student beliefs and perceptions before the workshop. Nevertheless, the COVID 19 pandemic interrupted the workshops on March 2020 (Figure 1). The students’ answer rates in the first and second survey were of 35 and 44%, respectively. The answer rate of the second survey was calculated as a percentage of the students who responded to the second survey among the 181 students who agreed to participate in the longitudinal study. However, due to the COVID 19 outbreak and resulting confinement from March 15th up to the end of the academic year, only 41 of the 77 respondents of the second survey benefitted from the workshop on zoonoses. Therefore, the students for which the perceptions could be compared only represented 18% of the students who completed the first survey. The chi-square test to compare the proportion of men and women in the overall population of students and the survey populations did not demonstrate any statistical differences (p>0.05). Based on the same analysis, no statistical difference was found when comparing the students' experiences in the different kind of practices. When considering the 41 respondents included in the longitudinal study, 87.8% of the respondents are female and 97.6% of them reported having a practical experience through various internships (Table 2). The perceived susceptibility and barriers were significantly lower after the workshop (p-values of 0.03 and 0.005, respectively) while no significant differences were observed for the other HBM constructs (Figure 2).

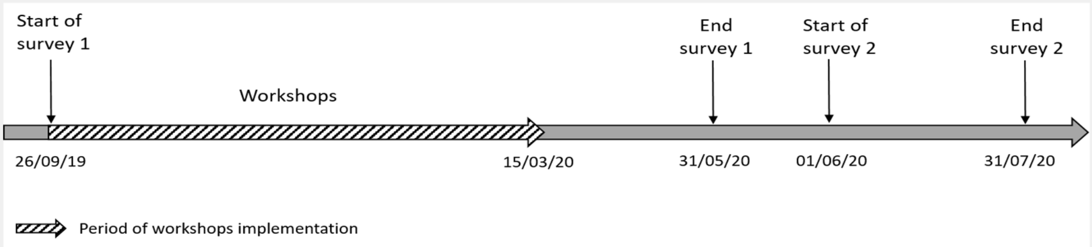

Figure 19. Timeline of the longitudinal survey

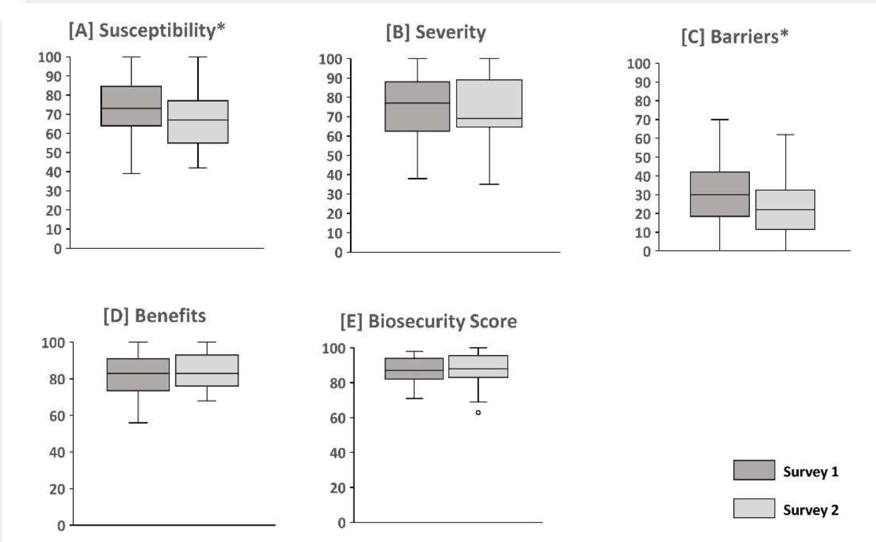

Figure 20. Perception scores of the Health Belief Model constructs
Note: *: perception scores significantly different at the beginning and at the end of the survey period

Table 2 : Demographics of the respondents

Respondents	Year of Education	N	Gender			Kind of Practice		
			Female	Male	None/ Other	Large Animals	Small Animals	Mixed
Veterinary students (Survey 1)	Total of students	227	78.41%	21.59%	7.49%	3.96%	48.90%	39.65%
	Master 2	162	75.31%	24.69%	7.05%	2.20%	35.68%	26.43%
	Master 3	65	86.15%	13.85%	1.54%	6.15%	46.15%	46.15%
Veterinary students (Survey 2)	Total of students	78	79.49%	20.51%	3.85%	6.41%	48.72%	41.03%
	Master 2	54	75.93%	24.07%	5.56%	5.56%	50.00%	38.89%
	Master 3	24	87.50%	12.50%	0.00%	8.33%	45.83%	45.83%
Longitudinal Study	Total of students	41	87.80%	12.20%	2.44%	4.88%	46.34%	46.34%
	Master 2	24	83.33%	16.67%	4.17%	4.17%	45.83%	45.83%
	Master 3	17	94.12%	5.88%	0.00%	5.88%	47.06%	47.06%

Discussion

This is the first pilot study investigating the possible effect of an intervention on the different beliefs and perceptions, which influences the implementation of preventive measures against zoonoses. The results are useful to determine if the students are sufficiently prepared to properly identify and address the zoonotic risks in their future practice in order to better preserve their health as well as the animals, humans and environmental health. The survey methodology addressed the possible volunteer bias by sending several reminders in order to increase the answer rate and managed an answer rate of 35% for the first survey with 44% of the respondents answering to the second survey. Such rates seem to be acceptable as personalized internet surveys usually generate a response rate of 4.7% [16]. Unfortunately, due to the COVID pandemic and despite a proper answer rate to the students' second survey, many students were not able to benefit from the training workshop on zoonoses and had to be excluded from the analysis. This affected the number of students eligible to the longitudinal study. Nevertheless, the sample can be considered representative of the overall population of students as the proportions of males and females as well as the proportions of mixed, small animals and rural practitioners were not significantly different among the groups. The workshop on zoonoses which was implemented during the academic year in order to raise awareness among the students on the zoonotic risks in veterinary practices and the importance of implementing proper BSM in order to facilitate the adoption of these measures by the student in their professional practices. In regards to the perceptions, the workshop was expected to increase the students' perceptions of the zoonotic risks and BSMs' benefits while reducing the barriers' perceptions.

If the barriers' perceptions is indeed significantly lower at the end of the year, the students' perception of the zoonoses' susceptibility was significantly lower at the end of the year (after attending the workshop) which is supposed to negatively affect the level of implementation of the BSMs. Many reasons could explain such observations, one of them being a failure of the intervention to change the behaviour as it has been the case in other interventional studies under which a more intensive communication on behaviour change was conducted [17]. It would illustrate the need to improve the communication campaigns by identifying the determinant factors and using them to trigger the proper behaviour. However, other elements might have influenced the perceptions as well, and interfered with the actual behaviour (e.g. internships and personal experiences). Out of the 41 respondents, 37% of them did made an internship between the first and the second survey and the behaviours and attitude of their supervisor regarding BSM might have an important influence on their perceptions. Considering that the level of implementation of some BSM by the veterinary practitioners are generally low as well as their risk perceptions [6], they might have a negative impact of the students beliefs, perceptions and practices.

The survey methodology for this longitudinal study was to assess the students' perceptions before the workshop and at the end of the academic year, not directly after the workshop in order to better measure the long-term impact of the workshop, leaving enough time for other external events to either consolidate or reverse the possible changes in beliefs and attitudes.

It would have been interesting to monitor the changes of perceptions and behaviours throughout the year instead of running only two surveys (one at the beginning and one at the end) in order to better capture the eventual changes over time, their duration and the events which could have determined these changes (e.g. internships). It also appear that a 2 hours workshop although judged really interesting and bringing a real added value (unpublished data on the students' feed-back) might be insufficient and that additional training activities on the topic should be integrated to the veterinary training in the future. As the analysis of the outcomes of the first survey, showed that the BS score was mainly influenced by the zoonoses susceptibility and BSM benefits, the communication materials should emphasize on these two aspects [8]. In addition, the information provided to the students and veterinary professionals should rely on evidence based studies as it appears that most of the time, the decision of the veterinary professionals to either implement or not a BSM is based on the case specific perception of the risks related to the intervention to be performed [8].

Conclusion

The level of implementation of the BSMs aiming at preventing zoonotic diseases by the veterinary practitioners in Belgium should be increased. One of the main strategies identified relies on a better training of the veterinary student on theses aspects. Nevertheless, a 2 hours workshop on the topic did not seem to have any significant influence and was proven inefficient even on a short-term basis. As for most interventional activities aiming at a long-term behaviour change, it is therefore recommended to increase the training sessions on this topic throughout the course as well as to pursue such communications towards the veterinary professionals in the future.

Author Contributions

Conceptualization, Véronique Renault and Claude Saegerman; methodology, Véronique Renault; software, Véronique Renault.; validation, Claude Saegerman and Sebastien Fontaine; formal analysis, Véronique Renault; investigation, Véronique Renault; resources, Véronique Renault; data curation, Véronique Renault; writing—original draft preparation, Véronique Renault; writting— review and editing, Claude Saegerman and Sebastien Fontaine; visualization, Véronique Renault; supervision, Claude Saegerman and Sebastien Fontaine; project administration, Claude Saegerman. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Informed consent was obtained from all subjects involved in the study. The data was collected, stored and used in accordance with the GDPR (EU) 2016/679.

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Conflicts of Interest

The authors declare no conflict of interest.

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