DISSERTATION

SOCIAL ECOLOGICAL DETERMINANTS OF OCCUPATIONAL ZOONOTIC DISEASE EXPOSURE ON COLORADO DAIRY FARMS

Submitted by

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ABSTRACT

SOCIAL ECOLOGICAL DETERMINANTS OF OCCUPATIONAL ZOONOTIC DISEASE EXPOSURE ON DAIRY FARMS

The presence of zoonotic pathogens in dairy farms is a known risk for people that work and live in these settings. People who work or live on a farm, farm visitors, service providers, and veterinarians are the most at risks of zoonotic infections. Dairy cattle operations represent a working environment with a high risk of exposure to zoonotic pathogens. The prevention of zoonotic diseases in animal-human interfaces can be challenging. Due to the complexity of the social ecological system, and it requires comprehensive, integrative, and culturally compelling interventions. It has been demonstrated that the behavior of the person at risk can affect their exposure to infectious agents. As demonstrated in other settings, the implementation of consistent and robust preventive measures can change the behavior of persons at risk and successfully decrease exposure to risk factors. One of the host factors that affect exposure to human infectious diseases is the behavior of the people at risk.

The SEM is a theory-based framework that has been used to scientifically explore the complex and interactive personal and environmental factors that affect people's preventive behaviors in specific settings. In general, the aim of epidemiological studies on infectious diseases using the SEM framework is to inform the development or improvement of comprehensive and compelling intervention strategies that directly target the behavior change process at different levels of influence.

In this research, we conducted several research activities using the Social Ecological Model (SEM) approach to expand our understanding of host and environmental factors that affect the exposure of zoonotic diseases as work hazards.

In the first research chapter (chapter 2) we proposed an SEM with potential factors affecting the preventive behavior of people at risk of zoonotic diseases in dairy farms. In the following chapter we use this model to build an instrument that measures SE factors for workers of dairy farms and provide sources of validity for that instrument. And in the last research chapter (chapter 3), we identify that self-efficacy and negative workplace perceptions are risk factors of *Salmonella* Dublin exposure (OR=1.43 [CI 1.11-2.22] & 1.22 [CI 1.02-1.53] respectively) and that knowledge and positive management perceptions were protective factors (OR = 0.90 [CI 0.79-1.00] & 0.91 [CI 0.82-1.00] respectively). Perception of supervisors and coworkers is a protective factor of *Campylobacter* exposure (OR=0.89 [CI 0.79-0.98]). Based on our observations, a supporting organizational environment, with supervisors and coworkers as deliverers of accurate safety information, and with increased knowledge and understanding of the potential risks and consequences of zoonotic diseases would help to reduce the occupational exposure of zoonotic disease in these farms.

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DEDICATION

To my children Eliana Lucía and Julián Enrique, and to my wife Andrea.

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Chapter 1. INTRODUCTION

The prevention of zoonotic diseases in animal-human interfaces can be challenging. Due to the complexity of the social ecological system, and it requires comprehensive, integrative, and culturally compelling interventions [1–4]. The aim of these interventions should be to induce behavior that reduces the chances of disease transmission. It has been demonstrated that the behavior of the person at risk can affect their exposure to infectious agents [1–5]. Therefore, leaning towards strategies that attempt to change the human prevention practices will, perhaps, reduce the risk of exposure to these infectious pathogens. As demonstrated in other settings, the implementation of consistent and robust preventive measures can change the behavior of persons at risk and successfully decrease exposure to risk factors [5,8,9].

The epidemiological triad is the most common and practical way to characterize the relationships between different factors that determine the transmission of infectious diseases. Host, environmental, and causative agent factors are classified using this characterization. One of the host factors that affect the exposure to human infectious diseases is the behavior of the people at risk [5–9]. Despite the importance of behavior and its drivers as potential determinants of infectious diseases, these factors and their effect on the transmission of infectious diseases seem to attract less research attention than other host factors. General health, immune status, or genetic traits are the most common host factors found on published works.

Similarly, published studies of environmental factors that affect behavior are even more scarce. We believe that the effect of preventive behavior on the transmission of zoonotic diseases as work hazards is an underexplored research area with great potential for intervention. In this research, we used the Social Ecological Model (SEM) to expand our understanding of this potential overlooked host and environmental factors that affect the transmission of zoonotic diseases as work hazards.

1.1 The problem

The presence of zoonotic pathogens in dairy farms is a known risk for people that work and live in these settings [10–23]. People who work or live on a farm, farm visitors, service providers, and veterinarians are the most at risks of zoonotic infections. Dairy cattle operations represent a working environment with a high risk for exposure to zoonotic pathogens. Many pathogenic agents have been found contaminating the dairy farm environment and associated with diseases in farmers, workers, and consumers of dairy products [19,20,24–36]. Among the most common pathogens found, *Salmonella*, *E. coli* (O157; H7), *Campylobacter jejuni*, and *Cryptosporidium parvum* are of our particular interest due to their abundance in the farm environment, and to the severity of illness they have been associated with [30,33,37–40].

Usually, the core interest of workplace safety training in farms is focused on the prevention of injuries, which are the primary health hazards on farms [41,42], neglecting the importance of infection prevention. While there have been extensive efforts towards the prevention of zoonotic pathogens in the food products of animal origin [1], the prevention of zoonotic diseases as occupational hazards has received much less attention [43]. Infections as an occupational hazard are a matter of concern in several settings where the exposure with potentially dangerous agents may occur. The bulk of work safety strategies for preventing infections in the workplace are directed towards personnel whose job task involves interaction with potentially contagious individuals and the manipulation of tissues, materials, or samples potentially contaminated with dangerous agents. These professions enclose mainly health care providers and laboratory personnel. As it has been demonstrated, the farm environment should be considered as, or even more contaminated than the mentioned above work settings and the equally important potential for biological hazards.

1.2 The social ecological model

The SEM is a theory-based framework that has been used to scientifically explore the complex and interactive personal and environmental factors that affect people's preventive behaviors in specific settings [44,45]. The SEM can be illustrated as a multilevel hierarchical model containing factors that can affect the behavior of a person (Figure 1). The levels that have been described as components of the SEM are intrapersonal, interpersonal, organizational, community, and public policy.

The SEM framework has been used broadly in addressing health prevention, particularly in public health research. The public health research using the SEM framework mainly focused on two extents. First, studying and addressing factors directly affecting preventive behaviors. And second, focusing on the reasons for adherence or withdrawals from medical treatments or health habits [46]. Some of the most researched topics that report the use of social-ecological framework are those in search for the drivers of physical activity, smoking prevention, cessation, and adherence to cessation, and obesity and diabetes prevention. The literature reporting the use of the SEM framework in the epidemiology of infectious diseases is scarce; studies about sexually transmitted disease and vector-borne disease prevention are the most common [4,5, chapter 2]. In general, the aim of epidemiological studies on infectious diseases using the SEM framework is to inform the development or improvement of comprehensive and compelling intervention strategies that directly target the behavior change process at different levels of influence. We hypothesized that these important factors have a relevant effect on the exposure to zoonotic diseases on workers of dairy farms.

1.3 Occupational infectious diseases relevant in the cattle-human interface.

1.3.1 Cryptosporidiosis

Cryptosporidium parvum is an agent that causes gastrointestinal illness in animals and humans. Cryptosporidiosis is one of the most common causes of waterborne diseases in humans. In cattle, cryptosporidiosis is identified frequently as a cause of diarrhea in calves. Its transmission occurs by ingesting the *Cryptosporidium* oocysts, which may be shed in large numbers by infectious animals [10,48].

Cryptosporidiosis manifests as an enteric disease. Its symptoms in humans include watery diarrhea, abdominal pain, nausea, among others. Immunocompromised individuals and children are particularly susceptible to this disease. The transmission to humans from cattle (infected calves) and in association with cattle and petting farms have been described. Some of the oocysts' virulent features are that they infectious immediately after excretion, very resilient to harsh environmental conditions surviving up to several months, resistant to the recommended uses and concentrations of commonly employed disinfectants [48]. These characteristics increase the chances of exposure in a potentially contaminated environment. The described risk factors are all related to the chances of ingestion of the oocysts. Many of the reports of risk factors are outbreak specific such as working in nurseries, accessing contaminated water, visiting farms, and others [49]. In the case of not waterborne transmitted cryptosporidiosis, the lack of hygienic behavior is a commonly reported risk factor [49]. Specifically for workers of livestock operations, evidence suggests that constant contact with small numbers of oocysts is protective [49], however secondary household cases are possible [50].

1.3.2 Salmonellosis

Salmonella spp. are one of the most important zoonotic pathogens there are. It was estimated by Monte-Carlo simulation models that 93.8 million cases (5^{th} – 95^{th} PCTL, 64.8 – 131.6 million) of salmonellosis occur each year worldwide [51]. Food contamination is the primary source of exposure to *Salmonella spp.* Contaminated poultry and eggs are often implicated in human salmonellosis cases. Close contact with livestock has also been associated with cases of salmonellosis. *Salmonella* bacteria can survive for long periods under adequate moisture and temperatures increasing the odds of exposure [52]. However, *Salmonella spp*. are susceptible to a variety of commonly used disinfectants used at the recommended concentrations [53,54]. Cattle can be subclinical carriers of this bacteria and can shed the bacteria for long periods [30,55].

In humans, the severity of the clinical disease varies depending on agent and host factors. Gastroenteritis signs such as nausea, vomiting, abdominal pain, and diarrhea are commonly reported. Systemic and extra-intestinal focal salmonellosis have also been described. Fatalities are mostly associated with being very young, very old, debilitated, or immunocompromised [56].

Besides the exposure to contaminated foods, other risk factors include working with animals, visiting production and petting farms, and working at slaughterhouses.

Another trait with public health relevance is the emergence of *Salmonella* strains with high resistance to multiple antibiotics making treatment even more challenging [57,58]. According to the CDC, about 100.000 cases per year of salmonellosis show antimicrobial resistance [59].

1.3.3 Campylobacteriosis

Selected species of *Campylobacter* are the most identified pathogenic agent associated with infectious enteritis in the world. The two most important species *C. jejuni* and *C. coli* of the bacterial genus account for 90% of all cases of human campylobacteriosis [60]. It has been estimated, adjusting for the presumed underreporting that 1.3 million illnesses occur per year in the US and 9.2 million in the EU [60–62].

Campylobacteriosis in humans is generally characterized by gastrointestinal infection symptoms such as watery diarrhea, abdominal pain, nausea, vomiting, and fever. Cattle are known asymptomatic carriers of *Campylobacter* [33,34]. Also, even though *Campylobacter* is not as resilient to the environmental condition as *Salmonella,* with adequate conditions of moisture and temperature, it can survive for up to a few months [63].

Most of the risk factors are associated with the exposure or consumption of contaminated meals. This includes improper food manipulation practices, undercooking, and bad hygienic habits when preparing foods, among others [64]. Also, there is a high risk for immunocompromised individuals, small children, and elderly adults. For non-foodborne campylobacteriosis, the most common risk factors are close contact with animals and the lack of hygienic practices [65,66].

1.3.4 Escherichia coli O157:H7

In contrast with the previous agents, *E. coli* can be found as a part of the normal intestinal flora in humans and animals. However, there are several pathogenic subsets of this species. That is the case of *E. coli* O157 H7 which has been associated with outbreaks worldwide [1]. Cattle harbor these bacteria asymptomatically and can shed large numbers of them to the environment [28]. The symptoms of *E. coli* O157 H7 infections are severe, including watery diarrhea, hemorrhagic colitis, and sometimes hemolytic-uremic syndrome that can lead to renal failure and death especially in children [67].

The transmission of this subset happens by ingesting the viable bacteria. This may occur if there is exposure to contaminated food or water, or by improper hygiene practices after contact with infected animals, humans, or fomites [68–70]. Besides the outbreak specific risk factors, sporadic close contacts with animals and consumption of undercooked meat are the most reported risk factors [23,68].

1.3.5 Other relevant infections in the cattle-human interface

Anthrax caused by *Bacillus anthracis* is an important zoonosis. Anthrax reported risk factors are those associated with close contact with contaminated cattle carcasses or infected animals. Veterinarians, farm workers, and butchers are populations at risk. Regionally, anthrax is more relevant in developing countries. Transmission to humans occurs when exposed to the sporulated forms of this bacterium. The signs of disease in humans depend as the route of entry of the spores and can be classified on cutaneous, gastrointestinal, and respiratory [10,71].

The pathogenic agent *Mycobacterium bovis* has been identified as a cause of tuberculosis in humans and cattle, as well as in numerous other animals. Infection signs in animals and humans vary depending on the point of entry and location of the lesions. Tuberculosis is an air-borne disease; inhalation of contaminated droplets has been demonstrated as an effective infection route of transmission, and pulmonary tuberculosis is the most common form of the disease. Its risk factors, however, include consumption of unpasteurized milk, undercooked meat, and living or working with cattle. The treatment of bovine tuberculosis in humans requires adherence to a long-term antibiotic protocol [10,72,73].

Several species of the genus *Brucella* cause brucellosis. Infection in humans is considered incidental and sporadic. Though there have been extensive efforts for its eradication; there is still reporting of cases of brucellosis occurring. One trait of tuberculosis infection is its latency capabilities and the fluctuation of clinical signs. The most reported risk factors include contact with infected aborted fetuses, placenta, bodily secretions, fomite, infected animals, and high-density dairy farming. This is why *Brucella* is of especial relevance as an occupational zoonosis from cattle [10,25].

Q-fever is another airborne and very contagious disease caused by *Coxiella burnetii.* This highly contagious agent can infect numerous hosts including humans. Animals can be asymptomatic carriers and shed the bacteria in large numbers in feces, urine, and milk. Inhalation of the aerosolized bacteria and ingestion are the most common transmission routes. These bacteria are very resilient to environmental conditions, and its resistance to many common disinfectants has been demonstrated. Occupational exposure of *C. burnetii* has been reported. Usually the signs of these disease in humans are mild, therefore this disease is underreported and underdiagnosed. In many cases Q-fever can cause severe illness that can last a few days [10,21,74].

Rift valley fever is caused by a virus from the Bunyaviridae family. Even though its primary route of transmission between non-human animals is vector-borne, direct contact and aerosolized contaminated tissues or fluids are the main sources of infection to humans. Consequently, this is considered an occupational zoonosis. Signs of Rift Valley fever infection are often mild flu-like symptoms, nonetheless, in some cases, complications of this infection including hemorrhagic fever, encephalitis, and acute hepatitis may occur [10,21].

Ringworm is the common name of a dermatophytosis caused by fungi of the genus *Trichophyton* and sometimes *Microsporum*. Ringworms is a zoonotic fungal infection that can affect domestic animals and humans. Its name is due to the characteristics ring-shaped skin lesions caused by these fungi. Direct contact with infected animals (farm and pets) and fomites are important risk factors [75,76].

Leptospirosis is a zoonotic disease caused by various species of the genus *Leptospira*. The primary reservoir of this spirochaetes are rodents, which shed the bacteria in the urine. Transmission to farm animals and humans occur after exposure to urine contaminated water and fomites. Rodents are common pests of farms as they usually are attracted to the animal feed storage places. *Leptospira* can survive for long periods in water reservoirs. Other bodily secretions and aborted fetuses are also common sources of *Leptospira* in the farms. Geographically, this disease is common in subtropical and tropical regions. Infected cattle can appear asymptomatic and shed bacteria for longs periods. Animal husbandry and healthcare occupations are at risk of this infection. Signs of leptospirosis in humans are diverse and depend on agent and host factors. The signs are like other infectious diseases and may include fever, malaise, diarrhea, nausea, even respiratory signs. Vaccination protocols are available; however, for greater effectivity, the vaccine should include local serovars. Other preventive measures include pest control, water reservoirs treatments, and prevention programs for people at risk [10,14,77].

Listeriosis is a severe and potentially fatal zoonotic disease that can be transmitted to humans from cattle. In most cases, listeriosis in humans manifests as a self-limiting gastroenteritis or can cause skin lesions in healthy individuals. However, infection in pregnant women can cause miscarriage, and in debilitated and immunocompromised individuals this disease can cause encephalitis and septicemia that can be potentially fatal. Cattle can shed *Listeria* in the milk, feces, and in tissues and fluids during delivery. Thus, listeriosis has become an important occupational biological hazard [78,79].

Rabies is a rare but potentially fatal zoonotic viral disease. It is primarily transmitted through bites of infected animals. Despite this, cases transmitted from cattle have been reported. This epidemiologic pathway of transmission implies the exposure of cattle from an infected animal though bite. Then due to the initial clinical signs in cattle, similar to an esophageal obstruction, an examiner can be potentially exposed to the contaminated saliva and infected. In the Americas, several wild animals can potentially serve as rabies source; e.g., raccoons, skunks, red foxes, coyotes, and hematophagous bats (primary sources of cases in the US). Due to the potential risk of this disease, vaccination of individuals with animal-related occupations is highly recommended [36,80].

Livestock-associated Meticillin-Resistant *Staphylococcus aureus* (MRSA) is an emerging zoonosis of public health concern. The CC398 variant of MRSA was isolated from humans and pigs in the Netherlands in the mid-2000s. Since then this variant has been found affecting other livestock including cattle. It is considered a food-borne agent, but transmission by direct contact with animals and humans has also been reported. *S. aureus* infections in humans are not rare, and antibiotic treatment is usually effective. This is not the case of MRSA variant infection since its resistance to antibiotics makes the treatment more difficult. *S. aureus* infections can present as bacterial dermatitis, cellulitis, rhinolaryngitis, or more severe affections such as pneumonia, endocarditis, or even septicemia which make this pathogen potentially fatal [10,81–83].

Even though the latter mentioned agents cause serious diseases, they were not included in the current research. Not in a specific order of relevance, our inclusion criteria for the chosen zoonotic agents where: frequency of reporting and potential for exposure, cattle as reservoir, asymptomatic, or subclinical carriers, severity and consequences of infection, transmission odds to their families and close-ones, direct contact with animals as an important route of infection, available laboratory means for identification of the agents, and budget constraints.

Considering this we want to mention the exclusion criteria for some of the agents that were not included. Anthrax was excluded since it is rarely reported in animals or humans in the US, its potential for human transmission is mainly outbreak related, and cattle are not reservoir or carriers of the agent. *M. bovis* was not included due to the low reports of occurrence, laboratory and budget constraints (level 3 laboratory required, slow-growing bacteria), and the measurement of direct contact exposure is rather difficult since its main route of exposure is foodborne. *Brucella* abortus was not included in the study because, due to the intensive control and surveillance programs, this disease occurrence is infrequent, most reported cases in the USA correspond to consumption of unpasteurized dairy products of abroad travelers, and due to its limited human to human transmission. The other agents excluded are rather rare, have laboratory or budget constraints, have other more important routes of exposure, or not relevant to the region of influence.

Despite measuring the exposure to just a few important agents, we consider that the social ecological factors here studied are relevant for the transmission of all the occupational zoonoses mentioned, as most of them share behavioral determinants. We also encourage the inclusion of these pathogens in further research efforts since they are, definitely, a risk for cattle related occupations.

1.4 Personal motivators and background

During the first years of my career as a junior researcher in Colombia, I had the opportunity to collaborate in the preparation of dissemination events to stakeholders. There, I started to notice many barriers to transfer scientific knowledge to lay public implied. The research group I was involved was composed of mainly veterinarians and microbiologists, and the research focus was animal health threats to production. Later on, the group starting to study animal welfare, and safety of produces of animal origin.

The focus of the research team, by that time, was to try to reduce the use of acaricides on cattle, since the problem of pesticide resistance was getting out of hand in the whole country. Many years of research of this group, combined with similar efforts of research groups in Brazil and Mexico created a robust knowledge core that could potentially reduce the use of acaricides up to an 80% with the same efficacy in controlling ticks and tick-borne diseases in cattle.

Here came the complex task to transfer this knowledge to the public; this was one of the most challenging tasks I have ever been assigned too. The gap between us (the knowledge generators), and the public (the knowledge users) was very considerable. On those opportunities, we noted several transfer barriers with no apparent solution from our part. Communication, language, trust, political enabling, were just the most evident. At that time, it was very frustrating for the team to have a ready to use solution to a particular problem and being unable to put it in practice just because of our lack of understanding of the social ecology of our target population. We realized we did not have the skills to deliver such information adequately. At that moment the team was looking to collaborate with educators, anthropologist, or social science experts in addressing such a problem. Keeping this in my mind, I got the chance to pursue graduate education and prepare for a career as a researcher.

Even though I focused the beginning of my graduate education program on acquiring basic epidemiological knowledge and analytical skills, I did not allow this idea to fade away, at the end of my master's degree and thinking on the future Ph.D. research. I started to get involved in courses such as extension and educational research, which provided me with knowledge and curiosity on translation science. During this stage of academic exploration, I was directed to meet Dr. Noa and Dr. Reynolds who were involved in the research of prevention and understanding work safety hazards on dairy farms. They, along with my advisor, turned me in the right direction on trying to find a solution to he problem in question.

1.5 Notes on the interdisciplinary approach

We want to emphasize that the success of this research is mostly due to the effort and commitment of a diverse team of experts from multiple scientific disciplines. Epidemiology, biostatistics, veterinary medicine, agricultural sciences, organizational psychology, work safety, and microbology were the main subjects merged in this research. One of the significant advantages of this interdisciplinary work was to have on hand the potential of diverse methods and approaches thus broadening the possibilities for results interpretation and application.

Overspecialization is a described phenomenon that is affecting science in general. Disciplines nowadays are narrowing their methodological resources dragged by the over-focus on the questions they want to answer. This increased specialization can induce undesirable effects, such as the reduction on interpretability and applicability of research results. No one can argue that looking at a problem from many perspectives provides a more complete picture and can provide better chances of finding a solution.

The interdisciplinary work also presents some disadvantages. Usually, interdisciplinary work requires the commitment of more resources compared to one subject research approach; including time and effort spent in collaborating. Barriers in language and communication are a fact, and confusion caused by contradictory philosophies is a possibility. Despite these, it has been demonstrated that due to the interdisciplinary exchange, attention has been drawn to questions that otherwise would not arise, fostering creativity. Moreover, we can deny that there are research questions that can only be answered by a multidisciplinary approach.

1.6 Objectives

The principal objective of this work is directed to decrease the risk of transmission of zoonotic diseases in dairy farm workers. To achieve this, we have based our specific objectives on several hypotheses: i) the behavior of the people at risk affect their exposure to zoonotic diseases, ii) the social ecological factors that affect the exposure to zoonotic diseases are unknown, and iii) the preventive behavior of the people at risk can be changed by intervening in the specific social ecological environment.

The specific objectives were: to develop an instrument that measures the social ecological variables with potential to affect the exposure to zoonotic diseases of dairy farm workers, to investigate what social ecological factors affect the exposure to zoonotic diseases of dairy farms workers, and to propose a social ecological model for the transmission of zoonotic diseases in dairy farms. These objectives are developed in the following dissertation chapters.

Some secondary objectives were: to provide reference points for further research efforts, including pitfalls and successes, and to inform the development or improvement of work safety interventions aimed to reduce the risk of exposure to zoonotic diseases.

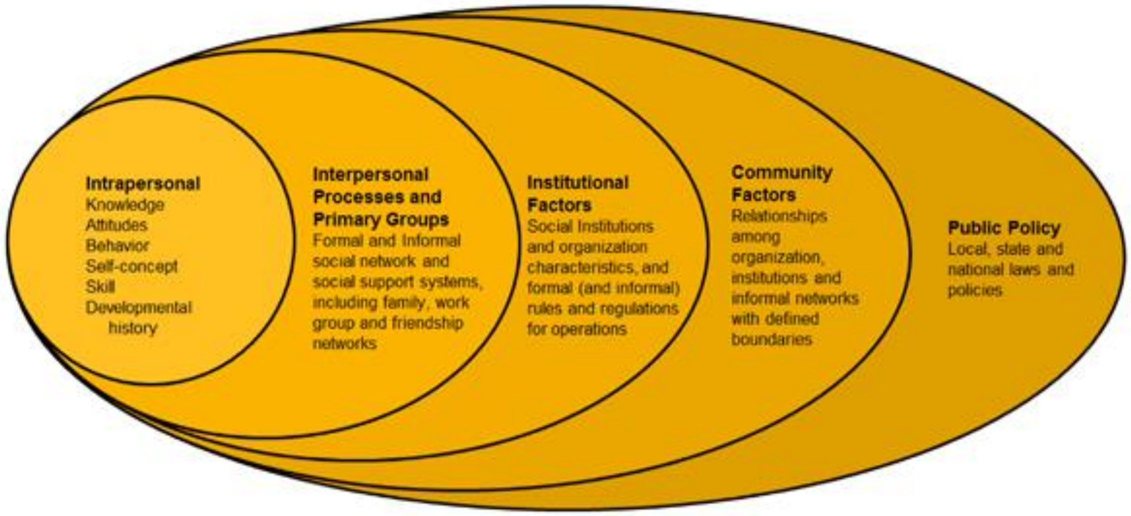

Figure 1 Basic SEM model (Adapted from McLeroy, K. R., Steckler, A., and Bibeau, D. (Eds.) (1988). The social ecology of health promotion interventions. Health Education Quarterly, 15(4):351-377. Retrieved May 1, 2012, from http://tamhsc.academia.edu/KennethMcLeroy/Papers/81901/An_Ecological_Perspective_on_Health_Promotion_Programs.)

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Chapter 2. OCCUPATIONAL EXPOSURE TO ZOONOTIC DISEASES: APPLICATION OF THE SOCIAL ECOLOGICAL MODEL

Summary

The social ecological model (SEM) framework has been successfully used for improving the prevention of multiple health problems. The behavior of the people at risk is a well-studied host-related disease determinant. Chronic metabolic diseases and addictions are the most frequent topics of research that report the use of SEM.

Regarding the prevention of infectious diseases, sexually transmitted diseases and a vector-borne disease are the most common. Transmission of zoonotic diseases in dairy farms and other animal-human occupational interfaces is a concern. Multiple zoonotic agents have been identified as causes of diseases in people working in farm environments. We conducted a parallel qualitative study and literature scoping review to elucidate the SEM that can potentially affect the preventive behavior of the people at risk of zoonotic diseases in dairy farms. We found that the use of SEM regarding infectious diseases prevention is scarce, only 19 of 43 selected papers were found that reported the use of SEM. Only two of them addressed the prevention of zoonotic diseases. Parallelly, responses from eight experts were analyzed qualitatively also to extract relevant SEM factors. Combining the results from both studies, forty items were allocated in five compartments of the SEM relevant to the prevention of zoonotic diseases in dairy farms. The proposed SEM can be used as a framework to understand, inform, and improve intervention programs aimed at the reduction of zoonotic disease exposure in dairy farms.

2.1 Introduction

The Social Ecological Model (SEM) is a theory-based framework for understanding the complex and interactive personal and environmental factors that affect people's behaviors in specific settings [1,2]. The SEM can be visualized as multiple levels that can affect the behavior of a person and , the social change in a community. These levels are Intrapersonal, Interpersonal, Organizational, Community, and Public Policy (Table 2).

The SEM framework has been used broadly in addressing health prevention, particularly in public health research. The public health research that has used the SEM framework is mainly focused on two extents, studying and understanding preventive behaviors and adherence to medical treatments (e.g., chronic metabolic condition and healthy habits) [3]. Some of the most researched topics that report the use of social-ecological framework are those in search for the drivers of physical activity, smoking prevention, cessation, adherence to cessation, and obesity and diabetes prevention. The literature reporting the use of SEM approaches in the epidemiology of infectious diseases is scarce; studies about sexually transmitted disease and vector-borne disease prevention are the most common [4,5]. The general aim of these studies is to inform the development or improvement of comprehensive and compelling intervention strategies directly targeting mechanisms of behavior change at different levels of influence.

Dairy cattle operations represent a working environment with a high risk of exposure to zoonotic pathogens [6–20]. As mentioned above, the behavior of the person at risk can affect their exposure to infectious agents [4,21–24]. Also, there is evidence that the use of a social-ecological framework is effective in providing useful guidance in developing or improving preventive interventions.

This study aimed to elucidate the potential social-ecological factors that are specific to the behaviors and setting of interest; i.e., external and internal social ecological factors that affect the intentions to practice, implementation, and maintenance of preventive behaviors towards minimizing the exposure to zoonotic disease agents in dairy farms. To achieve this aim, we used two parallel studies to synthesize the potential SEM factors that affect the prevention of zoonotic diseases as a work-related hazard in dairy farms. In one study we used a scoping literature review method to find published works that utilized the social ecological framework to assess the prevention of infectious diseases. In the second study, an open-ended questionnaire was developed and answered by multidisciplinary experts with experience and expertise in infectious diseases prevention in dairy farms to obtain SEM factors that were specific to the target population and the setting of interest. This framework can potentially serve as a source of theoretical support for further specific explorations.

2.2 Materials and methods

Two separate but simultaneous studies were conducted to achieve the above aim: 1) a scoping literature review of studies explicitly using social ecological framework for the prevention of infectious diseases, and 2) a qualitative survey of specific potential SEM factors that can affect the prevention of zoonotic diseases as a work-related hazard in dairy farms.

2.2.1 Scoping literature review

Scoping review is described as a process aimed to map or broadly synthesize research evidence [25,26]. Scoping reviews approaches are usually utilized to identify research gaps and summarize findings of research [25]. Scoping reviews primarily differs from systematic reviews in that often the research question is broader and that quality of included studies as a priority [25]. Based on this, also the synthesis of findings is done more qualitatively when compared to systematic reviews; i.e., systematic reviews usually seek to report a certain degree of confidence on the research reviewed. Other possible differences include the possibility to modify the selection criteria in the course of the study and that data extraction may or may not be required [25,26].

The search strategy and selection criteria focused on finding research papers that used a social ecological framework to address the prevention of infectious diseases. For this purpose, the following search string was used: [((social ecology*) OR (socio?ecolog*) AND (model OR framework)) AND prevent* AND (transmit* OR infectio*)]. The following sources and platforms were used in the search: Science Direct, PubMed, EBSCO (Medline and Academic search premiere), and Web of Science. Additional search filters such as health, medical, psychological, and social sciences related subjects, and only journal articles were applied when necessary[1].

After obtaining a database of the published works that matched the search string, a series of screenings were applied. After removing duplicates. the levels of screening

[1] We used Zotero 5.0.54 references management software developed by the Roy Rosenzweig Center of History and Media. George Mason University 4400 University Drive, MSN 1E7 Fairfax, Virginia 22030

included an initial manual title selection, followed by abstract scrutiny. The exclusion criteria included texts not in English, Spanish or Portuguese, not fully available documents, not related to infectious diseases, and not explicitly using a social-ecological framework/approach. The selected articles were then wholly screened for conclusive evidence of SEM factors and levels affecting the prevention of infectious diseases. The extracted factors were then recorded analyzed and allocated in the respective SEM level.

2.2.2 Qualitative study

Elicitation of more specific SEM potential components was also achieved using a qualitative study. A modified version of the Delphi method first stage was used [27]. The Delphi method is a flexible research technique that has been used for the exploration of constructs within and outside the information systems body of knowledge [28]. In general, the Delphi method is a process used to collect and distill the opinions, judgments, and knowledge of experts regarding a specific problem or topic [28]. A relevant characteristic of this method that suits the research purpose was that all responses are weighted equally regardless of the participants' expertise, background, or experience. This was accomplished by not linking the responses to any identifier and aggregation of responses for analysis.

Field and university veterinarians, epidemiologists, occupational health and psychology experts with experience of at least five years working with dairy farms (more than 20% of dedication) was chosen as the potential participants. Participants were also included based on their willingness to participate, availability for participation, effective communication skills, and expertise. A purposeful sampling method was used for reaching out to participants. Specifically, a two-stage “snowball” sampling technique was implemented. First, the author identified profiles that matched the inclusion criteria within the research team. The first potential participants were asked to participate in the study and, in turn, were asked to refer other potential participants that match the selection criteria. All participants were contacted by e-mail. They were provided with a briefing document that included the background, the objectives, and the scope of the study.

The questionnaire was composed of open-ended questions asking to list items that can potentially fit the SEM components (Table 1). The questions were reviewed, evaluated, and adjusted by the author and two reviewers before delivering it to the participants.

With the collaboration of Megan Dietz[2] MPH, the responses from this stage were analyzed using a grounded theory analysis approach [29]. Briefly, the method included, the building of a database containing the responses. Then the responses were evaluated using open coding centered on the question asked. Then an inductive categorization was used to group the codes into concepts or themes. The themes were then allocated to the correspondence SEM level of influence. This process was performed by two analyzers independently; discrepancies were discussed and conciliated.

[2] Meghan Dietz was, at the moment, coursing her Master of Public Health program at CSU and a collaborating researcher with expertise in qualitative research methods and analysis.

2.3 Results

2.3.1 Scoping review

A total of 421 papers were indexed into the reference management software (114 from PubMed, 251 from Science Direct, 15 from EBSCO Academic Search Premier, 25 from EBSCO Medline, and 16 from Web of Science). After the exclusion of duplicates, the first screening of titles and abstracts yielded 42 articles that were completely read in search for compelling evidence of SEM, variables, factors, components, items, or levels affecting the prevention of infectious diseases. In the end, 19 papers were found to have relevant data containing SEM factors that can potentially affect the transmission of zoonotic diseases in farms (Figure 2).

Most of the articles found were focused on HIV transmission prevention (9/19). Three out of 19 articles were about sexual health behavior and other STDs prevention. Malaria, dengue, hepatitis C, and tuberculosis prevention was addressed in individual papers. Two papers addressed zoonotic diseases, and one paper addressed social behavior and infectious agents in general. The factors identified for each SEM level are described in Table2.

2.3.2 Qualitative study

Eighteen experts were contacted in the first and second stage. From those, eight experts responded to the questionnaire (44% response rate). Among them, there were university veterinary hospital professors, extension specialist/personnel, epidemiologists/public health experts, and occupational safety/industrial hygiene professionals.

These eight responding experts provided a total of four hundred and sixty-two cumulative response items. By the grounded theory analysis method [29], 68 codes that were summarized into 16 themes were drawn. The results of this analysis are summarized in Table 3. The intrapersonal level was the one level that contained most of the codes, with 29 total codes, 17 of which were allocated to the theme Knowledge. The organizational level contained 17 codes, 13 of which were allocated to the theme Training practices. The interpersonal and the community levels accounted for ten codes each. Finally, only two codes were allocated to the public policy level.

2.3.3 SEM diagram

A diagrammatic representation of the potential SEM factors was composed based on the results of the two studies and is presented in Figure 3. Despite minor differences (discussed below), most of the items were identified by both studies.

2.4 Discussion

Only 19 papers explicitly used the social ecological framework to address the prevention of infectious diseases, and more than half of them were about or related to the prevention of HIV. Only two of them addressed the prevention of zoonotic diseases (rabies prevention in the community and zoonotic diseases control programs in farms). Despite the compelling evidence of the effectiveness of the use of an SEM framework for the prevention of health event, the use of this approach is still scarce for the prevention of infectious diseases.

As expected, when comparing the results obtained from both studies, the ones obtained in the qualitative study provided items that were more specific to the target population and the setting of interest. As previously mentioned, there is a good proportion of items that were found by both studies, increasing the validity of the results. The following are the considerations extracted from each SEM level.

2.4.1 Intrapersonal Level

In this level, the potential factors affecting the prevention of infectious diseases can be clustered into two groups, extrinsic factors, such as knowledge, socioeconomic status and educational level, and intrinsic factors such as perceptions, misconceptions, trust, beliefs, motivations, and self-efficacy. It is relevant to make this differentiation since, according to the transtheoretical behavioral change model, these groups have different levels of influences on the behavioral change stages [30]. The intrinsic factors have a more significant influence on the preparation and intentions to practice new behaviors. In contrast, the extrinsic factors have more influence on the transition process from intentions to change to the actual implementation of new behaviors, such as a new preventive practice [31].

In the scoping review, several papers mentioned misconceptions as a barrier to preventive behavior, but this was not clearly mentioned in the qualitative study. Despite, this item was indirectly mentioned in relation to knowledge regarding the faulty understanding of the necessary knowledge to practice prevention. Language was a concurrent item in different levels in the qualitative study but not mentioned in the scoping review. This is perhaps due to the specific demographics of our population of interest.

2.4.2 Interpersonal level

In this level, factors such as peer pressure, social norms, and communication were often mentioned in several of the papers included in the review, and also by the expert participants in the qualitative study. As a specific finding of the qualitative study, the interpersonal level was mentioned as a direct or indirect channel for acquiring and transmitting safety information or norms between the workers. Also, an important factor of this level is the quality of relationships and communication with prevention agents (e.g., extension agents, safety information providers, supervisors, etc.).

2.4.3 Organizational level

Holding key prevention factors such as decision-making power, resources availability, and organizational responsibility, among others, this level became one of the most important ones, when it came to promoting safety at the workplace. The effect of a supportive organizational environment has been described as a requirement for implementing and maintenance of preventive behaviors [32].

Specifically, from the qualitative study, items such as access to health care and prevention programs were identified as key prevention factors. In the same way, the importance of quality of communication and relationships across the levels were identified as important.

2.4.4 Community level

This level was also found as a source of general prevention information through culturally compelling interventions, community-driven interventions, and access to media. Culture and culturally appealing interventions play a significant role in the acceptability of prevention programs [33]. This factor was found in both studies; however, in the qualitative study, the responses tend to imply that the community was a source of inaccurate information becoming a barrier to the prevention of infectious diseases. In the scoping review, there were two factors mentioned in several papers: discrimination and inequality. Understandably, these two factors were mentioned by articles that directly targeted minorities as the population of interest, such as HIV positive patients, African Americans, or youth living in economic struggle, among others. It is probable that these two factors also play an important role in our target population since it fits the minority population consideration as composed in general by Latinx/Hispanic immigrants.

An important factor identified in the qualitative study is the potential for private or non-estate/government related certification programs, like the ones that apply to food safety or animal welfare certifications (e.g., cage free, organic, or green-labeled products, national dairy FARM program, etc.). We believe that this can influence the organizational level directly as a point of leverage from the consumers on safety practices.

2.4.5 Public policy level

Due to the properties of this level as the one that provides the political means and allowances to achieve the prevention goals, this can be set as the enabling level. Common factors found in both studies were related to the regulatory and oversight role of the policymakers. Interestingly, the scoping review provided two essential additional factors: the availability of research resources, and the multidimensionality and multidisciplinary approach to prevention enabling.

2.5 Limitations

Even though we followed many steps and processes used in systematic reviews, our aim was not to achieve a degree of confidence in the SEM factors. Also, it is probable that using a less specific search string; more papers can be found that explored social ecological factors affecting the prevention of infectious diseases in different settings and populations. The findings here described can be used to broaden the spectrum of a string search formula for a more specific systematic review that explores one or several levels of the particular SEM. The author is aware that there is a good number of published works that address the knowledge, attitudes, believes, and practices (KABP) relationships for the prevention of diseases. However, these studies were not included since they did not comply with the inclusion criteria set. Specifically, these articles did not explicitly mention the use of a social ecological framework in their assessment. Further research on this specific factor is encouraged since there is compelling evidence of the influence of these factors on the prevention of zoonotic disease transmission.

One of the major limitations of qualitative studies is that the human subjectivity of analyzers cannot be avoided. Moreover, this subjectivity is sometimes desirable for answering the research question. We tried to minimize this by having two independent analyzers and by ensuring the anonymity of the responses. Also, finding similar results in both studies indicates that these factors are not exclusively applied to a particular population, disease, or setting. More tangible evidence on the generalizability of these factors is needed to conclude the external validity of the results presented.

2.6 Conclusions

We successfully conducted two simultaneous studies to plot the potential SEM factors that affect the prevention of zoonotic diseases as a work-related hazard in dairy farms. Not only was there a good proportion of agreement in the factors found, but the results were complementary in providing a rich and diverse set of potential SEM factors applicable to dairy farm workers and the potential zoonotic risk they are exposed to at work.

One relevant finding of the qualitative study is that the experts did not mention misconceptions, discrimination, and inequality, but there is evidence that these factors play significant roles in the prevention of infectious diseases. Its absence in the qualitative study indicates that these may be underestimated or overlooked factors.

We encourage the use of the proposed zoonosis prevention SEM as a framework for future research aimed at the implementation of effective compelling intervention programs. There is evidence that integrated multilevel, multifactorial, and multidisciplinary approach prevention programs have more chances of success than otherwise. Similarly, as found in the scoping review, there is evidence that the use of SEM allows for the identification of multiple interacting factors/levels and gaps and bridges between them that facilitates the integral approach in prevention intervention design. However, other research inquiries emerge that may require to be addressed before the design of an intervention. This is for instance: how much effect size does each item add to each level, how these factors interact in within the level, how do levels interact between each other, and what is the direct effect that the levels have on the behavior change process. Answering these questions would lead us all to improve our understanding of the complex social, ecological and epidemiological circumstances of zoonotic diseases occurrence in dairy farms.

Table 1 Final questions submitted to the participants

1. Please, list the TOPICS or SUBJECTS that workers of dairy farms should understand to prevent exposure to zoonotic diseases.
2. Please, list the most EFFECTIVE CHANNELS or METHODS for communicating and transferring accurate information about the prevention of zoonotic disease exposure to dairy workers.
3. List the CONTENT of topics that a training program for workers for the prevention of exposure to zoonotic agents in farms should address.
4. List the most ACCURATE sources the workers of dairy farms should use to find information about prevention of exposure to zoonotic diseases.
5. List the most INACCURATE sources the workers of dairy farm MAY use to find information about prevention of exposure to zoonotic diseases.
6. List OTHER factors regarding the sources or channels of information that you think may be important for the prevention of exposure to zoonotic disease of dairy workers.
7. List the CHALLENGES or BARRIERS that dairy farm workers encounter that might prevent their acquisition of information to prevent zoonotic diseases exposure.
8. List the personal protection equipment (PPE) that should be worn by workers while performing their job duties ... throughout the dairy farm
9. ...Specifically in the milking parlor area
10. ...Specifically in the calf-pens area
11. ...Specifically in the hospital area
12. ...Specifically in the maternity/calving area
13. List the FACILITIES that a farm should have to prevent the exposure to zoonotic disease of its workers.
14. List OTHER factors regarding the workplace that you think may be relevant to the prevention of exposure to zoonotic diseases in dairy farms.
15. List the potential PROMOTERS that may improve the implementation of practices for the prevention of exposure to zoonotic diseases on a dairy farm

16. List the potential COMMUNICATION barriers that may impair the implementation of practices for the prevention of exposure to zoonotic diseases in a dairy farm.

17. List the potential ORGANIZATIONAL barriers that may impair the implementation of practices for the prevention of exposure to zoonotic diseases in a dairy farm.

18. List what practices a worker should implement for her/his protection to prevent exposure to zoonotic agents.

19. List the practices that dairy farms should implement to protect the exposure to zoonotic agents of their workers.

20. Please use this space to input any comments or suggestions

Table 2 SEM levels and descriptions, and components found using scoping literature review.

SEM LEVEL	DESCRIPTION [1]	SEM COMPONENTS FOUND.
INTRAPERSONAL	• Characteristics of an individual that influence behavior change, including knowledge, attitudes, behavior, self-efficacy, developmental history, gender, age, religious identity, racial/ethnic identity, sexual orientation, values, goals, expectations, literacy, stigma, and others.	• Perception of illness severity [34,35] • Mistrust, misconceptions on prevention measures and prevention agents [5,36–38] • Knowledge and skills of prevention measures [4,5,34,36–40] • Prevention beliefs and motivations [4,5,38,41] • Self-efficacy of prevention [4,5,38,40,42,43] • Psychosocial factors [4,5,38,40,42,43]. • Prioritization [37] • Socioeconomic status [44] • Educational level [42]
INTERPERSONAL	• Formal (and informal) social networks and social support systems that can influence individual behaviors, including family, friends, peers, co-workers, religious networks, customs or traditions.	• Peer pressure, social norms [4,5,34,36,37,40,45] • Communication [4,5,34,36,37,40,45] • Relationship with prevention agents [42] Leadership perceptions [46]
ORGANIZATIONAL	• Organizations or social institutions with rules and regulations for operations that affect how, or how well, for example, MNCH services are provided to an individual or group.	• Reliable, precise, and accurate prevention information provided [36] • Availability of prevention resources [4,5,38,39,43,47] • Organization responsibility on protecting their affiliates [40] Decision-making power [38]

SEM LEVEL	DESCRIPTION [1]	SEM COMPONENTS FOUND.
COMMUNITY	• Relationships among organizations, institutions, and informational networks within defined boundaries, including the built environment (e.g., parks), village associations, community leaders, businesses, and transportation.	• Discrimination [5,34,39,48] • Media reports [37] • Culturally appealing prevention strategies [4,5,37,45,49] • Community driven interventions [46,47]
POLICY/ENABLING ENVIRONMENT	• Local, state, national and global laws and policies, including policies regarding the allocation of resources prevention programs and access to health care services, research priorities, restrictive policies or lack of policies.	• Existence of regulations [50] • Public health policy [38,45,47,50] • Oversight [40]Oversight [40] • Multidisciplinary approach [46]

Table 3 Qualitative study summary codes and themes by SEM level.

SEM LEVELS	THEME	CODES EXTRACTED
INTRAPERSONAL: 29 CODES, FOUR THEMES.	Knowledge	Biological Hazards Biosecurity Cleaning/Disinfection/Sanitation Germ Theory/Microbiology of Diseases and Immunity Food Safety Zoonoses Handwashing Risk Factors (Disease Transmission/Exposure) Personal Hygiene Personal Protective Equipment Health Risks/Consequences Family/Community Health Symptoms of Zoonotic Disease Best Practices Animal Disease Risk/Hazard/Injury Reporting Lack of Knowledge
	Attitudes & Beliefs	Benefit/risk Perception Trust in Source Trust in Authority Figures Job Security Training Incentives Time consumption
	Education	Lack of Training Programs Education Level Access to Education Materials Literacy
	Language	Language barriers
INTERPERSONAL: 10 CODES FOUR THEMES.	Information Sources	Co-Workers Family Producer/Manager/Owner Peers Knowledge (Supervisor)
	Culture	Safety culture
	Communication	Multilevel communication Language Jargon

SEM LEVELS	THEME	CODES EXTRACTED
	Social	Peer pressure
ORGANIZATIONAL/INSTITUTIONAL (WORKPLACE): 17 CODES, FIVE THEMES.	Training practices	Simple Language Language accurate Post-Training Evaluation Demonstration Case Studies Discussion-Based Learning In-Person Learning Participatory-Based Learning Training Frequency Small Group-Based Learning Owner/Producer Training Visual-Based Learning Training Incentives
	Communication	Multilevel communication
	Healthcare	Health Care Access Health Monitoring and Screening
	Resources	Available resources
	Work climate/culture	Work climate/culture
COMMUNITY: 10 CODES, TWO THEMES	Certification	Private party safety certification
	Information sources	Universities extension offices Human Health Professionals Lay Journals Animal Health Professionals Equipment Manufacturers Radio Rural Health Centers Internet Academic Instructions/Universities
PUBLIC POLICY: 2 CODES, 1 THEME	Certification and licensing	Regulatory role of government institutions Public certifications

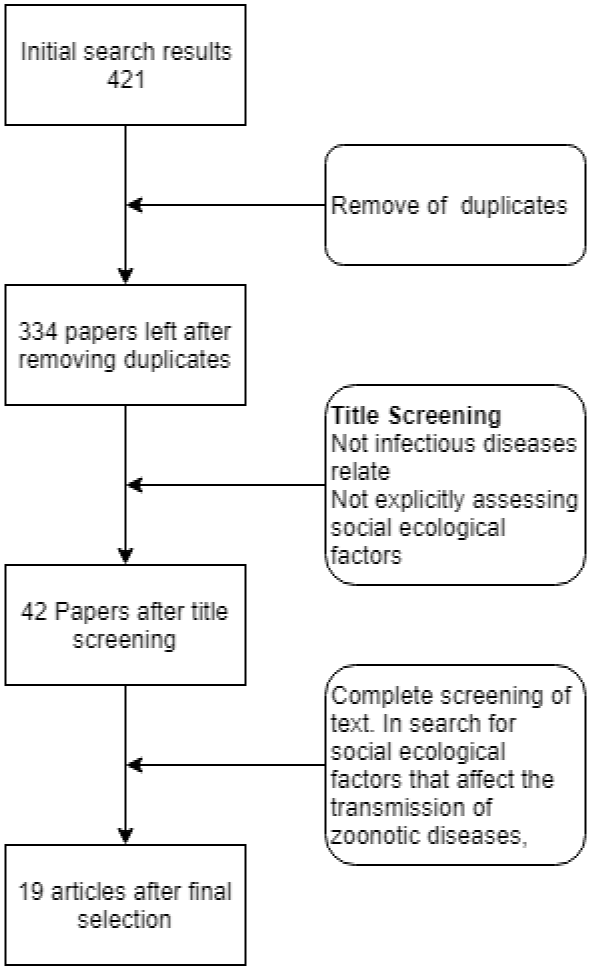

Figure 2 Schematic representation of the literature scoping review methods related to the use of Social-ecological framework for the prevention of infectious diseases.

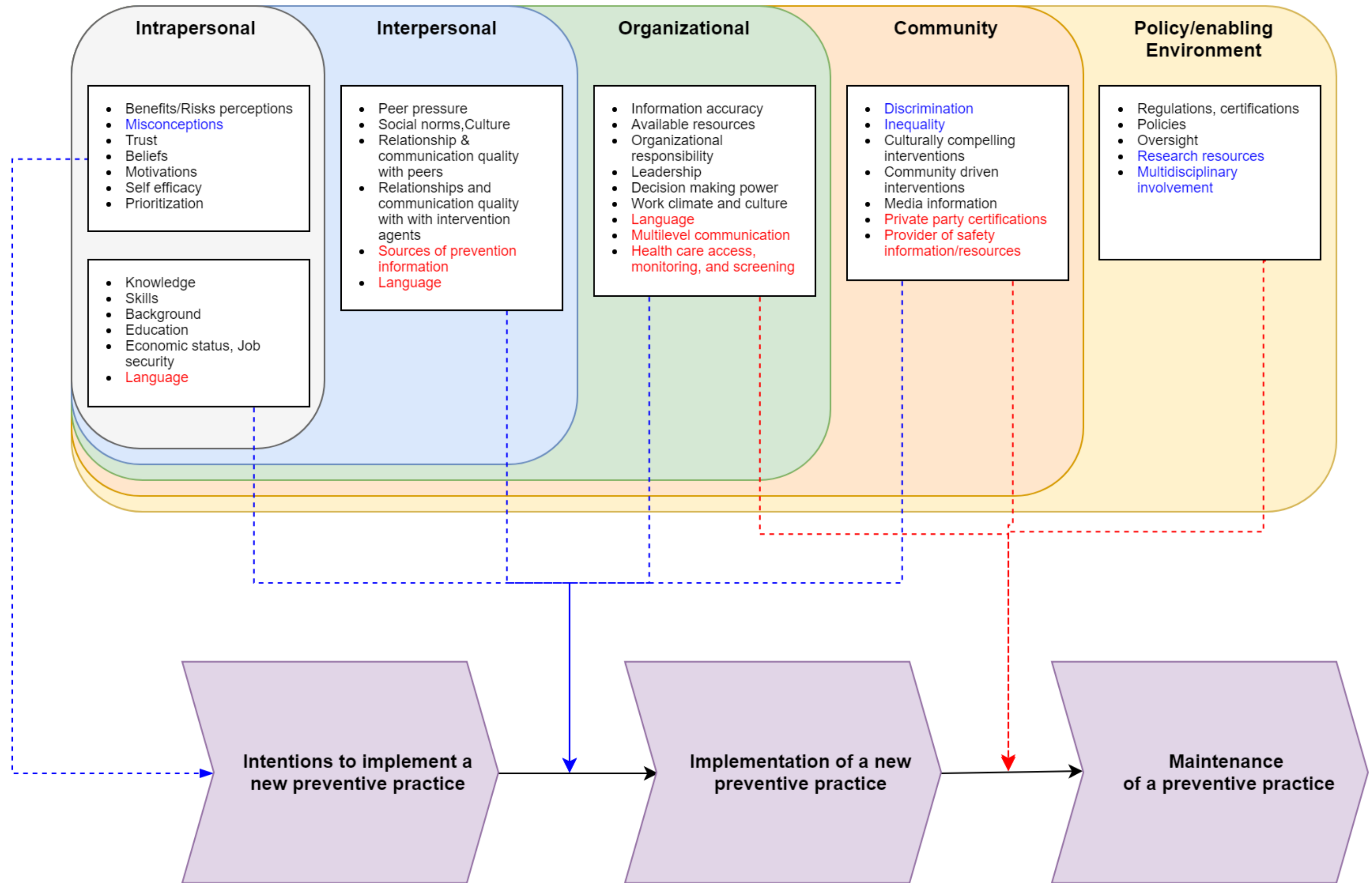

Figure 3 Proposed SEM for the prevention of zoonotic diseases as a work-related hazard in dairy farms. The items in black are shared items mentioned in both the scoping review and the qualitative study. In red are the items that were only mentioned in the qualitative study and blue are the items mentioned only in the scoping review

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Chapter 3. DEVELOPMENT AND VALIDATION OF A BILINGUAL QUESTIONNAIRE FOR THE EVALUATION OF SOCIO-ECOLOGICAL FACTORS AFFECTING ZOONOTIC DISEASE EXPOSURE IN DAIRY FARMS

Summary

Questionnaires are broadly used tools for epidemiological studies. Although they are recognized as important for obtaining epidemiological information, lesser attention is usually paid to the planning, development and conducting of questionnaires when compared to laboratory instruments.

The exposure to infectious diseases is determined by complex traits. Using the epidemiological triad (host, agent, environmental), researchers have been able to identify and characterize many of those traits. Regarding the transmission of zoonotic diseases in occupational settings, there have been considerable efforts to study their determinants. Host and environmental factors such as social, behavioral, psychological, and organizational factors affecting the exposure to zoonotic diseases in places of work still need to be more deeply addressed.

We developed a bilingual instrument that addresses the factors mentioned above and examines its several sources of evidence of validity using the classification of sources of validity evidence published in the Standards for Psychological and Educational Research (AERA 1999).

The following sources of content were used for drafting questionnaire items: a literature review of prevention practices, a literature review of validated questionnaire items measuring the adoptions of new practices at work, and a qualitative survey. The

latter was used not only to draft complimentary items but to give contextual framing to the items drawn from other sources.

Concurrently, we took systematic steps for obtaining evidence of validity from other different sources: quality evaluation and review, pre-testing with volunteer participants, independent binary translation, a field test of the questionnaire with representing subjects, and complementary statistical analysis.

For this questionnaire, using a systematic approach, we demonstrated strong evidence of internal validity from the content, the response processes, internal structure, and consequences. The evidence here presented, provides scientific support that this questionnaire is an adequate tool for measuring important epidemiological factors of zoonotic exposure in animal-human interfaces.

3.1 Introduction

The presence of zoonotic pathogens in dairy farms is a known risk [1–6]. Cases of zoonotic infections affecting humans in close contact with dairy farms have been reported [7–14]. While there have been extensive efforts towards the prevention of zoonotic pathogens in the food products of animal origin [15], the prevention of zoonotic diseases as occupational hazards have received much less attention [16]. Usually, the core interest of workplace safety training in farms is focused on the prevention of injuries, which are the primary health hazards on farms [17,18], leaving the prevention of infections in a second plane.

The prevention of transmission to zoonotic diseases requires comprehensive, integrative, and culturally compelling interventions [15,19–21]. These interventions aim to induce behavior that reduces the chances of disease transmission. However, there is a complex system of several interacting factors that can affect people's behavior towards disease prevention [22–24]. The behavior of the persons at risk towards their protection is one of the critical components of the prevention of diseases in potentially contaminated environments [25]. The socio-ecological model (SEM) has been used in assessing the factors that affect preventive behavior [24,26,27]. The SEM provides a useful framework for a better understanding of the multiple promoters and barriers that impact preventive behaviors and therefore can guide the development of culturally appropriate intervention strategies for dairy farm workers.

Questionnaires are tools often used in epidemiology to assess the determinants of disease transmission [28]. As other instruments used to research and diagnosis, questionnaires need a set of minimum requirements on quality, reliability, and validity [29,30]. To demonstrate evidence of these characteristics in an instrument, a careful and meticulous process of development, validation, and analysis should be applied [30]. According to the American Educational Research Association (AERA), there are several sources of internal validity evidence. These are evidence of validity based on content, on response processes, on internal structure, on the relationship between variables, and on the consequences of applying the questionnaire [31].

In this chapter, we describe the development of a questionnaire that can be used to measure components of the SEM that can affect the preventive behavior towards exposure to zoonotic diseases. And we provide evidence of validity for the sources mentioned above.

3.2 Materials and methods

The development of the questionnaire underwent a sequential process from the establishment of the content, validation, translation, pilot testing, and statistical analysis. The following are the steps taken.

3.2.1 Questionnaire Content

The SEM was used as the reference framework to establish the potential sections of the developing questionnaire (Figure 4). The SEM is composed of multiple compartments that contain factors that have been described as affecting the behavior of the population of interest. The content of the questionnaire was build using a literature review and a qualitative study.

Literature review. A comprehensive literature review was used for identifying recurrent recommended practices for the prevention of exposure to microbial diseases at work. Simultaneously, a literature review was performed searching for instruments measuring behavioral, social, organizational, and personal factors that could be adjusted to be added to the current instrument.

Expert qualitative exploration. Content regarding recommended prevention practices, prevention knowledge, safety training, and required skills to practice prevention on the farm job was reviewed and assessed. We utilized a modified version of the initial stage of a Delphi method. The Delphi method is a flexible research technique that has been used for the exploration of new concepts within and outside the information systems' body of knowledge [32,33]. We included field and university veterinarians, an epidemiologist, an occupational health specialist, and a psychology expert with experience of at least five years working with dairy farms. The participants were also selected based on their willingness to participate, availability for participation, effective communication skills, experience, and expertise. A purposeful two stages "snowball" sampling[3] method was used for reaching out to participants. Potential experts were asked to respond to the questionnaires after explaining the background, objectives, and scope of the study.

The scoping questionnaire was composed of open-ended questions asking experts to list items that may be part of the SEM (Table 4). The questions were reviewed, evaluated, and edited by the author (JP) before delivery to the experts. The responses were recorded without any link to the experts' names to reduce the risk of analyzer bias.

With the collaboration of a qualitative study analysis expert (Megan Dietz), the responses from this stage were analyzed using a grounded theory approach. Briefly, the data were coded and then grouped into concepts. These concepts were then examined and put into one or several SEM compartments for the construction of relevant questionnaire items. These processes were performed by two analyzers independently. Differences were discussed and conciliated.

3.2.2 Questions quality

Based on the literature search and the qualitative study stage, an original questionnaire was developed in English. The questions were drafted using the recommendations of Fowler [34]; i.e., trying to avoid double-barreled questions, lack of clarity, ambiguousness, use of jargon, and unbalanced or biased questions. The questionnaire was organized according to the sections of the SEM. These questions underwent a thorough

[3] **Snowball sampling** (or chain **sampling**, chain-referral **sampling**, referral **sampling**) is a nonprobability **sampling** technique where existing study subjects recruit future subjects

quality evaluation; using criteria of spelling, wording, clarity, language, structure, and grammar.

At this stage, the questionnaire was presented to 4 volunteer graduate students from the Departments of Animal Sciences and Clinical Sciences of Colorado State University (CSU) as a pilot test. The questionnaire was administered as a face-to-face interview; suggestions, questions, comments, or concerns were recorded for further discussion and adjustment.

3.2.3 Questionnaire translation

Since the target population is composed mainly of immigrant workers from Mexico and other Spanish speaking countries, a Spanish version of the questionnaire was developed. The translation of the questionnaire was conducted by two translators independently. One of the translators was the primary author (JP) of this manuscript, a bilingual native Spanish speaker with graduate education in veterinary medicine and epidemiology. The second translator was a native Spanish speaker veterinarian from northern Mexico (same region as most of the target population).

The two Spanish translations were then contrasted to detect translation differences. The discrepancies were discussed and conciliated by the two translators working together, with special attention paid to items that were difficult to translate and to common jargon used in the region. The Spanish version was presented to a third bilingual expert on dairy extension with broad field experience in the region for adjustment or adaptations.

3.2.4 Testing the questionnaire

With the previous approval by the Colorado State University – Institutional Review Board (CSU- IRB). The instrument was pre-tested on five volunteer dairy farm workers of Latino ethnicity from a Colorado dairy farm. The questionnaire was administered in a face-to-face interview with each volunteer. The duration of the interview was recorded, and comments or clarity issues were recorded for further adjustment. Order of the questions was revised, and no major adjustments were performed after this test. The administration of this questionnaire was done following the recommendations of Hatge and Cahill [35], i.e., the interviewer completely read the questions as well as the answer choices (if applicable) to the volunteer, trying to maintain a neutral voice tone to avoid highlighting any of the options. If a question was not clear, a short clarification was allowed by defining the confusing term avoiding examples in favor of a particular answer.

3.2.5 Delivery of the questionnaire

The questionnaire was administered to a total of 42 workers from dairy farms in northern Colorado. The workers were selected conveniently due to the limited access to dairy farms. A short verbal introduction and a letter of invitation and consent were presented to the potential participants, including an economic compensation offer. Workers of milking parlors, calf rearing, maternity, and hospital area were selected due to the reported high-risk areas for exposure to zoonotic diseases in these areas. As the above pre-test, the questionnaire was administered following the recommendations of Hatge and Cahill [35].

3.2.6 Statistical analysis

Principal components analysis (PCA) with varimax rotation was the chosen methodology to explore the evidence of validity based on internal structure. If the PCA results are convergent with the expected sections, we can say that this is evidence of validity based on the internal structure of the questionnaire.

Parallel analysis was used for choosing the number of factors to retain. The parallel analysis was described by Horn (1965) [36], and it is based on the Scree Test. The procedure generates some random matrices with dimensions corresponding to the original data and examines the scree plots obtained from their correlation matrices. The components retrained are those which eigenvalues (proportion of the total model variance explained by that component) of the original data are larger than or equal to those of the simulated random data [37].

Variables and subjects with a large proportion of missing answers were removed (>20%) [38]. The rest of the missing values were imputed using an Iterative Principal Components Analysis method. The iterative PCA (iPCA) method is also known as the EM-PCA algorithm [39,40]. This process provides scores and loadings minimizing the least squares criterion on the observed entries, which is optimal according to the PCA criterion. The minimization is achieved through an iterative procedure: missing values are replaced by random values, and then PCA is applied on the completed data set, missing values are then updated by the fitted values using a predefined number of dimensions. The number of dimensions for the iPCA imputation was obtained using the recommended mean square error cross-validation method.

The principal components procedure was performed using the iPCA imputed dataset and retaining the total of components obtained from the parallel analysis. The orthogonal Varimax rotation was used. A correlation between items and component greater than 0.5 was selected as the cut point for the selection of items. Some items with a correlation of less than 0.5 were selected based on its interpretability within the component.

All the statistical tests were run on R statistical software [41]. The following are the lists of r packages used: stats [41], missMDA [42], nFactors [43], and psych [44].

3.3 Results

3.3.1 Sources of questionnaire content

Literature review of preventive measures and recommendations. Several relevant documents focused on comprising the occupational risk of zoonoses and prevention practices at work were found. The description of the contribution extracted from these papers is summarized in Table 5. All the documents were screened in search for prevention content relevant to the SEM. Table 6 describes the most frequently recommended practices for the prevention of exposure to occupational zoonotic diseases that are pertinent to farm environments. The found prevention subjects were grouped into four sections: facility control measures, management control measures, personal control measures, and external control measures.

Literature review of validated instruments. With the help and advice provided by behavioral science consultant (Dr. Gwen Fisher[4]) and her team, several previously

[4] Associate Professor, I/O Program Coordinator and Director, Occupational Health Psychology Concentration at the department of Behavioral sciences of Colorado State University

validated instruments were identified (Table 7). From those instruments, selected items that adequately measure various components of the SEM sections were adjusted and included in the questionnaire draft.

Qualitative study. Eighteen experts were identified and contacted. Eight of them responded to the questionnaire (44% response rate). Among them, there were university veterinary hospital professors, dairy industry consultants, extension specialist/personnel, epidemiologists/public health experts, and occupational safety/industrial hygiene professionals.

From those eight respondents, a total of four hundred and sixty-two responses were gathered. One hundred and eight codes that comprised 22 themes were extracted. The most common codes and themes are summarized in Table 8.

3.3.2 Questionnaire validation, translation, and testing

Based on the literature search and the qualitative study, 154 items were drafted using the recommendations of Fowler [34]. The items were organized into the following sections: background, knowledge and skills, training, organizational factors, social factors, preventive practices, interpersonal/personal factors, self-efficacy, and demographics.

During the review process and the initial tests, the items were adjusted, combined, or removed according to the established criteria and the feedback from reviewers. At the end of this stage, 74 questions (123 items) composed the questionnaire.

During the translation, process adjustments were made to make the language of the questions more familiar to the target population. The translator from northern Mexico included terms proper of the region to enhance clarity. For example, the word “farm” can be translated as “granja” in standard Spanish, but in Mexico, the best word defining farm is “rancho.” Similarly, the reviewer with field experience in dairies helped to identify jargon commonly used by dairy workers of the region. Over time, the community of dairy workers in Mexico has created their slang with several idioms that are only proper to that population. Sometimes you can hear words used that are neither English nor Spanish but a mix of both. For Example, the verb “pushear” or the subject “pusheador” is a derivative of “push” and is used for defining the act of “pushing” the cows into the milking stalls.

After the pre-test with dairy workers, four questions were removed due to clarity or pertinence issues. The duration of the questionnaire varied from 35 to 40 minutes.

3.3.3 Administering the questionnaire

Of the 54 workers asked to participate, 42 workers agreed to complete the questionnaire (78% response rate). The interview was performed after the work-shift. The main reasons for not participating were time restrictions or lack of availability of transportation after the interview. On average, the time for completing the questionnaire was 40 minutes.

3.3.4 Principal Components Analysis results

After transcribing the responses, the database had a total of 4% of missing values. Nineteen items and one responder were dropped due to their high proportion of missing responses (>20%). This reduced the proportion of missing values to approximately 1%. After this, iPCA was effective for imputing the remaining missing values. All other procedures were conducted using the imputed dataset.

According to the parallel analysis, ten components had equal or larger eigenvalues to those randomly simulated and were retained (Figure 5). The imputed data set was then used for running the PCA. Results from the PCA are summarized in Table 9

The ten factors retained accounted for 74% of the variance (eigenvalues ranging from 9.35 to 5.43). From the 102 items, 76 items remained as important contributors to component variance. The dropped items did not have enough correlation (>0.5) values or have low correlations with multiple components.

Based on the contributor items, clear construct discrimination was found. The constructs that correspond to the ten principal components (PC) are shown in Table 10

Six out of the ten principal components are related to the workplace. Knowledge and risk perception related to zoonotic diseases is an important component with a contribution of ~9% of the total variance. Attitudes towards health problems were found composing two different dimensions. Injury attitudes items were discriminated from other items asking about health issues. The dimensions that contribute less to the variance (PC10, PC9, PC8) contained more diverse items.

3.4 Discussion

The AERA and APA (American Psychological Association) accepted definition of instrument validity (score, questionnaire, test, etc.) is “the degree to which evidence and theory support the interpretation of the test results” [31]. According to this definition, in the 1999 edition of the Standards for Educational and Psychological Testing [45], new key concepts were introduced about instrument validity. It was then stated that “the process of validation involves accumulating evidence to provide a sound scientific basis for the proposed instrument…” and redefine the classification of the potential sources of such evidence. Before the 1999 edition, there were three main validity criteria: content validity, criterion validity, and construct validity (so-called, the trinity of instrument validity). In the 1999 edition, these concepts were not replaced, though, they were included in the new classification and complemented with the inclusion of new concepts beyond the mere characteristics of the instrument itself. According to the new edition (1999), the validity of an instrument should be evaluated by multiple sources of validity evidence. In this section, we use the AERA classification of sources for evidence of validity for discussing the evidence of the validity of the proposed instrument.

3.4.1 Evidence of validity based on the content of the instrument

The evidence of validity based on the content refers to whether the content of the instrument is representative of the phenomena that it is attempting to measure [30,46,47].

In this research, we used three complementary sources of content. The first one was a complete scoping review of the literature for themes related to knowledge and prevention practices. For this part, it was clear that the knowledge and recommendations for prevention of infectious diseases were congruent among different sources, which can be an indicator of the validity of such practices as being effective on preventing infections on the workplace.

The second source of content was a literature review, and in this case, the review was used to obtain items measuring organizational factors that had been previously validated and used in the behavioral sciences. The principal search criteria for this part was to identify items that had been found to significantly affect the adoption of new practices at work (eg., preventive practices). Thanks to the experience and expertise of

Dr. Fisher and her team, we were able to compile several items that group into all the organizational factors that have been described as affecting the adoption of a new practice at work.

The third source of content was a qualitative study for the extraction of items related to several of the themes of interest. This study resulted in an effective way of obtaining items on knowledge, training and general safety climate. There was an agreement between experts even among those that worked in different science fields. The field experience and the diversity of the respondent group complemented the literature reviews previously described. The themes extracted using the ground theory methodology were used to draft additional items that were complementary to the previous ones.

3.4.2 Evidence of instrument validity based on response processes

This source of evidence can be defined as the extent to which the types of participant responses match the intended construct [46,48]. This definition can be put in other words such as - to what extent the respondents are not just giving responses that are socially or organizationally accepted. We performed several steps for providing evidence of validity based on response processes.

We took meticulous steps in writing, reviewing and editing the questions giving special attention to writing questions so that they did not induce any particular answer, that was very clear (not using jargon, and using common idioms and slang for the target population, language of preference), and avoided asking about very common socially acceptable preventive behaviors. As an example, a pretty common preventive behavior asked is washing hands, which is also a very socially accepted behavior. We knew beforehand that if we directly ask whether the responder washes her(his) hands the responses would have come from the social acceptability side of this behavior. Rather, we asked about the respondent's opinion about washing hands as an effective preventive behavior; we believe that this type of question would gather a most honest response and it would serve our purposes of indirectly measuring the behavior and attitudes towards this practice.

Another step taken was the testing of the initial questionnaire on a few volunteers. This allowed us to preview what reasoning process the responder makes when responding to problematic questions. The most sensitive questions were those related to their attitudes and perception of coworkers, supervisors, and top administration in general. Based on observations by the interviewers the statement of confidentiality helped in preventing dishonest answers. Another important step was performing the interview in a face to face manner using neutral speech tone and clarifying items as needed. This also decreased the chances of answering according to norms [48]. Beyond that, problematic items were removed under suspicion of lack of honesty when answering.

3.4.3 Evidence of instrument validity based on internal structure.

This source of evidence is defined as the degree to which the relationships among tests items and components conform to the constructs on which the proposed instruments interpretation is based [46].

The method recommended to study evidence based on internal structure is the factor analysis (e.g., PCA). We used the responses from the 42 dairy workers to perform a PCA. It was expected that some of the components converge to the SEM factors described previously. According to the results, the principal components were mostly related to workplace factors. This was anticipated since we included a large proportion of previously validated items that measure organizational factors. In the same way, PC4 was found to be an important contributor to the total variance due, again, to the use of previously validated items in this regard.

In contrast, when analyzing the non-work-related components, we found that PC1 (eigenvalue of 9.06. 12% total variance contribution) compiled important items related to knowledge, perception, attitudes, and concerns about risks of zoonotic diseases (PC1). This is a very important finding since this component is closely related to the rationale behind this study's objectives. Interestingly, we also found discrimination of items related to injuries from items related to other health conditions (symptoms of infectious diseases). This is an indicator of the use of a different thought process when responding to injuries compared to other health events.

3.4.4 Evidence of validity based on relationships between variables

This type of source of evidence of validity for instruments is based on the assumption that the instrument should measure the same construct among different populations [49]. In this case, we only applied the test to one population, so it is difficult to assess this source of evidence. Nevertheless, an indicator of relationships among variables is that most of the items that we extracted from previously validated instruments are also present as principal components of the PCA. We can assume that our finding enforces the hypothesis that these items are measuring the same construct across different populations.

3.4.5 Evidence of validity based on the consequences of applying the instrument

This concept introduced in the AREA standards in 1999 refers to the fact that the application of an instrument can affect the participants directly or indirectly. The effects of implementing an instrument can be as good as they can be harmful [45].

Using the CSU-IRB recommendations of protection of participant subjects, we ensured that the responses of the survey could not be traced back to its respondent and so would avoid any potential retaliation based on the responses. Also, we were careful in trying to interfere as little as possible with their daily routine. All the participants were asked to participate in the study voluntarily and had the option of terminating the interview at any time. Since we requested permission from the farm's administration and we performed the interview during non-shift hours, we believe that participation in the interview did not have a negative impact on the dairy workers.

3.5 Conclusions

A large proportion of epidemiological studies use data gathered from questionnaire instruments. Logically, the quality of an epidemiological study may be harmed if the instruments used are not accurate, i.e., if they do not measure what they are intended to measure. For this reason, sources of evidence of validity should be evaluated to ensure the accuracy of any test used in epidemiological studies. In this case, we used the concepts and strategies for evaluating validity that is used in the behavioral and education sciences to evaluate diverse and complementary sources of evidence of validity.

In this case, one of the major study limitations is having a small sample size regarding total participants and number of sampled farms. It will be necessary to expand

and improve the relationships and collaborations between the researchers (with institutional support) and the stakeholders, in order to obtain access to more field locations for research.

Further research goals are recommended to ensure the quality of the instrument here presented. It is necessary to assess with more confidence the external validity and reliability of the instrument. This assessment can be achieved by repeating the measurement process on a similar population, by administering the instrument to different populations to check the consistency of responses, and by administering it to a random sample of subjects.

Though it was possible to find complete information on questionnaire design and implementation strategies in epidemiological sources, it was often very fragmented, and few of them, if any, referenced other disciplines. In contrast, there are very detailed, complete and standardized protocols and methods for laboratory instruments.

The here developed questionnaire can be used as a primary means of data collection for multiple purposes. This instrument can measure different parts of the social ecological model of transmission of diseases. The diagnostic use of this tool may be used to assess the constructs individually for a particular interest, e.g., an employer wants to evaluate the perception of workers towards supervisors. Similarly, this tool can be used as a research tool to investigate the effect that these constructs have in a particular outcome, e.g., the effect of supervisor perception on training effectiveness.

It can be stated that in epidemiological studies, a large proportion of the resources are spent on the data analysis but not on the development of accurate and reliable instruments. We firmly believe that at least the same amount of attention and effort should be applied to the validity and reliability of measurement instruments (laboratory instruments and questionnaires). In this aspect, we consider that epidemiology, as a scientific discipline, needs more collaborative efforts for building standards for using questionnaire instruments.

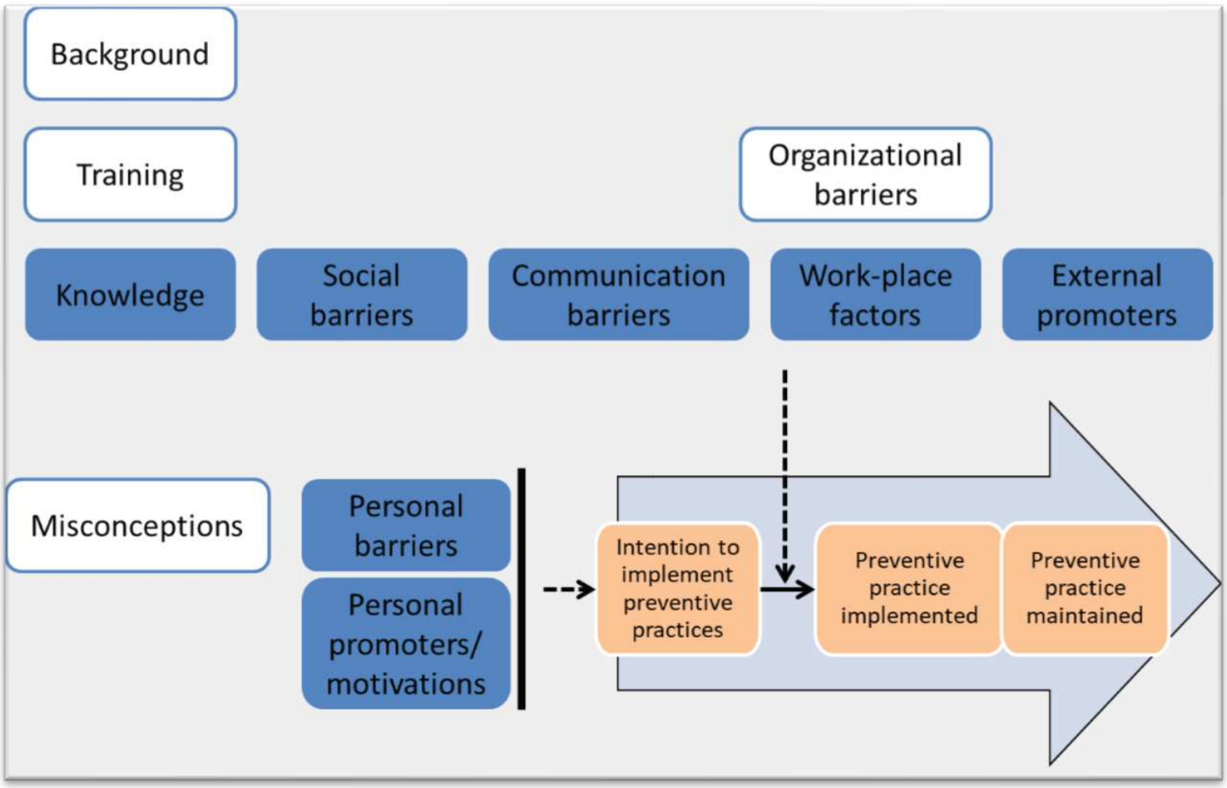

Figure 4. A social ecology model of preventive behavior. Adapted from Panter-Brick et al. (2006) [22]

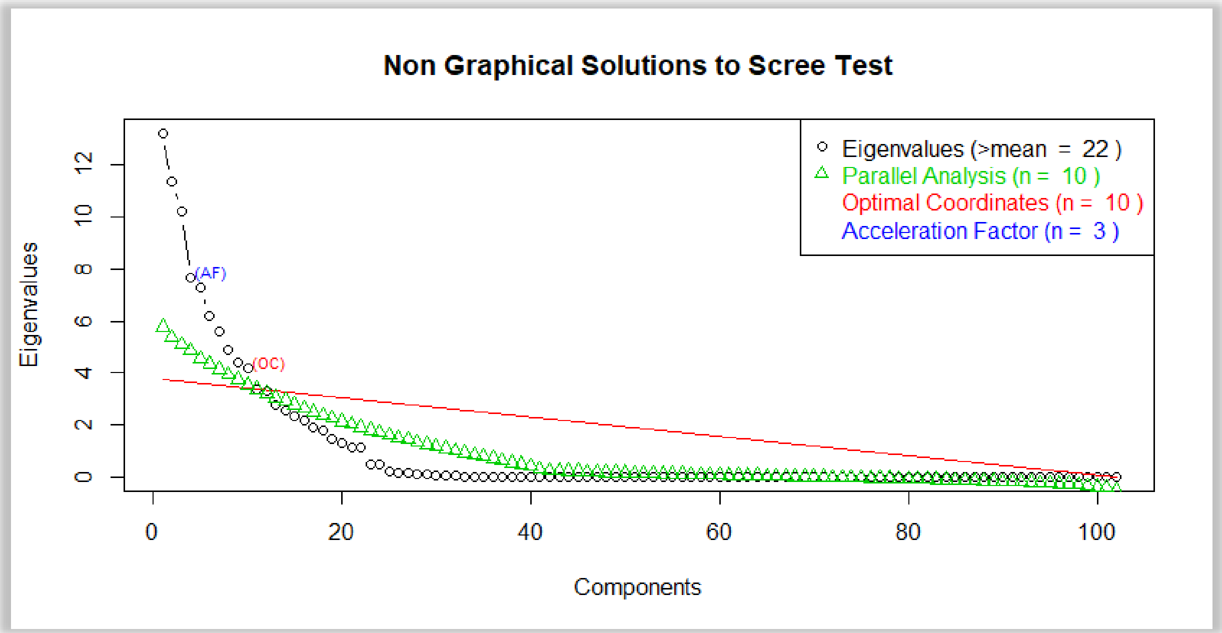

Figure 5 Eigenvalues of observed (°) and simulated (△) data

Table 4 Final questions presented to the expert participants

1. Please, list the TOPICS or SUBJECTS that workers of dairy farms should understand to prevent exposure to zoonotic diseases.

2. Please, list the most EFFECTIVE CHANNELS or METHODS for communicating and transferring accurate information about the prevention of zoonotic disease exposure to dairy workers.

3. List the CONTENT of topics that a training program for workers for the prevention of exposure to zoonotic agents in farms should address.

4. List the most ACCURATE sources the workers of dairy farms should use to find information about prevention of exposure to zoonotic diseases.

5. List the most INACCURATE sources the workers of dairy farm MAY use to find information about prevention of exposure to zoonotic diseases.

6. List OTHER factors regarding the sources or channels of information that you think may be important for the prevention of exposure to zoonotic disease of dairy workers.

7. List the CHALLENGES or BARRIERS that dairy farm workers encounter that might prevent their acquisition of information to prevent zoonotic diseases exposure.

8. List the personal protection equipment (PPE) that should be worn by workers while performing their job duties ... throughout the dairy farm

    a. ...Specifically in the milking parlor area

    b. ...Specifically in the calf-pens area

    c. ...Specifically in the hospital area

    d. ...Specifically in the maternity/calving area

9. List the FACILITIES that a farm should have to prevent the exposure to zoonotic disease of its workers.

10. List OTHER factors regarding the workplace that you think may be relevant to the prevention of exposure to zoonotic diseases in dairy farms.

11. List the potential PROMOTERS that may improve the implementation of practices for the prevention of exposure to zoonotic diseases on a dairy farm

12. List the potential COMMUNICATION barriers that may impair the implementation of practices for the prevention of exposure to zoonotic diseases in a dairy farm.
13. List the potential ORGANIZATIONAL barriers that may impair the implementation of practices for the prevention of exposure to zoonotic diseases in a dairy farm.
14. List what practices a worker should implement for her/his protection to prevent exposure to zoonotic agents.
15. List the practices that dairy farms should implement to protect the exposure to zoonotic agents of their workers.
16. Please use this space to input any comments or suggestions

Table 5 Relevant documents included that describe the measures for prevention of infectious diseases as work hazard and the SEM component that they cover.

AUTHOR	TITLE	DESCRIPTION	SEM SECTIONS
Rim and Lim (2014) [16]	Biologically Hazardous Agents at Work and Efforts to Protect Workers' Health: A Review of Recent Reports	This article is a complete review of the many Biologically Hazardous Agents found in different work environments and includes sound and thorough prevention recommendations	Knowledge and Prevention practices
LeJeune and Kersting (2010) [50]	Zoonoses: an occupational hazard for livestock workers and a public health concern for rural communities	This review focuses on the different populations at risks of zoonoses, also presents an appraisal of prevention strategies and a summary of essential elements of agricultural significance of zoonoses in the U.S.	Knowledge and Prevention practices
Donham (2006) [19]	Zoonotic diseases: overview of occupational hazards in agriculture, in Agricultural Medicine: Occupational and Environmental Health for the Health Professions	This chapter provides information for health care providers on the potential risks of zoonotic diseases on agricultural workers	Knowledge
World health organization (WHO) (2004) [51]	Biosafety guidelines, in Laboratory Biosafety Manual	This document is a detailed guide that contains recommendations towards the prevention of biohazard risks caused by managing microbiological samples in controlled laboratory environments.	Prevention practices.

AUTHOR	TITLE	DESCRIPTION	SEM SECTIONS
Cook and Farrant [52]	Occupational Zoonoses	This article gives a general overview of the occurrence and transmission of zoonotic diseases	Knowledge
Wilkinson [53]	Zoonotic Disease Risk for Livestock Production Workers	This document aim is to increase the awareness of the actual risks for zoonoses occurrence in farms.	Knowledge

Table 6 Most common recommended preventive practices for prevention of occupational exposure to zoonotic diseases.

Facility control measures

- Containment, isolation, or quarantine areas for sick animals
- Facilities design that decreases the contact between personnel and animals
- Allow for segregation or separation of clean facilities from potentially contaminated ones
- Availability of sanitary facilities (showers, dress/locker-rooms, rest area)

Management control measures

- Training
- Supervision
- Operative procedures or protocols
- Availability of physical and economic resources for prevention
- Proper disposal of contaminated material
- Good husbandry practices and heard health management
- Personnel health prevention and surveillance programs
- Pest and vector control measures
- Biosafety management plan

Personal control measures

- Hygiene and cleanings (especially hand hygiene)
- Use of PPE
- Vaccination
- Regular medical evaluations
- Proper prevention knowledge

External control measures

- Regulations
- Policies
- Research
- Dissemination of information

Table 7 Items and sources of previously validated instruments

SEM SECTION	CONSTRUCTS MEASURED	EXTRACTED FROM	REFERENCE
Workplace	General job satisfaction	Cammann et all. (1979)	[54]
	Organizational commitment	Allen and Meyer (1990)	[55]
	Role overload	Seashore et al. (1982) & Cammann et al. (1979)	[54,56]
	Role conflict	Haynes et al. (1999)	[57]
	Role ambiguity	Breaugh & Colihan (1994)	[47]
	Job control	Karasek (1985)	[58]
Community and workplace	Social and organizational support	Eisenberg et al. (1986)	[59]
Job-related self-efficacy	Workability	Tuomi et al. (1998)	[60]
	Self-efficacy	Tierney y Farmer (2002)	[61]
Social	Safety culture and climate	Dejoy (2005)	[62]
Training	Intent to adopt Intent to continuing use	Liao & Lu (2008)	[63]
	Experience with prior training	Machin & Fogarty (2003)	[21]
Training & self-efficacy	Pre-training self-effacing, motivation to learn	Quinones (1995)	[64]
Training & attitudes	Training effective perception	Holton et al. (2000)	[65]
Attitudes	Perception of work safety	Hayes et al. (1998)	[66]

Table 8 Themes based on most frequent responses by the experts.

THEME	MORE FREQUENT CODES	CODES FREQ. BY TOPIC
Knowledge and training content	PPE Cleaning/Disinfection/Sanitation Risk factors Basic microbiology and immunity Handwashing Personal hygiene Health risks and consequences Zoonoses	37
Information sources	Training programs Internet Producer/manager/supervisor Printed materials Family(barrier) Extension Animal and Human health professional	24
Training practices	Post-training evaluation Training frequency Demonstration Participatory Producer/manager/supervisor training	10
Training materials	Print materials Language sensitive/bilingual material	5
Attitudes beliefs	Risk/benefit perception Time constraints Trust in trainers/supervisors/sources of information	6
Others	Language/communication Education level/literacy Culture Health care access Peer pressure Work climate/culture	26

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*Table 9 Descriptive statistics and components loadings (n=41). Unless specified by the symbols, †, *, or ‡, the responses have a scale of 1-5.*

VARIABLES	$\bar{x}$	*SD*	PC3	PC1	PC4	PC2	PC6	PC7	PC5	PC10	PC9	PC8
SS loadings (eigenvalues)			9.35	9.06	8.43	7.88	7.78	7.30	7.04	6.56	6.18	5.43
Proportion of Variance explained			0.12	0.12	0.11	0.10	0.10	0.10	0.09	0.09	0.08	0.07
Cumulative proportion of Variance explained			0.12	0.25	0.36	0.46	0.57	0.66	0.76	0.85	0.93	1.00
Cumulative proportion of total Variance			0.09	0.18	0.26	0.34	0.42	0.49	0.56	0.62	0.68	0.74
My employer provides adequate resources for protection at work	4.48	0.75	0.81	-0.13		0.00		-0.04		0.36		0.09
Management is heading the farm in the right direction	4.49	0.76	0.71	0.12		0.33		-0.13		0.00		-0.11
Management is honest and open with me	4.40	0.74	0.71	0.22		0.07		0.04		-0.01		0.01
I feel the farm problems are my problems too	3.77	1.37	0.71	-0.08		0.04		-0.15		-0.25		-0.19
Farm management provides accurate safety information	4.18	1.03	0.70	-0.17		0.27		-0.12		0.11		0.05
Farm management provides adequate safety training	4.18	1.08	0.61	-0.17		0.37		-0.17		-0.04		0.07
I'm proud to tell others I work here	4.56	0.59	0.61	-0.20		-0.16		0.16	0.51	-0.22		-0.10
Help is available from my coworkers when I have an inquiry about safety	4.29	1.08	0.57	-0.11		0.20		0.02		-0.18		-0.40
I have a strong sense of belonging with the farm	3.85	1.10	0.55	0.20		-0.15		0.15		-0.36		0.20
Which of the flowing is a measure of infectious diseases prevention?	0.65†	0.30	-0.55	-0.20		0.03		-0.29		-0.16		0.16
What is the main aim of cleaning?	0.98†	1.13	-0.54	-0.17		-0.07		0.29		-0.07		-0.12
Cattle can transmit diseases to humans	0.76*	0.62		0.91		-0.11		-0.14		-0.04		0.03
Zoonotic diseases can cause serious health problems	0.73*	0.62		0.88		-0.05		-0.18		-0.01		-0.00

VARIABLES	$\overline{x}$	*SD*	PC3	PC1	PC4	PC2	PC6	PC7	PC5	PC10	PC9	PC8
How long would it take you to report to your supervisors? - Flu symptoms	3.67	0.84		0.76		0.12		0.11		0.02		0.01
How long would it take you to decide to go to the doctor? - Flu symptoms	3.22	1.01		0.74		0.00		0.28		0.14		-0.01
Diseases transmitted from cows to people can harm workers permanently	0.50*	0.63		0.59		-0.25		0.07		-0.05		-0.22
How much risk do you believe zoonotic diseases pose to workers' health and safety?	3.41	1.07		0.59		0.09		0.19		-0.27		0.11
How much risk do you believe zoonotic diseases pose to workers' family health and safety?	3.44	1.18		0.58		-0.07		0.15		-0.25		0.22
How concerned are you that you family can get an infectious disease from your work place?	3.15	1.53		0.56		-0.05		-0.03		0.06		0.44
I know what my boss considers a satisfactory work performance	4.15	1.11		-0.51		-0.20		-0.11		-0.07		0.14
If you have intestinal infection symptoms, how long would it take you to report to your supervisors?	3.77	0.58		0.50		0.39		0.25		-0.26		-0.07
How much risk do you think the contact with a sick animal represents to you?	3.44	1.36		0.46		-0.10		0.23		-0.37		0.19
How afraid are you that you can get an infectious disease at work?	2.71	1.42		0.42		0.02		0.29		0.17	0.53	0.55
I am confident about my ability to perform my job tasks	4.63	0.58		-0.02	0.82	0.06		0.14		-0.09		0.19
How do you grade your quality of work?	8.63‡	1.36		-0.05	0.81	-0.00		-0.11		0.31		-0.15
How would you rate your interest on prevention of diseases at work?	4.78	0.57		0.00	0.80	0.03		-0.02		-0.23		-0.02

VARIABLES	$\overline{x}$	*SD*	PC3	PC1	PC4	PC2	PC6	PC7	PC5	PC10	PC9	PC8
I have the skills necessary to implement preventive practices	4.12	0.84		-0.33	0.73	0.15		0.01		-0.13		0.05
How do you grade your ability to meet technical demands?	8.78‡	1.44		0.00	0.69	-0.13		0.03		0.10		-0.13
I am confident about my ability to implement preventive practices	4.07	0.93		-0.34	0.69	0.04		0.10		0.13		0.18
How easy is it to comply with work safety recommendations?	4.76	0.58		-0.03	0.63	0.21		-0.24		-0.20		-0.05
Grade the quality of communication with top Management	3.92	1.04		-0.33	0.63	0.14		0.05		0.19		-0.03
The management has my best interest in mind	4.15	1.08		0.12	0.57	-0.11		-0.00		-0.30		-0.12
How easy would it be for the group to adopt a new preventive practice	3.80	1.11	0.51	0.31	0.50	-0.19		-0.03		0.11		0.13
How likely are you to report to your supervisors if you see that a co-worker is sick?	4.37	1.04		-0.00		0.77		0.13		-0.25		0.04
My supervisors encourage the use of PPE	4.40	0.98		0.04		0.70		0.07		0.46		0.00
How likely are you to report to your supervisor if you have fever?	4.37	0.97		0.06		0.69		0.25		0.01		0.12
My supervisors show a lot of concern about my safety	4.71	0.51		-0.12		0.67		0.03		0.18		-0.11
My coworkers show a lot of concern about my safety	4.08	1.12		-0.19		0.62		-0.27		0.01		-0.44
My supervisors are knowledgeable about how to correctly wear PPE	4.73	0.45		0.45		0.62		0.30		-0.00		0.06
Everyone at work cares whether I wear or not PPE	3.97	1.32		0.35		0.55		-0.19		-0.04		-0.15
Grade the quality of communication with your coworkers	4.26	0.94		-0.31		0.55		0.09		0.38		0.00

VARIABLES	$\bar{x}$	*SD*	PC3	PC1	PC4	PC2	PC6	PC7	PC5	PC10	PC9	PC8
How likely are you to report to your supervisor if you have a sprained/twisted wrist?	4.61	0.92		0.02		0.00	0.92	-0.02		0.12		0.02
How likely are you to go to the doctor if you have a wound with moderate bleeding?	4.80	0.72		-0.08		0.05	0.88	0.06		-0.12		0.06
How likely are you to report to your supervisor if you have wound with moderate bleeding?	4.76	0.70		-0.12		0.05	0.86	-0.02		-0.02		0.05
How likely are you to report to your supervisor if you have vomit?	4.22	1.19		0.01		0.49	0.73	0.20		-0.01		0.16
How likely are you to report to your supervisor if you have diarrhea?	4.15	1.28		-0.12		0.20	0.68	-0.06		0.18		0.31
How likely are you to go to the doctor if you have a sprained/twisted wrist?	4.43	0.93		0.26		0.13	0.68	0.06		0.13		-0.13
How likely are you to go to the doctor if you have diarrhea?	3.00	1.40		0.13		0.04		0.84		0.12		0.05
How likely are you to go to the doctor if you have fever?	3.37	1.43		0.07		-0.02		0.82		0.13		0.09
How likely are you to go to the doctor if you have vomit?	3.03	1.54		0.09		0.06		0.78		0.07		0.07
If you have intestinal infection symptoms, how long would it take you to decide to go to the doctor? -	3.75	0.54		0.29		0.12		0.70		-0.04		-0.01
How likely are you to go to the doctor if you have fever and sore throat?	3.18	1.32		0.11		0.21		0.67		-0.21		-0.03
How likely are you to go to the doctor if you have sore-throat?	2.70	1.30		-0.42		-0.04		0.67		-0.03		-0.05
How likely are you to go to the doctor if you have flu like symptoms?	3.21	1.40		-0.06		-0.08		0.66		0.07		0.08

VARIABLES	$\overline{x}$	*SD*	PC3	PC1	PC4	PC2	PC6	PC7	PC5	PC10	PC9	PC8
How likely are you to go to the doctor if you have intestinal infection symptoms?	4.08	1.07		0.42		0.24		0.49		-0.06		0.07
Reporting my health problems would get me in trouble with my supervisors	1.76	1.59		0.11		0.03		0.11	-0.88	-0.13		-0.15
Help is available from the managers when I have an inquiry about safety	4.78	0.42		-0.17		0.17		0.04	0.73	0.24		-0.13
I like working here	4.76	0.43		-0.08		-0.04		0.17	0.70	0.00	-0.52	0.10
I am satisfied with my job	4.78	0.42		-0.14		0.16	0.56	0.16	0.65	0.12		0.03
From your point of view, how many of your coworkers think wearing PPE does not serve any purpose	2.38	1.37		-0.16		0.17		-0.02	-0.62	-0.18		0.16
Attendants to training are involved in training activities/demonstrations	2.74	1.60		0.12		0.20		0.07	0.58	0.03		-0.03
What of the following vaccines are strongly recommended for dairy farm workers?	0.33†	0.33		-0.06		-0.18		0.13		-0.83		-0.08
It is clear to me what are my duties at work	4.73	0.63		-0.09		0.04		0.10		0.77		0.17
What is the highest degree or level of school you have completed?	2.12	1.19		-0.19		-0.42		0.16		-0.60		-0.22
My supervisors are knowledgeable about safety at work	4.68	0.57		0.09		0.38		0.38		0.58		0.03
I have received clear instructions on how to adequately use PPE	4.36	1.27		0.07		0.00		0.02		0.55		-0.02
Grade the quality of communication with your supervisor	4.26	0.99		-0.26		0.40		-0.01		0.52		0.32
I believe that training sessions are a waste of time	4.59	1.04		-0.10		-0.25		0.13		-0.05	-0.81	0.05
How often is the training given in the language of your preference?	4.07	1.21		0.03		-0.21		0.12		0.18	-0.72	0.04

VARIABLES	$\bar{x}$	*SD*	PC3	PC1	PC4	PC2	PC6	PC7	PC5	PC10	PC9	PC8
Upper management makes conflicting demands on me	2.46	1.31		0.06		-0.17		0.27		0.02	0.61	-0.13
Help is available from the organization when I have an inquiry about safety	4.29	1.05		-0.23		-0.18		0.18		-0.10	-0.61	-0.06
I'm always rushing doing my job	2.27	1.30		-0.06		-0.05		0.07		0.08		0.85
On my job, I have freedom to decide how I work	3.32	1.57		0.09		0.18		0.18		0.18		-0.72
How likely are you to report to your supervisor if you have the following symptoms - Coughing	3.66	1.41		0.21		0.30		0.28		0.17		0.63
At work, I feel discriminated	1.60	0.81		0.10		0.22		0.00		0.13		0.51
How likely are you to report to your supervisor if you have the following symptoms - Sore throat	3.61	1.32		-0.21		0.39		0.23		0.07		0.50

PC: Principal components

† Bivariate answer question; Correct answer=1, incorrect answer=0

* True/false question, False=-1, true=1, not sure=0

‡ Scale question; range=1-10

Table 10 Constructs extracted from the principal components (PC)

COMPONENT	CONSTRUCT
PC3	Workplace Administration perception Organizational commitment Provided resources
PC1	Knowledge & risk perception Knowledge relevant to zoonotic diseases Risk perception and concerns
PC4	Self-efficacy Workability Preventive practices ability
PC2	Workplace Supervisor and coworker perceptions and attitudes
PC6	Injuries Reporting Seeking healthcare
PC7	Other health issues (non-injuries) Seeking healthcare
PC5	Workplace Job satisfaction Reporting retaliation
PC10	Workplace Safety culture and climate Supervisor communication
PC9	Workplace Role conflict Organizational support Training sessions perception
PC8	Workplace Job control

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Chapter 4. SOCIO-ECOLOGICAL FACTORS AFFECTING ZOONOTIC DISEASE EXPOSURE AMONG COLORADO DAIRY FARMS WORKERS

Summary

The presence of zoonotic pathogens in dairy farms is a known risk for people that work and live on dairy farms. *Salmonella* serovars, *E. coli* (O157; H7), *Campylobacter jejuni*, and *Cryptosporidium parvum* exposure and transmission have been documented to occur in the dairy farm environment. Social ecological factors have been identified as determinants of preventive behaviors of people at risk of infectious diseases. Combining survey results and measures of exposure to zoonotic agents, we determine the effect of social ecological factors on the epidemiology of zoonotic diseases in dairy farm workers. We identified positive occupational exposure to *Salmonella* ser*.* Dublin and *Campylobacter spp.* Additionally, we found evidence of social ecological factors affecting the exposure to zoonotic diseases in farm workers. Self-efficacy and negative workplace perceptions are risk factors of *Salmonella* Dublin exposure (OR=1.43 [CI 1.11-2.22] & 1.22 [CI 1.02-1.53] respectively). Knowledge and positive management perceptions were found to be protective (OR = 0.90 [CI 0.79-1.00] & 0.91 [CI 0.82-1.00] respectively). Perception of supervisors and coworkers is a protective factor of *Campylobacter* exposure (OR=0.89 [CI 0.79-0.98]). Based on our observations, a supporting organizational environment, with supervisors and coworkers as deliverers of accurate safety information, and with increased training on prevention measures, and potential risks and consequences of zoonotic diseases would help to reduce the occupational exposure of zoonotic disease in these farms.

4.1 Introduction

Dairy cattle operations represent a working environment with a high risk of exposure to zoonotic pathogens [1–14]. Many agents have been found not only contaminating the dairy farm environment but causing diseases to farmers, workers, and consumers of dairy products [10,11,15–27]. Among the most common pathogens found are *Salmonella* serovars, *E. coli* (O157; H7), *Campylobacter jejuni*, and *Cryptosporidium parvum*, which are of particular interest due to their abundance in the farm environment, and due to the illness severity they may cause [21,24,28–31]. While there have been extensive efforts towards the prevention of zoonotic pathogens in the food products of animal origin [32], the prevention of zoonotic diseases as occupational hazards have received much less attention [33]. Usually, the core interest of workplace safety training in farms is focused on the prevention of injuries, which is the primary health hazards on farms [34,35].

The prevention of zoonotic diseases in animal-human interfaces can be challenging. Several factors determine whether a person may be exposed and others determine if the exposed person becomes infected with a zoonotic disease [10–12]. The preventive behavior is, if not the most, one of the more critical components of prevention of diseases in potentially contaminated environments [36].The socio-ecological model (SEM) has been heavily used in assessing the factors that determine behavior regarding prevention of events causing health issues [37–39]. The SEM provides a useful framework for achieving a better understanding of the multiple promoters and barriers that impact safety practices and prevention in the farm and therefore can guide the development of culturally congruent prevention strategies for dairy farm workers.

It has been demonstrated that the behavior of the person at risk can affect their exposure to infectious agents [40–44]. Therefore, leading towards strategies that attempt to change the human prevention practices will, perhaps, reduce the risk of exposure to these infectious pathogens. As demonstrated in other settings, the implementation of consistent and robust preventive measures can change the behavior of persons at risk and successfully decrease exposure to risk factors [40,43,44]. However, the complexity of factors that drive human behavior represents a challenge for designing interventions that effectively change behavior. Therefore, according to the social ecology theory and science, for a preventive program to be successful, it should build on existing practices, skills, and priorities, recognizing and being aware of the complexity and limitation of the human social environment [44,45].

The science of human behavior and its theory have been applied to preventive programs for several health issues; prevention of nutritional diseases, exposure to cancer risk factors, sexually transmitted diseases (e.g., AIDS/HIV), and cardiovascular illness are often addressed using this framework [46]. In 2006, Panter-Brick et al. compiled the potential barriers that affect behavior change towards the prevention of diseases [44]. These factors can be divided into intrinsic barriers that include social norms, beliefs in self-efficacy, and attitudes; and extrinsic barriers that include community or social barriers, workplace barriers and, those barriers that affect knowledge [44,47].

In a recent research project (Enhancing Safety Training Effectiveness in Dairy Production-HICAHS) several social and workplace barriers to training effectiveness have been identified. In focus groups, workers identified multiple relevant extrinsic and intrinsic barriers that they perceive are affecting the effectivity of training [48]. These factors include communication barriers, cultural and language differences, occupational safety culture, organizational climate, training issues, and management disagreements, among others.

In this work, we explore the potential effects of social ecological factors on the exposure to zoonotic diseases as an occupational safety hazard in dairy farms.

4.2 Materials and methods

A cross-sectional research design method was used to obtain simultaneously social-ecological data regarding the exposure to zoonotic diseases of dairy farm workers, and microbiological samples as an indicator of exposure to zoonotic pathogens on dairy workers while performing their usual job tasks.

4.2.1 Population subset

Like many of the other agriculture industries, the US dairy industry relies on an immigrant, primarily Latinx workforce. They mostly came from Mexico and other Spanish speaking countries of Central and South America [45,49]. Many of them do not speak English, and they do not have a farm background, usually seeking temporary employment [50].

To get access to target population individuals, a database of dairy farms was made using the publicly available list of the Colorado livestock association. Farm operators were contacted via email (at least two times) and asked for access to their farms and the workers for participation in the current study. They were also contacted by phone if no email response was obtained. The recruitment of farms period was approximately within four weeks. When access to the farms was granted, and after receiving authorization from the IRB (Institutional Review Board), a short verbal introduction and a letter of invitation/consent were presented to the potential participants, including economic compensation for their participation. Workers of milking parlors, calf rearing, maternity, and hospital area were selected due to the reported high-risk areas for exposure to zoonotic diseases in these areas.

4.2.2 Collection of socio-ecological data

A questionnaire instrument was developed and validated for collecting information regarding the SEM factors[5]. The sources of validity for this instrument were evaluated using the American Educational Research Association standards [51].

The content of the questionnaire was assessed using two parallel sources. First with a comprehensive literature review scoping on recommended practices for the prevention of exposure to microbial diseases at work. Moreover, a search for previously validated instruments measuring behavioral, social, organizational, and personal factors. Second, a complementary qualitative study was used to assess prevention practices, prevention knowledge, safety training, and required skills to practice prevention on the farm.

The drafted questionnaire was broadly evaluated for spelling, wording, clarity, language, structure, and grammar. This questionnaire underwent pilot testing stages that include applying the draft questionnaire to volunteer graduate students from the Departments of Animal Sciences and Clinical Sciences of Colorado State University.

Since the target population is mostly Hispanic, a double-blinded translation was performed by two native Spanish speakers independently. The translated questionnaire

[5] The questionnaire is available from the author upon request.

was then tested on a small sample of Spanish speaking dairy workers. All the above steps were used for refinement and adjustment of the final questionnaire.

4.2.3 Laboratory procedures

Exposure to zoonotic pathogens was assessed by laboratory means. Based on the literature, four important pathogens were chosen as indicators of zoonotic diseases exposure; *Salmonella*, *E.coli, Campylobacter, and Cryptosporidium* [1].

4.2.3.1 Sample collection

Collection devices were placed over the working clothes and collected after a period of 15 to 20 minutes. The collection devices were designed to represent the contamination that dairy workers may experience during their regular work shift. The microorganisms included in this study have been reported to be transmitted orally. Thus, to represent splash contamination to the face and mouth, a piece of collection material was attached to the upper chest (~1m^2) (Figure 6).

In the same way, taking in to account the likely probability of hand to mouth contamination, sleeves that approximately covered ½ of the length of the arm from the wrists and the gloves used during the same period were collected. Figure 6 depicts the schematic representation of the approximate location of the collection devices. Boots and environmental surfaces in the areas of work were swabbed with sampling sponges to represent the potential environmental contamination. The collection of samples was performed at the start of the work shift.

The collection devices, gloves, and swabs were put immediately onto individually labeled sample bags with Bolton Peptone Water (BPW), as transportation media, in the collection site, and then transported to the laboratory for their processing.

Once in the laboratory, the transportation media was squished into individual testing containers and split for the multiple isolations and identification procedures.

4.2.3.2 Isolation and confirmation of zoonotic pathogens

Salmonella is a well-known zoonotic agent that affects numerous species. In humans, it may cause severe gastrointestinal illness. *Salmonella* is commonly diagnosed in dairy cows and calves, and the presence of *Salmonella* on dairy farms has been well documented [52].

The isolation and identification of *Salmonella* were made through culture-isolation-serogrouping techniques and followed by confirmation by PCR [53,54].

To recover injured or low numbers of *Salmonella* cells, the sample was inoculated into BPW and incubated at 37°C for 24 hours. Then the pre-enrichment media was inoculated into iodine supplemented TET and RV media and incubated again 37°C for 24 hours. This media was then streaked into XLT-4 plates and incubated 37°C for 24 hours for isolation. Morphologically compatible colonies were then tested by plate agglutination for various antisera (O, Poly A, group B, group D, group C).

Based on XLT-4 colony morphology and serogrouping, positive isolates were analyzed using a multiplex-PCR for confirmation of genus and differentiation of *Salmonella enterica* subsp*. enterica* serovar Typhimurium *and* serovar Dublin. This procedure was previously described by Tennant (2010) [53]. Below is the list of primers used.

- H-for, a primer sequence common to fliC of both *Salmonella* Typhimurium (H: i) and *Salmonella* Dublin (H:g,p): ACTCAGGCTTCCCGTAACGC
- Hi, unique to fliC of H:i organisms (Typhimurium reverse primer): ATAGCCATTTACCAGTTCC (551bp product)

- Hgp, unique to fliC of H:g,p organisms (Dublin reverse primer): ATTAACATCCGCCGCGCCAA
- InvA from Malorny et al. 2003 [54] : invA-F: GTG AAA TTA TCG CCA CGT TCG GGC AA, invA-R: TCA TCG CAC CGT CAA AGG AAC C

Campylobacter jejuni infections are one of the leading causes of bacterial diarrhea in the U.S., and the number one cause worldwide [28,55]. It is characterized by profuse, often bloody diarrhea, acute abdominal pain, and fever [28]. Because of the ambiguity of symptoms and due to the lack of medical coverage in the dairy worker population, we believe that campylobacteriosis may be an underreported disease. Its presence in the dairy environment has been broadly demonstrated as well [17,24,25,56].

For *Campylobacter* isolation, BB (Bolton broth) media was inoculated with the samples' transport media and incubated at 42°C for 20-44 hours. After incubation, the inoculated media was streaked to mCCDA plates and incubated for 42°C for additional 48-72 hours on anaerobe environment. Morphology compatible colonies were then confirmed as *Campylobacter* by latex agglutination (LAG) test.

Similar than for *Salmonella*, PCR was performed to positive LAG samples for identification of the lpxA sequence as per the method of Klena, et al. (2004) [57]. The following was the primers used.

- lpxA for *C. coli* AGA CAA ATA AGA GAG AAT CAG: nmol: 20.2.
- lpxA *C. jejuni* ACA ACT TGG TGA CGA TGT TGT A: nmol 70.9
- lpxARKK2m CAA TCA TGD GCD ATA TGA SAA TAH GCC AT

Cryptosporidium parvum is a common protozoan parasite responsible for enteric illness in humans and animals. Cryptosporidiosis constitutes one of the most common causes of protozoan diarrhea worldwide [58]. Dairy animals of different ages are known shedders of *C. parvum* oocysts [59–63]. Transmission of these disease agents to workers can occur through direct contact with cattle or contaminated environment [17].

For identification of *Cryptosporidium* oocysts presence on the collected samples, a direct fluorescence antigen detection was used (DFA). Specifically, we used Merifluor® Giardia/Cryptosporidium detection kit after a concentration step. Briefly, a fraction of the transport media was concentrated by centrifugation (800 x g/10min) to 2ml. Then the concentrated sample underwent a gradient concentration in Sheather's Sucrose (sp g. 1.275). The concentrated sample then was laid on the pretreated kit slides, and the samples were stained with the fluorescence reagents as indicated by the instruction manual. The slides were read on a fluorescence microscope (Excitation wavelength: 490-500 nm, Barrier filter: 510-530 nm.) for the identification of the compatibles forms of oocysts.

The pathogenic O157-H7 subset of *E. coli* causes moderate to severe signs of gastrointestinal infection, among them watery diarrhea and hemorrhagic colitis [64]. The epidemiology of *E. coli* in the dairy environment has been a highlighted research topic since cattle are identified as reservoir host [1,13,65]. Moreover, evidence of *Escherichia coli* O157:H7 causing outbreaks in people in close contact with dairy farms have been reported broadly [14,20,66–69].

The identification of *E. coli* O157-H7 was made by PCR targeting the *rfb* gene as previously described [13]. The procedure was performed directly from the enrichment media with no isolation or culture preceding.

4.2.4 Data analysis

Descriptive statistics were calculated for variables characterizing the population of interest; e.g., demographics and background. Also, descriptive statistics are presented for variables that have been described to be related to behavior change; e.g., knowledge, training, and attitudes.

Cross-tabulations, Fisher's exact test (ET) for independence (or Chi-square if expected cell counts >5), bivariate analysis tools such as Pearson or Spearman r, two independent samples Wilcoxon/Mann-Whitney U, or Student's t-test when applicable, and group comparison ANOVA or Kruskal-Wallis test, were used to explore bivariable statistical associations.

Confirmatory factor analysis was used for the establishment of geometric co-variability (multivariate) relationships among the social-ecological variables. Principal components analysis (PCA) with varimax rotation was the chosen methodology. Parallel analysis was used for choosing the number of factors to retain. The parallel analysis was described by Horn (1965) [70], and it is based on the Scree Test. The procedure generates random matrices with dimensions corresponding to the original data and examines the scree plots obtained from their correlation matrices. The components retrained (Principal Components=PC) are those which eigenvalues (proportion of the total model variance explained by that component) of the original data are larger than or equal to those of the simulated random data [71].

Variables and subjects with a large proportion of missing values were removed (>20%). The rest of the missing values were imputed using an Iterative Principal Components Analysis method. The iterative PCA method is also known as the EM-PCA algorithm [72,73]. This process provides scores and loadings minimizing the least squares criterion on the observed entries, which is optimal according to the PCA criterion. The minimization is achieved through an iterative procedure: missing values are replaced by random values, and then PCA is applied on the completed data set, missing values are then updated by the fitted values using a predefined number of dimensions. The number of dimensions for the iPCA imputation was obtained using the recommended mean square error cross-validation method [72,73]. Scores produced by the principal components were also used as dependent variables for the bivariable and multivariable analysis. Multivariable logistic regression was used to model the factors that are associated with positive laboratory results.

All the statistical tests were performed on R statistical software [74]. The following are the lists of the most important R packages used: stats [74], missMDA [75], parallel [76], psych [77], arms [78], and Hmisc [79]. Microsoft Excel® was used for building and organizing the databases and performing basic descriptive statistics.

4.3 Results

Thirty-eight farms were identified and contacted via email and phone. Six farms responded to the request, four positively and two negatively. The rest of the farms never responded, or the contact information was not accurate. One of the four farms cut communications with the research group in the preparation phase, and one more was located out of the reach of the area of influence and was dropped from logistic constrains. From the rest two farms, 42 workers were sampled and interviewed.

4.3.1 Descriptive analysis

Laboratory results: The laboratory results show a substantial proportion of samples that were positive to two of the pathogens of interest; *Salmonella* and *Campylobacter* (Table 11). In contrast, it was not possible to identify *E. coli* nor *Cryptosporidium* by our laboratory methods. Regarding *Salmonella* O antigen agglutination test (O ant. Salm. A-I & Vi), there is an apparent prevalence between 16.6% (on boots) and 33.3% (on chest piece) (Table 11). The only *Salmonella* serotype identified by PCR was *Salmonella* Dublin.

The proportion of positive samples of *Campylobacter* identified by latex agglutination test (L. aglut.) was 9.52% (on boots), 19,5% (on chest piece) and 35.7% (on gloves/sleeves). *C. jejuni* and *C. coli* were identified by PCR (4.76% and 2.38% respectively) in all the sampling devices except gloves/sleeves samples were *C. Coli* was absent (Table 11).

Educational level and demographics: Forty-six percent of the population surveyed have had access only to primary education, and other 41% reported enrollment to not less than middle school. There is only a 13% of interviewees that completed at least some high school education (Figure 7 Proportion of educational level of the interviewed participants). The population surveyed is mostly composed of men (63%). Fifty percent of the population is younger than 30 years old, and the age ranged between 21 and 51 years of age (Figure 8). About 74% of the interviewees have worked in the current dairy for about two years. Half of the sampled population reported experience working on dairy farms of about three years in total (Figure 11). Most of the workers (88.1%) are foreign-born coming to the U.S. from different Hispanic countries including Mexico, Guatemala, Honduras, and Colombia (Figure 9). Forty percent of the respondents reported having felt discriminated against (Figure 10).

Knowledge scores: The questionnaire included several questions aimed at scoping the knowledge of the participants in several important topics such as zoonoses, prevention, and safety practices. In general, 50% of the respondents performed over 70% of the knowledge score and about 80% performed over 60% (Figure 12). Ninety percent of the respondents are not sure of or don't know what the recommended vaccines for people working on the dairy farm (Figure 13) are. Sixty-one percent of participants did not respond entirely correctly to the questions about infectious agents, and 54% are not familiar with the word "zoonosis" (Figure 13). Forty-nine percent of respondents think that people that do not work on farms are not exposed to zoonotic diseases, and 51% think that pathogens cannot be carried by the workers to their homes (Figure 14). Thirty-four percent of the participants are not sure of the possibility that zoonotic diseases can harm workers permanently.

Training: In terms of reported training content, the most recalled content topic was steps to follow in case of an incident (62%), proper PPE use (60%), and injuries and accident prevention (52%), followed by hygiene practices, sources of safety information, and hand washing (24%-31%). Zoonotic diseases, consequences of infectious diseases and cleaning/disinfection/sanitation practices were the least recalled (5%-14%) (Figure 15). Regarding training frequency, about 75% of respondents reported that training occurred more than one time in the last six months (Figure 16). The most reported training style was classroom type lectures (Figure 17). Respondents reported that the most influential person for getting safety practices instructions is their supervisor (40%) following by coworkers (26%) (Figure 18).

Attitudes toward preventive practices. Fifty-eight percent of participants use PPE because they think PPE protects them, and 24% use it because it is mandatory (Figure 19). According to the responses, 28% of participants think that more than half of their coworkers think that wearing PPE does not serve any purpose.

Current preventive practices report: The least used implement of personal protection was the face mask, including 15 respondents (35%) who reported that they have never used it (Figure 20). Figure 21 depicts a comparison between elements that are mandatory, implements that are provided, and their frequency of use. The face mask was mostly reported as not being provided nor mandatory. The use of rubber boots was mostly reported as mandatory but was reported as not provided by the farm.

Prevention practices and risk attitudes and perceptions: The participants showed a high rate of intentions of reporting health events related to injuries and coworkers' health issues (Figure 22). Moreover, they are less likely to report infectious diseases signs, and even less likely to report respiratory illness signs (Figure 22). Again, when asking about their attitudes towards seeking health care in case of a health event, a high proportion (81%-93%) of participants reported intentions to seek medical care in case of a wound or an injury. Intestinal infection symptoms followed with a 75% of more than neutral intentions to seek medical care. There is an even distribution of intentions to seek medical care when asking about other health problems.

Thirty-two of 41 respondents (78%) graded the risk of exposure to a sick animal treater than 3 of 5 (Figure 23). About half of the participants are a little or not afraid at all of getting a disease at work, but 64% are at least moderately concerned that they can carry diseases to their families (Figure 25). Thirty percent of the participants do not think that PPE reduces the risk of diseases. Moreover, 25% disagrees that washing hands reduces the chances of disease transmission (Figure 24).

4.3.2 Independence, associations, and correlations (bivariable analysis).

Association between diagnostic tests: The identification of *Salmonella* O antigen and the identification of *S.* Dublin by PCR was associated with the identification of Campylobacter by latex agglutination test ($\chi2$=30.08, df=1, p<0.001; Fisher's ET p<0.001 respectively) (Table 12). All the samples identified by PCR as *Salmonella* were also identified as *S*. Dublin (Table 13).

Laboratory tests & categorical variables: The identification of *Salmonella* Dublin by PCR was found not to be independent of the farm; farm A presented a significantly larger proportion of positive samples compared to farm B (Fisher's ET p-value>0.01) (Table 14). Educational level was also found associated with both farm and identification of S. Dublin by PCR (Table 14). Area of work, gender, country of origin or motivations for using PPE were independent of the laboratory results.

Training, Knowledge, lab results, and categorical variables. The knowledge scores were not associated with educational level, farm, the area of work, gender, or any of the laboratory results. In the same way, neither training content, training frequency, training methods, nor training deliverer was found to be associated with any other variable (data not shown).

4.3.3 Multivariate analysis

Confirmatory factor analysis. Based on the Parallel analysis, 12 components were retained and interpreted (Figure 26). The results from the principal components analysis are summarized in Table 16. Correlations above |0.4| were used to interpret the retained components. The retained components contributed to a total of 81% of the total variance in the data arranged. The contribution to the total variance was evenly distributed among the retained components (4.1% to 8.06%). Eighty-five out of 92 variables were correlated (r>|0.4|) with at least one component. There were several variables (13) that correlated with more than one principal component. The retained components compiled between 7 and 12 variables. The interpretation of the retained components is summarized in Table 16.

Bivariate correlations of retained components scores & laboratory results. There were three components significantly associated with the identification of *Salmonella* Dublin (PC4, PC1, PC8) (Table 17). Only one retained component (PC9) was found to have a significant relationship with the identification of *Campylobacter spp.* Besides the significant relationships found (p-value<0.05), we consider that there were several other retained components that show relevant relationships with the identification of pathogens in the samples and were analyzed (p-values between 0.05-0.1) (Table 18).

Bivariate correlations of retained components scores & other relevant categorical variables. Three of the retained components were found to be not independent of the farm factor (PC4, PC12, PC8) (Table 18). In the same way, gender was significantly associated with PC2 (Mann-Whitney U=275, p-value=0.03; Table 18). area of work was found to be not independent of PC5, PC12, and PC10 (Table 20). There were significant differences in PC5 and PC12 scores between participants of milking parlor and calves rearing (Tukey HSD p-value = 0.025 and 0.047 respectively). For PC10 scores, there were significant differences between respondents from the hospital/maternity and the calf rearing (Tukey HSD p-value=0.033).

The country of origin was also significantly associated with several retained components (PC4, PC5, PC2, and PC6) (Table 19). The results for the Tukey HSD post-hoc test is shown in.

Multivariable Logistic Model

As expected, due to the small sample size and other assumptions not holding, the multivariable logistic model showed not interpretable results. There was some degree of dependence (multivariability) between the retained factors which made them less suitable for logistic regression.

4.4 Discussion and conclusions

4.4.1 Limitations

One of the major limitations of the study was the low response rate from the farms' managers/owners. In fact, we were only able to get access two farms that usually collaborate in a lot of academic and scientific activities with Colorado State University.

We used recommended reaching strategies of social exchange approaches. The primary objective of these approaches is to convince the person of interest that participating in the survey will be on the exchange of something useful and that exceeds the cost of the resources used (e.g., time) for participating in the study [80]. In our case, we included in the invitation some compelling arguments such as a brief paragraph describing the seriousness, potential consequences for the workers and the animals, and the potential risks of zoonotic diseases in dairy farms. Also, we briefly explained the potential benefits of the expected results of the study (0). Personalization of invitation letters is another recommended strategy that we used. It has been reported that email and phone contact have lower responses rates than face to face recruitment. This is due to the impersonality that those means represent [80].

Despite our efforts, our farm sample was low. We can see in the analysis that farm is an essential factor, but with only two farms, it is difficult to draw a robust conclusion about the effect of farm factors have on the exposure to zoonotic diseases on farm workers. The low sample size also implies that the statistical power is low so the confidence in the associations that were not significant is low.

4.4.2 Univariate analysis

Laboratory results: *Campylobacter* and *Salmonella* have been broadly isolated from dairy farms environments [8,15,24,25,30,52,56,81,82,82,83]. As per our literature review, no studies have reported the direct contamination of gloves or work clothes on personnel with these pathogens. This is an important indicator of high levels of exposure to the contaminated material. Stenkamp-Strahm et al. (2017) reported positive gloves samples contaminated with *E. coli* 015H7 [13]. Similarly, occupational exposure to endotoxins and particulate material has been studied as occupational hazards for dairy workers [84,85]. Though we were not able to identify neither *E. coli* nor *Cryptosporidium* other studies have shown important evidence of presence, exposure, and infection caused by these two pathogens related to the dairy farm environment

[11,13,14,29,60–63,65,66,68,86–89]. *E. coli* has been reported to present seasonal variation, it is probable that at the time of sampling did not coincide with a abundance peak of this bacteria. For *Cryptosporidium* it has been reported that the analytical sensitivity is very low making very difficult to be able to detect it in the environment.

Educational level and demographics: The demographic composition of the sampled population is similar to the reported in other studies done in similar populations [45,48,50]. The educational level is also similar to what has been reported elsewhere [45,90] with a slight difference. In one of the farms surveyed there were four professional college trainees from Colombia which shifted the educational level average upward.

Knowledge scores: the overall performance of knowledge about zoonotic diseases and prevention was acceptable. However, analyzing individual questions, there are some concerning results. For instance, 90% of respondents do not know what vaccines are recommended when working with cattle. Also, deficiencies were noted on knowledge about the causes, transmission mechanisms, and possible consequences of infectious diseases and zoonoses.

Training: Results from this section show evidently that prevention of injuries, use of PPE, and steps to follow after an accident are recurrent topics in their training. However, is also concerning that the least reported topic is the prevention of zoonotic and other infectious diseases, being this a permanent risk when working with animals. Regarding training frequency, we found very consistent responses due to the limited number of farms sampled. It seems that the method of training does not vary a lot, and demonstration or participatory activities are lacking. This is important since it has been recommended by experts the use of different training methods and participatory activities to increase the effectivity of knowledge transfer in these settings [45]. Also as reported in other studies done in a similar population, it seems that supervisors and coworkers play an important role in spreading knowledge in the workplace as far as they maintain good relationships and communication [48,91].

Attitudes towards preventive practices: Similar to the recalled training topics, most of the workers use PPE because they think it is protective. However, 24% reported that the first motivation is external as is mandatory from the workplace management. Also, this percentage is similar to the perception of the utility of PPE use by their coworkers. This may indicate that this fraction of the population does not know the real purpose of using PPE and this may increase their risk of exposure.

Current preventive practices reports: The mask is an implement that is highly recommended when working in a potentially contaminated environment with infectious agents [92]. There should be no difference in the prevention practices when working around these microorganisms whether it is in a laboratory or the field. Similar safety recommendations should be followed. This is why the low report of the use of any face protection in the farm concerns, more when the potential for aerosolized contaminated droplets is unavoidable.

In our data, the most common PPE elements used were those which had as motivation for their use a sum of being mandatory and provided. Moreover, we believe that if the workers understand the basics of the protective effect of PPE, it will increase the frequency of its adequate use.

Prevention practices and risk attitudes and perceptions: Since injury prevention is probably a reiterative topic in the organizational environment, is not strange that reporting intentions and seeking health care related to these types of incidents are also more likely to occur. Infectious disease symptoms are less reported; this may be related to the perception of the severity of signs, the perception of the urgency of the onset of signs, overconfidence, and in part to a culture of stoicism and lack of knowledge on seriousness and consequences of infectious diseases. Menger et al. (2016), found that workers are proud of their ethnic background including the characteristic of being hard-working, sometimes they interpose duty over caring for their welfare [48]. Their attitudes and perceptions towards zoonotic diseases risks are related to this finding too since they are more concerned about transmitting diseases to their families than to themselves.

4.4.3 Inferences from the bivariate analysis.

Association between diagnostic tests: *Salmonella* and *Campylobacter* occurred concomitantly in our samples. It has been described before the identification of these two agents in the same samples; mostly found contaminating food (avian food products), which may indicate a common source of contamination [1,8,93]. In this case, finding the two microorganisms in the same workers may indicate that there are shared features in these workers that make them more susceptible to get exposed to both agents. *Salmonella* Dublin was the only serotype identified by PCR in this study. This serotype has been found on dairy farms before and has been associated with large dairy farms [15].

Laboratory tests & categorical variables: *Salmonella* Dublin was found to be more abundant in one of the farms which, as reported previously is an indication of the relationship between husbandry practices and prevalence of this serotype [15,94]. Another factor found to be associated with the presence of the Dublin serotype was the educational level. However, the farm may be in fact an effect modifier in this relationship since educational level, and the farm was found to be not independent as well. As stated before, one of the farms had a greater proportion of professional trainees which decreases the chances of finding independence between these two variables.

Training, Knowledge, lab results, and categorical variables: Surprisingly we were unable to find an association between training variables (frequency, method, recalled content, or deliverer) and knowledge. Based on our descriptive analysis, it seems that due to the lack of inclusion of zoonotic or other infectious diseases prevention in the safety training content, the participants have acquired this information from other sources such as supervisors or coworkers.

4.4.4 Multivariable analysis discussion

Confirmatory factor analysis: We interpreted 12 components of the PCA (Table 16). As mentioned above, each retained component compiled between 7 and 12 variables each. The interpretation of the principal components was based on the hypothesized SEM model. Interestingly, self-efficacy was found to be the factor that contributes the most to the total variance. This indicates that self-efficacy is an important construct in the interviewees. This construct may be related to their cultural and ethnic background, since as stated before this trait is strong among the Latinx workforce.

Some variables that did not fit into the self-efficacy construct but that were positively related to this were management communication and trust, and, perhaps more importantly, interest in adopting infectious diseases prevention. It has been reported broadly, in the organizational psychology field, that management perception affects worker's confidence that in turns have a positive effect on job performance; it seems that similar relationships are in place in these dairy farms [48,95].

The next retained factor in contributing to the total variance order was called knowledge and risk perceptions (PC1). This encloses the measures of infectious diseases preventions and risk perceptions and concerns. It is important to know that this construct is contributing importantly to the prevention of zoonotic diseases is the focus of this study. In this factor, there were also some interesting related variables such as seeking health care and reporting in case of infectious diseases symptoms and the perception of their supervisors' safety knowledge. We hypothesize that knowledge of zoonotic and infectious diseases changes risk perceptions, then, in turn, this can change the behavior towards reporting and seeking health care in case of infectious signs. Moreover, again the supervisor factor appears to be important in the role of provider of safety information.

Next in the list is PC5, which encloses variables related to reporting and seeking health care in case of injuries. As for the safety training content most common answers, injuries reporting and seeking health care appear to be a relevant construct also in the principal components analysis. Examining the related, non-injury variables found (diarrhea and vomiting reporting), it is possible that the perception of severity or urgency of the health event influences this factor. Job satisfaction, use of face shield, and trust in training were also found related to this factor (0.46-0.55).

Management attitudes and perceptions were compiled in PC3, including the support of coworkers. It must be noted that this factor has an inverse correlation (-0.56) with discrimination reports. PC9 compiled perceptions and attitudes with supervisors and coworkers. Use of sleeves and apron was also related to this factor. This may be an indicator of the difference in supervisors and coworker's relationships in different areas since the apron and sleeves are more frequently used in the milking parlor and maternity areas.

PC7 compiled the variables related to attitudes and behavior towards infectious diseases symptoms. It is interesting to note that injuries and infectious disease attitudes are part of different constructs. Based on the differences found on training contents recall and the perceived severity and urgency of the onset of signs, it is possible that these two constructs come from different thought processes. Workability was found correlated to this factor, which is congruent with finding infectious diseases interest within the self-efficacy factor (PC4).

The following factors can be grouped around two main constructs. PC2, PC6, and PC8 represent different traits of the workplace perceptions. PC2 mostly represents job control and satisfaction that includes trust in management. Retaliation for reporting health problems was negatively correlated to this factor. In contrast, positive coworker safety attitudes and training trust was positively correlated. PC6 was mainly composed of variables related to direct work orders such as role ambiguity, supervisors and coworkers' communication quality and trust, and perception of provided safety resources. The educational level was positively related to this. It is probable that the communication skills improve with higher educational level, and that they affect the work relations and the role ambiguity and safety perceptions. PC8 is highly related to role overload and lack of job control and less related variables measuring coworkers' relatability, support, and concern. This is the opposite to job satisfaction and control and was also found significantly related to the farm factors. So this factor is probably affected by organizational climate, which can be unique for every workplace.

The other group of components interpreted was PC12, PC10, and PC11 all mostly composed of variables measuring training perception constructs. PC12 grouped reporting and perceptions of PPE use. PC10 group negative perception of training sessions, training language, role conflicts, poor communication, management trust and previous experience with dairy farms. Moreover, PC11 represents good training practices perceptions in correlation with workability and organizational commitment.

Relationships between retained principal components and lab results: Self-efficacy, and negative workplace perceptions were positively associated with the presence of *Salmonella* Dublin by PCR (OR=1.43 & 1.22 respectively). In contrast, Knowledge and Management perceptions were found to be negatively associated (OR = 0.90 & 0.91 respectively).

High confidence has been reported as a risk factor for injuries on farms [96]. According to Neal and Griffin (2004) "Overconfidence is a strong source of bias in evaluating risk and has been related to unsafe behavior" [97]. In a study with Latinx roofers, Hung et al. (2013) reported that the safety behavior among workers is perpetuated by workers' perception that they know about safety and that the workers do not value work safety due to their overconfidence [98]. Is probable that this same overconfidence makes the workers more careless on their protective behavior and this can lead to a higher level of exposure to infectious agents as well. However, this interpretation should be taken cautiously. Conchie et al. (2006) stated that “trust (as a self-efficacy driver) and its role in shaping organizational safety is poorly understood” [99]. This article analyses a compilation of studies focused on management trust, safety climate, and safety performance. Where some of the analyzed papers found positive correlations between trust and safety climate, and negative correlations between trust and safety performance, which may sound contradictory. The authors then encourage the conducting of more research to elucidate the complexity of the relationships between these constructs. An important factor that may be playing a role in this interpretation is the Farm factor. In this case, Farm is associated with Self-efficacy, good training perception, and positive samples; thus, the farm can be taken as an effect modifier, i.e., other farm factors could influence the presence of Salmonella Dublin in the samples.

Safety knowledge has been related to safety performance. However, there is always a condition that precedes this relationship, and that is a robust and supportive organizational safety climate [100]. This supports our findings and reinforces the findings that good management perception and knowledge of zoonotic diseases are protective for zoonotic agents’ exposure.

Campylobacter positive samples had a positive relationship (OR=1.09 p-value=0.09) with Self-efficacy (PC4) as well. In contrast, the perception and attitudes toward supervisors and coworkers (PC9) is a protective factor (OR=0.89, p-value=0.03).

Other apparent protective factors for exposure to *Campylobacter* were knowledge (PC1, OR=0.92, p-value=0.07), Attitudes towards reporting of injuries (including reporting vomiting and diarrhea) (PC5, OR=0.84, p-value=0.07), and perceptions and reporting of PPE use (PC12, OR=0.89, p-value=0.07).

The role of supervisors as drivers of safety performance have been studied in farm settings including dairy farms. It has been described that supervisors have a significant influence on the practice of prevention at work [91]. All of this framed under the excellent job relationships and communication norms and a supportive organizational environment.

Retained components scores & relevant categorical variables: As demonstrated in other settings, in our sample Job satisfaction (PC2) is perceived different by gender. In general women report higher levels of job satisfaction than men [101]. Injuries reporting and seeking health care attitudes (PC5), attitudes towards use and reporting PPE (PC12), and Training perception (PC10) is perceived differently in different areas of the farm. For instance, the milking parlor presents a higher score for PC5 (injury reporting and seeking health care attitudes) and PC12 (attitudes and reporting of PPE use) compared to the calf rearing area. Moreover, the hospital/maternity area has lower scores of attitudes and perception of training (PC10) compared to the calf rearing area as well. These differences are probably influenced by the type of tasks they perform in each area. For instance, working in the milking parlor implies, working with a large number of adult cows, and a wetter environment compared to the other areas surveyed, affecting the scores on the factors mentioned.

There were also principal components score differences among people from different countries. Self-efficacy was low among Colombians compared to the other countries. Injuries reporting and seeking health care attitudes were lower on US workers compared to Hondurans and Guatemalans. Importantly, US workers have lower scores on job satisfaction-job control (including trust in management and training, and perception of coworkers safety attitudes) compared to all the other nationalities.

4.5 Conclusions considerations

Knowledge, risk perceptions, positive management perceptions, supportive work environment, and good supervisors and coworker's perceptions were found to be protective. In contrast, self-efficacy and negative workplace perceptions appear to be risks factors.

Based on these finding it may be possible to draw some recommendations leading to reduce the risk of exposure to zoonotic diseases in dairy farms.

Knowledge and risk perception were protective factors. Thus, we encourage the frequent inclusion of infectious zoonotic diseases prevention topics on the farm's safety information flow. Some of the safety knowledge bases that we believe are useful are identification of signs and symptoms of serious infectious diseases; based on this, when it is recommendable to report and seek health care, recommendable prophylactic actions for farm workers and families (e.g., vaccines), causes of infections, transmission mechanisms, potential risks and consequences of infectious diseases and zoonoses for workers and their close ones, and overconfidence as risk factor of injuries and infectious diseases exposure due to the found positive relationship with exposure.

A second important aspect is how the information flows through the workplace. Our study supports the hypothesis that supervisors and coworkers play an important role in being channels of safety information. It is advisable to take advantage of this information flow and make sure that supervisors and experienced coworkers continue to provide accurate and precise safety information and that the management supports these leading roles with the adequate training and resources.

According to experts, more interactive, participatory, and demonstrative transfer methods are related to effective and lasting knowledge acquisition [45,50,102]. There are also social and cultural factors that should be taken in to account when designing and implementing safety knowledge transfer programs in the farms. Evaluation and follow up of knowledge transfer is also encouraged. For a more detailed reference on factors affecting designing of training methods for dairy workers, the reader can consult Menger et al. 2016 [45].

The other mentioned factor and perhaps the most important one is the supportive work environment. Good management perception was found to be apparently protective of exposure to zoonotic agents, and farm management influences all the social-ecological factors found associated with exposure to zoonotic diseases. Top management has the responsibility to design, plan, and implement preventive programs, not only through training sessions but with the accurate flow of information through supervisors and more experienced coworkers. They have the challenge to maintain a robust safety climate and promote safety culture. Confirmed by our laboratory results, the exposure to zoonotic diseases agents in dairy farms does exist and is potentially dangerous for people working in the different areas of the farm. Due to the abundance of zoonotic pathogens found in this study and reported elsewhere, the farm environment should be considered to be always contaminated with zoonotic agents. We confirmed that potentially dangerous agents could indeed be splashed to the eyes, nose, and mouth in the work areas. Face and nose/mouth protection should be instructed and encouraged or mandated in the workplace.

Caution is advised when extrapolating the findings of this study, due to the lack of representativeness of other dairy farms. Despite our efforts, our farm sample was low. In the analysis above, farm appeared to be a relevant factor but, with just two farms, it is difficult to draw a robust conclusion regarding the actual effect that farm factors have on the exposure to zoonotic diseases on farm workers. However, we found compelling evidence of many social-ecological factors affecting the exposure to zoonotic diseases of dairy farm workers. As a pilot study, the findings presented here should be used as support and justification for developing new proposals aiming to deepen on the understanding of the social ecology and epidemiology of the exposure to zoonotic diseases in dairy farms.

Table 11 Summary of the proportion of positive samples (AP: apparent prevalence) per laboratory test

SAMPLE	TEST	AP
CHEST PIECE	O ant. Salm. (A-I + Vi)	33.33%
	PCR Salm. InvA	9.52%
	PCR S. Tiph.	0.00%
	PCR S. Dub.	11.90%
	L. aglut. Campy.	19.05%
	PCR *C. jejuni*	4.76%
	PCR *C. coli*	2.38%
	PCR *E. coli*	0.00%
	Cripto DFA	0.00%
BOOTS	O ant. Salm. (A-I + Vi)	16.67%
	PCR Salm. InvA	7.14%
	PCR S. Tiph.	0.00%
	PCR S. Dub.	9.52%
	L. aglut. Campy.	9.52%
	PCR *C. jejuni*	4.76%
	PCR *C. coli*	2.38%
	PCR *E. coli*	0.00%
	Cripto DFA	0.00%
GLOVES AND SLEEVES	O ant. Salm. (A-I + Vi)	30.95%
	PCR Salm. InvA	11.90%
	PCR S. Tiph.	0.00%
	PCR S. Dub.	16.67%
	L. aglut. Campy.	35.71%
	PCR *C. jejuni*	4.76%
	PCR *C. coli*	0.00%
	PCR *E. coli*	0.00%
	Cripto DFA	0.00%

Table 12 Independence Fisher's exact test p-values for test results.

		FISHER ET P. VALUES
O Ant. Salm. (A-I + Vi)	L. aglut. Campy.	**4.13E-08*** (χ^2=30.08, df=1)
	PCR *C. jejuni*	0.34
	PCR *C. coli*	0.47
PCR Salm. Inva	PCR S. Dub.	**9.35E-14**
	L. aglut. Campy.	0.13
	PCR *C. jejuni*	0.46
	PCR *C. coli*	1.00
PCR S. Dub.	L. aglut. Campy.	**4.38E-02**
	PCR *C. jejuni*	0.57
	PCR *C. coli*	1.00
PCR *C. jejuni*	PCR *C. coli*	0.09

*Independence calculated by Pearson's χ^2 (Yates continuity correction) as expected cell counts were>5

Table 13 2x2 frequency tables of laboratory results

		PCR Salm. InvA		PCR S. Dub.		Lat. agut. Campy		PCR C. jejuni		PCR C. Coli		M. c
		-	+	-	+	-	+	-	+	-	+	
O ant. Salm. (A-I + Vi)	-	91	1	91	1	84	8	89	3	91	1	92
	+	23	11	19	15	15	19	31	3	33	1	34
PCR Salm. InvA	-			110	4	92	22	109	5	112	2	114
	+			0	12	7	5	11	1	12	0	12
PCR S. Dub.	-					90	20	105	5	108	2	110
	+					9	7	15	1	16	0	16
L. aglut. Campy.	-							98	1	99	0	99
	+							22	5	25	2	27
PCR C. jejuni	-									119	1	120
	+									5	1	6
Marg. counts		114	12	110	16	99	27	120	6	124	2	126

Table 14 Frequency table and Fisher's ET p-value and Odds Ratios of significant non-independent categorical variables

		Farm		**PCR S. Dublin**		**OR for PCR S.Dublin (95% CI)**	**M. c**
		A	**B**	**+**	**-**		
Ed. level	1	3	19	1	22	Reference	22
	2	7	7	6	8	0.07 (0.00,0.53)	14
	3	0	1	0	1	0.2* (0.01,7.3)	1
	4	0	4	0	4	0.6* (0.02,17.2)	4
	p-value		0.049		0.014		
Farm	A			7	3	132.9* (6.18,2885)	10
	B			0	31		31
	p-value				<0.001		
Marg. Counts (M.c.)		10	31	7	34		41

* Taylor series used for calculation of ORs and confidence intervals.

Table 15 Descriptive statistics and principal components analysis results.

Variables	$\bar{x}$	***sd***	**PC4**	**PC1**	**PC5**	**PC3**	**PC9**	**PC7**	**PC2**	**PC6**	**PC12**	**PC10**	**PC8**	**PC11**
SS loadings (Eigenvalues)			8.06	7.64	6.98	6.97	6.6	6.55	6.51	5.97	5.39	4.77	4.7	4.1
Proportion of Variance explained			0.11	0.1	0.09	0.09	0.09	0.09	0.09	0.08	0.07	0.06	0.06	0.06
Cumulative proportion of Variance explained			0.11	0.21	0.31	0.4	0.49	0.58	0.66	0.74	0.82	0.88	0.94	1
Cumulative proportion of total Variance			0.09	0.17	0.25	0.32	0.39	0.47	0.54	0.6	0.66	0.71	0.76	0.81
I am confident about my ability to perform my job tasks	4.63	0.58	0.85		-0.25		0.20		0.07		0.07		0.28	
How do you grade your quality of work	8.63	1.36	0.82		-0.01		-0.12		0.13		0.06		-0.21	
I have the skills necessary to implement preventive practices	4.12	0.84	0.78		-0.01		0.08		-0.22		-0.27		0.05	
I am confident about my ability to implement preventive practices	4.07	0.93	0.77		0.00		-0.06		-0.09		-0.22		0.17	
How do you grade your ability to meet the following demands - technical demands	8.78	1.44	0.76		0.40		-0.18		-0.13		-0.10		-0.14	
How do you grade your interest for infectious diseases at work	4.78	0.57	0.74		-0.04		0.12		0.30		0.05		0.03	
Grade the quality of communication with top Management	3.92	1.04	0.64		-0.11		0.03		-0.02		-0.07	-0.49	-0.13	
How easy is it to comply with work safety recommendations?	4.76	0.58	0.58		-0.05		0.22		0.17		0.02		-0.07	
The management has my best interest in mind	4.15	1.08	0.52		0.28	0.50	0.00		0.00		0.21		0.00	
How do you grade your ability to meet physical demands	8.63	1.44	0.50		0.43		-0.18		0.26		0.09		-0.03	
How easy would it be for the group to adopt a new preventive practice	3.80	1.11	0.47		0.08		-0.16		0.09		0.34		0.18	

Variables	$\bar{x}$	*sd*	PC4	PC1	PC5	PC3	PC9	PC7	PC2	PC6	PC12	PC10	PC8	PC11
How long would it take you to decide to go to the doctor if you have flu symptoms?	3.22	1.01	-0.20	0.76	-0.07		-0.16		-0.08		0.03		-0.14	
How much risk do you believe these diseases pose to workers' health and safety?	3.41	1.07	-0.29	0.73	0.09		0.07		-0.23		0.13		0.04	
How much risk do you believe these diseases pose to workers' family health and safety?	3.44	1.18	-0.02	0.72	0.28		-0.06		-0.19		0.19		0.18	
How long would it take you to report to your supervisors if you have flu symptoms?	3.67	0.84	-0.05	0.71	-0.02		0.10		0.01		-0.03		-0.17	
Aggregated score of the knowledge section	8.96	5.03	0.06	0.70	0.03		-0.15		-0.22		0.00		0.01	
How concerned are you that you family can get an infectious disease from your work place?	3.15	1.53	0.18	0.69	-0.31		-0.11		-0.07		0.24		0.32	
My supervisors are knowledgeable about how to correctly wear PPE	4.73	0.45	0.03	0.65	-0.10		0.54		-0.02		-0.08		-0.06	
How much risk do you think the contact with a sick animal represents to you?	3.44	1.36	-0.04	0.64	0.00		-0.07		-0.12		0.13		0.17	
How long would it take you to report to your supervisors if you have intestinal infection symptoms?	3.77	0.58	0.03	0.63	0.05		0.42		0.25		-0.19		-0.15	
How afraid are you that you can get an infectious disease at work?	2.71	1.42	-0.09	0.56	-0.08		0.05		-0.16		0.44		0.44	
How likely are you to go to the doctor if you have intestinal infection symptoms?	4.08	1.07	0.01	0.49	-0.13		0.19	0.45	0.02		-0.08		-0.06	

Variables	$\bar{x}$	*sd*	PC4	PC1	PC5	PC3	PC9	PC7	PC2	PC6	PC12	PC10	PC8	PC11
How likely are you to report to your supervisor if you get Injured? (sprained/twisted wrist)	4.61	0.92	-0.03		0.96		0.02		-0.03		0.05		0.00	
How likely are you to report to your supervisor if you got a wound? (Cut of the skin with moderate bleeding)	4.76	0.70	0.02		0.90		0.05		-0.14		-0.09		0.03	
How likely are you to go to the doctor if you got a wound? (Cut of the skin with moderate bleeding)	4.80	0.72	0.01		0.90		0.06		-0.02		-0.13		0.09	
How likely are you to report to your supervisor if you experience vomiting?	4.22	1.19	0.11		0.67		0.58		0.05		-0.07		0.17	
How likely are you to go to the doctor if you get Injured? (sprained/twisted wrist)	4.43	0.93	-0.22		0.66		0.23		0.14		0.32		-0.14	
How likely are you to report to your supervisor if you experience diarrhea?	4.15	1.28	0.40		0.63		0.31		0.21		0.24		0.33	
I am satisfied with my job	4.78	0.42	-0.10		0.55		0.22		0.72		-0.12		0.06	
How often do you use goggles/face shield?	4.49	0.81	-0.15		0.49		0.08		0.07		-0.33		-0.06	
Training sessions provides reliable information	4.21	1.40	0.30		0.46		-0.26		0.49		-0.41		0.12	
I feel the farm problems as my problems	3.77	1.37	0.07		0.05	0.75	-0.18		-0.19		-0.16		-0.18	
Management is heading the farm in the right direction	4.49	0.76	-0.12		-0.07	0.73	0.24		-0.31		0.13		-0.10	
Help is available from my coworkers when I have an inquiry about safety	4.29	1.08	-0.09		0.00	0.73	0.25		0.25		0.00		-0.31	

Variables	$\bar{x}$	*sd*	PC4	PC1	PC5	PC3	PC9	PC7	PC2	PC6	PC12	PC10	PC8	PC11
Management is honest and open with me	4.40	0.74	-0.13		-0.16	0.70	0.17		0.07		0.39		0.11	
I'm proud to tell others I work here	4.56	0.59	-0.15		-0.16	0.67	-0.09		0.42		0.06		-0.03	
I have a strong sense of belonging with the farm	3.85	1.10	-0.04		-0.22	0.63	-0.15		-0.01		-0.12		0.30	
My employer provides adequate resources for protection at work	4.48	0.75	0.04		0.03	0.58	-0.13		-0.06	0.54	0.33		0.05	
At work, I feel discriminated	1.60	0.81	-0.31		0.15	-0.56	0.17		0.03		-0.04		0.37	
The management has my best interest in mind	4.15	1.08	0.52		0.28	0.50	0.00		0.00		0.21		0.00	
Farm management provides accurate safety information	4.18	1.03	0.29		-0.09	0.46	0.20		-0.10		0.29		0.00	0.52
My organization shows a lot of concern about my safety	4.37	0.73	-0.09		-0.24	0.46	0.08		0.44		-0.40		0.06	
Farm management provides adequate safety training	4.18	1.08	0.30		-0.15	0.45	0.32		-0.22		0.18		0.04	
How likely are you to report to your supervisor if you have fever?	4.37	0.97	0.12		0.42		0.72		0.12		-0.07		0.11	
How likely are you to report your supervisors if you see that a co-worker is sick?	4.37	1.04	0.08		0.16		0.80		-0.13		-0.17		0.03	
My supervisors show a lot of concern about my safety	4.71	0.51	-0.04		0.03		0.75		0.16		0.22		-0.14	
How likely are you to report to your supervisor if you have fever	4.37	0.97	0.12		0.42		0.72		0.12		-0.07		0.11	
My supervisors encourage the use of PPE	4.40	0.98	0.06		0.13		0.67		0.18	0.53	0.26		-0.08	
How often do you use plastic sleeves?	4.28	1.48	-0.17		0.00		0.61		0.31		0.23		0.26	
How likely are you to report to your supervisor if you experience vomiting	4.22	1.19	0.11		0.67		0.58		0.05		-0.07		0.17	

Variables	$\bar{x}$	***sd***	**PC4**	**PC1**	**PC5**	**PC3**	**PC9**	**PC7**	**PC2**	**PC6**	**PC12**	**PC10**	**PC8**	**PC11**
My supervisors are knowledgeable about how to correctly wear PPE	4.73	0.45	0.03	0.65	-0.10		0.54		-0.02		-0.08		-0.06	
How often do you use Gown/apron?	3.47	1.62	-0.24		-0.16		0.54		0.13		0.32		-0.02	
My coworkers show a lot of concern about my safety	4.08	1.12	0.11		0.20		0.49		-0.22		-0.07		-0.47	
I care whether my coworkers wear or not PPE	4.03	1.24	-0.23		0.22		0.49		-0.33		-0.03		0.01	
How likely are you to go to the doctor if you have Fever	3.37	1.43	0.14		0.21		0.07	0.83	0.00		0.06		0.08	
How likely are you to go to the doctor if you have Diarrhea	3.00	1.40	-0.18		0.22		0.09	0.82	0.01		0.28		0.03	
How likely are you to go to the doctor if you have Vomiting	3.03	1.54	-0.10		0.37		0.13	0.78	-0.04		0.23		0.10	
How likely are you to go to the doctor if you have a Sore-throat	2.70	1.30	-0.12		0.02		-0.03	0.72	0.20		-0.36		0.00	
How long would it take you to decide to go to the doctor if you have intestinal infection symptoms?	3.75	0.54	-0.15		0.00		0.08	0.67	0.17		0.01		-0.08	
How likely are you to go to the doctor if you have flu symptoms?	3.21	1.40	0.34		-0.34		-0.17	0.64	0.08		-0.03		0.01	
How likely are you to go to the doctor if you have fever and Sore throat?	3.18	1.32	0.05		-0.24		0.26	0.61	-0.32		0.04		-0.03	
I am self-assured about my capabilities to perform my job tasks	4.61	0.59	0.31		-0.25		0.39	0.47	-0.08		-0.01		-0.02	-0.48
How likely are you to go to the doctor if you have intestinal infection symptoms?	4.08	1.07	0.01	0.49	-0.13		0.19	0.45	0.02		-0.08		-0.06	
Reporting my health problems would get me in trouble with my supervisors	1.76	1.59	-0.27		-0.09		-0.01		-0.86		-0.05		-0.17	

Variables	$\bar{x}$	*sd*	**PC4**	**PC1**	**PC5**	**PC3**	**PC9**	**PC7**	**PC2**	**PC6**	**PC12**	**PC10**	**PC8**	**PC11**
I like working here	4.76	0.43	0.33		-0.07		0.05		0.74		-0.13		0.18	
I am satisfied with my job	4.78	0.42	-0.10		0.55		0.22		0.72		-0.12		0.06	
Help is available from the managers when I have an inquiry about safety	4.78	0.42	-0.27		-0.02		0.28		0.71		0.12		-0.13	
How many of your coworkers think wearing PPE does not serve any purpose?	2.38	1.37	-0.44		0.03		0.07		-0.69		-0.27		0.15	
It is clear to me what are my duties at work	4.73	0.63	0.03		-0.03		-0.04		0.52	0.72	0.26		0.09	
Training sessions provides reliable information	4.21	1.40	0.30		0.46		-0.26		0.49		-0.41		0.12	
Grade the quality of communication with your Supervisors	4.26	0.99	0.29		-0.19		0.07		-0.03	0.82	-0.11		0.13	
Grade the quality of communication with your Coworkers	4.26	0.94	0.01		0.04		0.34		-0.07	0.75	-0.01		-0.07	
It is clear to me what are my duties at work	4.73	0.63	0.03		-0.03		-0.04		0.52	0.72	0.26		0.09	
What is the highest degree or level of school you have completed?	2.12	1.19	0.14		0.06		-0.26		0.07	-0.70	-0.29		-0.10	
My supervisors are knowledgeable about safety at work	4.68	0.57	-0.01		0.12		0.24		0.27	0.65	0.30		-0.13	
My employer provides adequate resources for protection at work	4.48	0.75	0.04		0.03	0.58	-0.13		-0.06	0.54	0.33		0.05	
My supervisors encourage the use of PPE	4.40	0.98	0.06		0.13		0.67		0.18	0.53	0.26		-0.08	
How often do you use work boots?	2.89	1.89	0.13		-0.21		-0.10		0.06		0.67		-0.24	
How often do you use face mask?	2.39	1.41	-0.15		0.00		0.05		-0.05		0.65		-0.07	
I have received clear instructions on how to adequately use PPE	4.36	1.27	-0.26		-0.03		0.08		0.24		0.63		-0.01	
How often do you use hat?	4.35	1.29	0.22		0.00		-0.16		0.26		0.58		-0.31	

Variables	$\bar{x}$	*sd*	PC4	PC1	PC5	PC3	PC9	PC7	PC2	PC6	PC12	PC10	PC8	PC11
How often do you use Disposable latex/nitrile Gloves?	4.90	0.30	-0.07		-0.10		-0.25		0.40		-0.57		-0.22	
How often is the training given in the language of your preference?	4.07	1.21	0.41		0.11		-0.16		0.10		0.21	0.63	0.11	
I believe that training sessions are a waste of time	4.59	1.04	0.32		-0.15		-0.19		0.32		-0.31	0.63	0.14	
How long have you been working in dairies?	48.10	51.65	-0.03		**-0.19**		-0.02		-0.09		0.09	0.60	-0.07	
How often do I receive different instructions from two or more people?	2.46	1.31	-0.19		-0.08		-0.18		-0.04		0.19	-0.57	-0.12	
Grade the quality of communication with Top Management	3.92	1.04	0.64		-0.11		0.03		-0.02		-0.07	-0.49	-0.13	
Help is available from the organization when I have an inquiry about safety	4.29	1.05	-0.05		-0.20		-0.23		-0.26		-0.25	0.45	0.01	
I'm always rushing to do my job	2.27	1.30	0.10		0.18		-0.02		0.06		-0.06		0.88	
On my job, I have freedom to decide how I work	3.32	1.57	-0.06		-0.08		0.06		-0.11		0.20		-0.81	
How likely are you to report to your supervisor if you have Coughing?	3.66	1.41	-0.15		0.16		0.28		-0.06		0.11		0.55	
My coworkers show a lot of concern about my safety	4.08	1.12	0.11		0.20		0.49		-0.22		-0.07		-0.47	
I identify myself with the cultural background of most of my coworkers	2.29	1.33	-0.15		-0.09		-0.16		0.01		0.08		0.46	
How often do you use rubber boots?	4.58	0.98	-0.01		-0.24		0.08		-0.03		-0.18		0.46	
How often have you received safety training?	3.29	3.30	-0.03		0.02		-0.23		0.37		0.25		0.46	

Variables	$\bar{x}$	***sd***	**PC4**	**PC1**	**PC5**	**PC3**	**PC9**	**PC7**	**PC2**	**PC6**	**PC12**	**PC10**	**PC8**	**PC11**
Trainers often used examples/demonstrations	3.56	1.64	0.09		0.08		0.04		0.17		0.06		0.06	0.85
I have been involved in the training activities/demonstrations	2.74	1.60	0.02		-0.01		0.16		0.44		0.08		-0.18	0.71
Farm management provides accurate safety information	4.18	1.03	0.29		-0.09	0.46	0.20		-0.10		0.29		0.00	0.52
I am self-assured about my capabilities to perform my job tasks	4.61	0.59	0.31		-0.25		0.39	0.47	-0.08		-0.01		-0.02	-0.48
I feel the farm problems as my problems	3.77	1.37	0.07		0.05	0.75	-0.18		-0.19		-0.16		-0.18	0.44

Table 16 Interpretation of retained factors by the principal component analysis. In parenthesis () is the number of variables that were correlated (r>|0.4|) to each component.

RETAINED COMPONENTS	***UNOBSERVED FACTORS***
PC4 (11)	Self-efficacy • Workability • Job-related self-efficacy • Preventive practices ability Other • Interest in infectious diseases • Communication with top management • Trust in management
PC1 (11)	Knowledge & risk perception • Knowledge relevant to zoonotic diseases • Risk perception and concerns Other • Seeking health care or reporting infectious disease symptoms • Supervisor safety knowledge perception
PC5 (9)	Injuries attitudes • Reporting • Seeking healthcare Other health problems attitudes • Reporting vomiting • Reporting diarrhea Other • Job satisfaction • Use of face/eye protection • Training trust
PC3 (12)	Management attitudes and perceptions • Organizational commitment • Trust in management • Coworkers support Other • Discrimination perception (inverse)
PC9 (11)	Perceptions and attitudes of Supervisors and coworkers • Reporting health problems to supervisor • Trust in supervisor • Supervisor communication • Trust in co-workers Other • Use of Sleeves • Use of Apron
PC7 (9)	Infectious diseases related symptoms attitudes • Seeking healthcare Other • Workability

RETAINED COMPONENTS	***UNOBSERVED FACTORS***
PC2 (7)	Workplace Satisfaction • Job control • Job satisfaction • Trust in management • Reporting retaliation (lack of) Other • Perception of coworkers' safety attitudes • Training trust
PC6 (7)	Workplace perceptions of supervisors and coworkers • Supervisor and coworker's communication quality • Supervisor trust • Role ambiguity (lack of) • Provided safety resources perception Other • Educational level
PC12 (5)	Perceptions and reporting of personal protective equipment use
PC10 (6)	Training perception • Language of training • Negative perception of training sessions Other • Role conflict • Poor communication with managers • Organizational trust • Experience in dairy farms
PC8 (7)	Workplace negative Perceptions • Role overload • Job control (lack of) • Coworkers' support (safety concern) Other • Cultural relatability • Training frequency • Reporting health problems to supervisor • Using work boots
PC11 (5)	Training Miscellaneous • Training frequency • Use of examples/demonstrations • Being involved in training demonstrations • Adequate safety information Other • Workability • Organizational commitment

Table 17 Significant (p-value≤0.05) and relevant (0.05<p-value≤0.1) bivariate logistic regression analysis results of principal component factors and laboratory results.

	PCR Salm Dublin				Lat Ag. Campy			
	OR	2.5%	97.5%	p-value	OR	2.5%	97.5%	p-value
PC4	1.43	1.11	2.22	0.04	1.09	1.00	1.21	0.09
PC1	0.91	0.82	1.00	0.05	0.92	0.84	1.00	0.07
PC5					0.84	0.68	0.97	0.07
PC3	0.90	0.79	1.00	0.06				
PC9					0.89	0.79	0.98	0.03
PC12					0.89	0.78	1.00	0.07
PC8	1.22	1.02	1.53	0.04				

Table 18 Significant (p-value≤0.05) and relevant (0.05<p-value≤0.1) Mann-Whitney U test for independence of two groups results for Farm and Gender vs. principal components.

	Farm		Gender	
	U	**p-value**	**U**	**p-value**
PC4	**241**	**0.01**		
PC1	94	0.07		
PC2	212	0.09	**275**	**0.03**
PC6			258	0.09
PC12	**73**	**0.01**	261	0.08
PC8	**261**	**<0.01**		

Table 19 Results of the pair-wise Tukey HSD post-hoc test for the country and retained components.

	Comparison	p-value
PC4	GUAT-COL	0.01
	HON-COL	<0.01
	MEX-COL	<0.01
	US-COL	0.06
PC5	US-GUAT	0.05
	US-HON	0.05
PC2	US-COL	<0.01
	US-GUAT	<0.01
	US-HON	<0.01
	US-MEX	<0.01
PC6	US-GUAT	0.07

Table 20 Significant (p-value≤0.05) and relevant (0.05<p-value≤0.1) results for comparison between multiple groups for area of work, country of origin, and reasons to wear PPE vs. principal components.

	Area of work			Country of origin			Why wear PPE		
	F	**df**	**p-value**	**F**	**df**	**p-value**	**H***	**df**	**p-value**
PC4				**4.46**	**4**	**0.01**	7.69	3	0.05
PC5	**3.76**	**2**	**0.03**	**3.49**	**4**	**0.02**	**10.66**	**3**	**0.01**
PC3							**9.67**	**3**	**0.02**
PC7							6.84	3	0.08
PC2							7.56	3	0.06
PC2				**19.97**	**4**	**<0.01**			
PC6				**2.67**	**4**	**0.05**	**13.89**	**3**	**<0.01**
PC12	**3.23**	**2**	**0.05**						
PC10	**4.35**	**2**	**0.02**						
PC8							**10.02**	**3**	**0.02**

* Kruskal-Wallis H statistic used after ANOVA assumptions check.

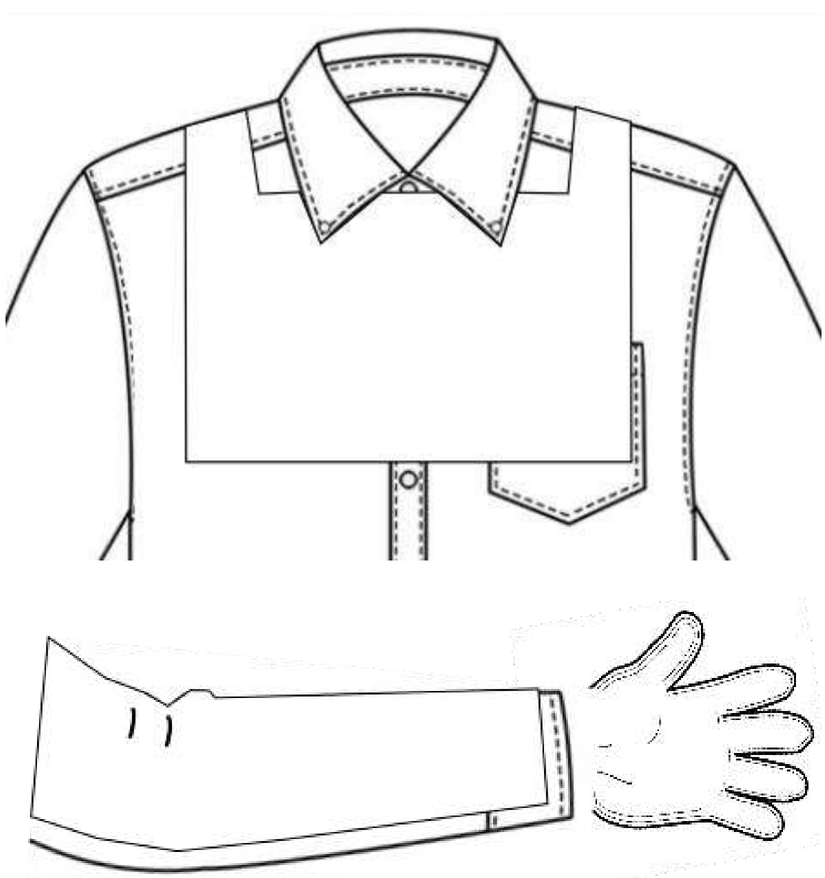

Figure 6 Schematic representation of collection devises allocations.

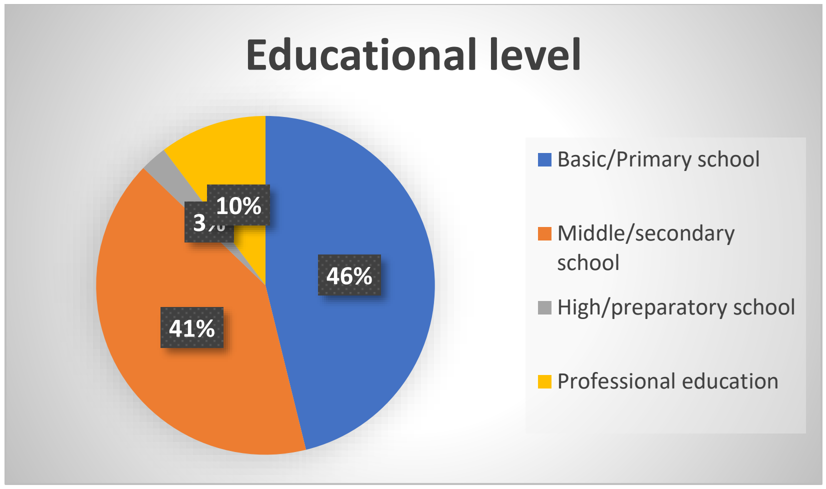

Figure 7 Proportion of educational level of the interviewed participants

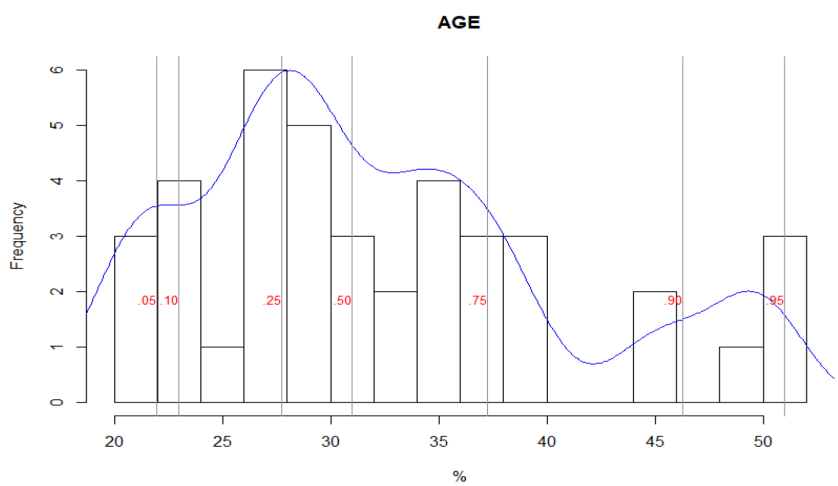

Figure 8 Histogram and density plot with percentile lines of the age distribution of the population sampled.

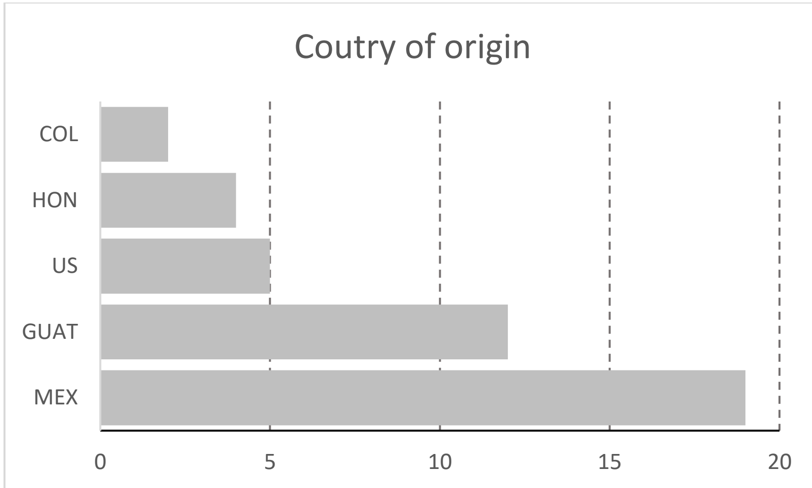

Figure 9 Distribution of country of origin of participants.

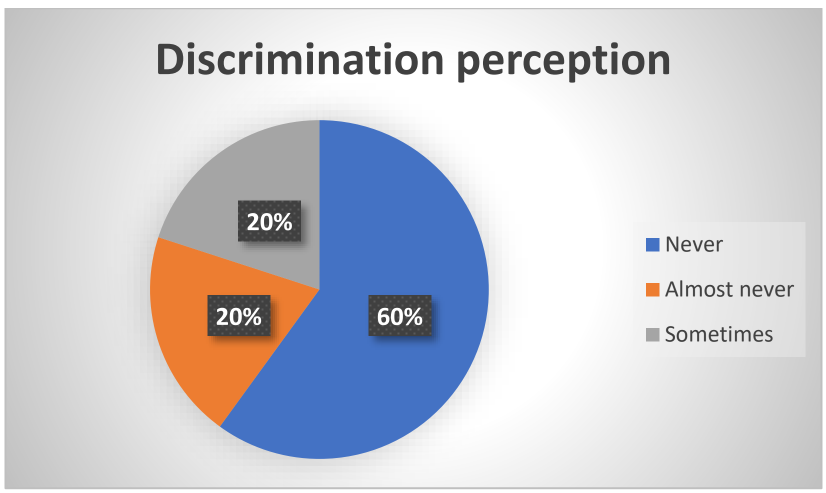

Figure 10 Percentage of responses on discrimination perception

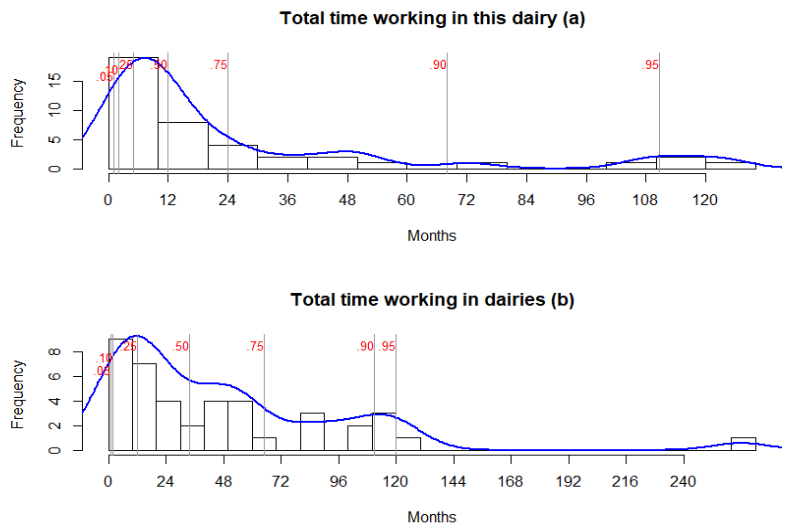

Figure 11 Frequency and density plots with percentiles references of the distribution of the time in months that the workers have been appointed in the current dairy farm (a) and total in the dairy industry (b).

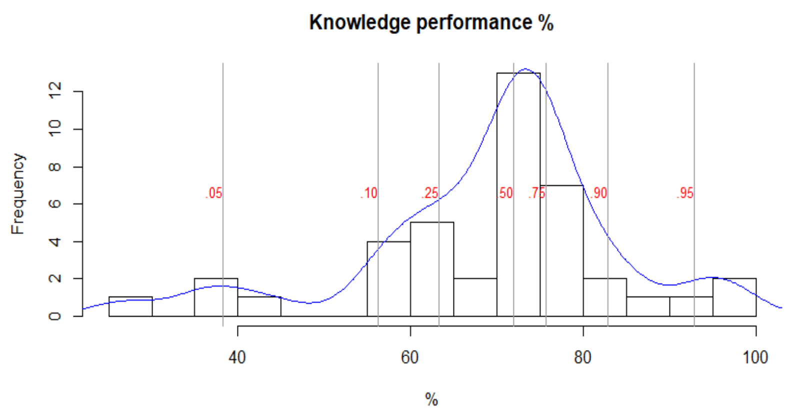

Figure 12 Frequencies and density plot with percentile references of knowledge score percentage performed by the participants. 100% means all the responses were correct, 0% means none of the responses were correct.

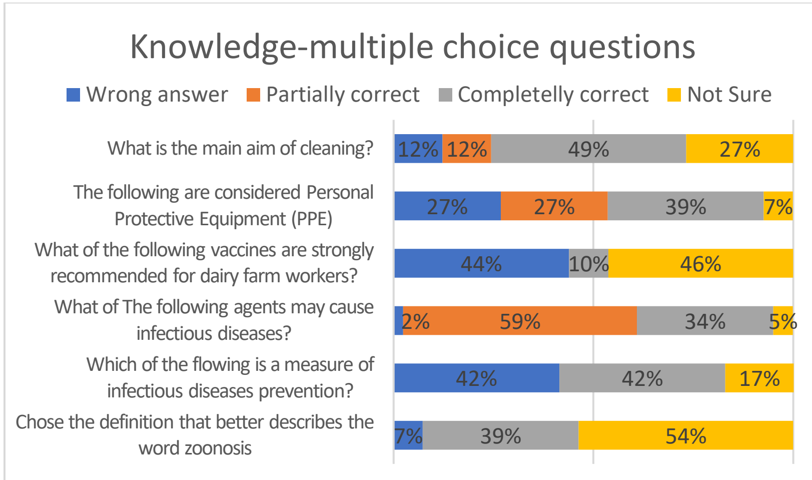

Figure 13 Proportion of answers for multiple choice questions of knowledge on general prevention measures.

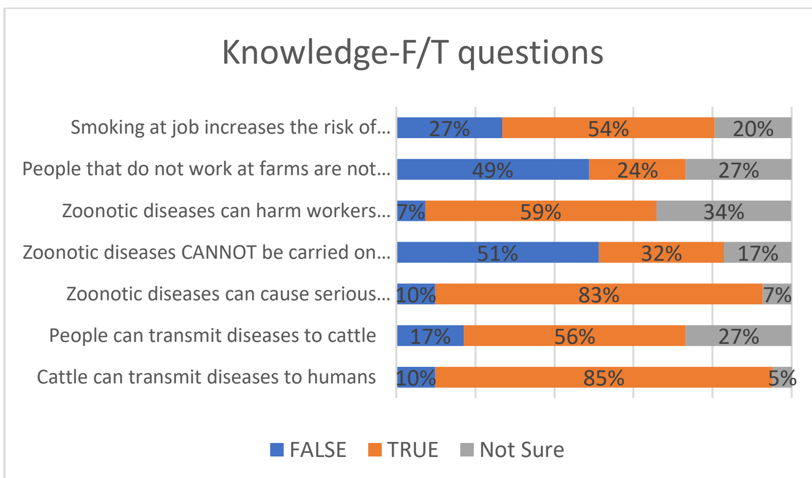

Figure 14 Proportion of responses to False/True questions (F/T) of knowledge of zoonotic diseases.

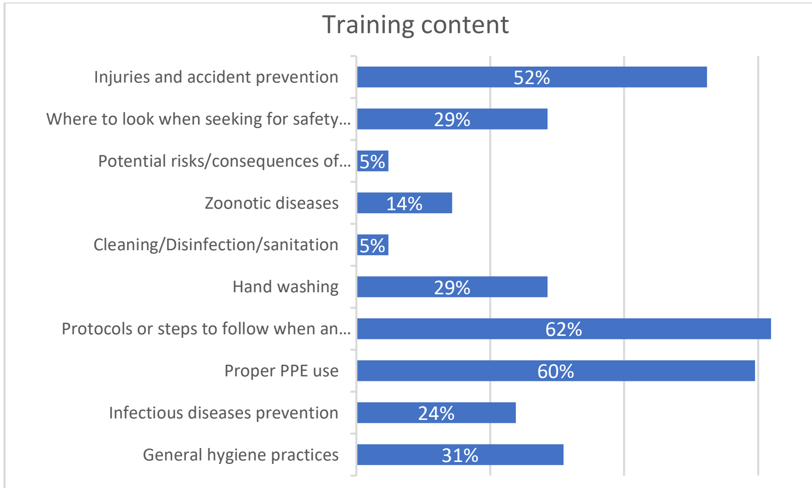

Figure 15 Percentage of training topic recall.

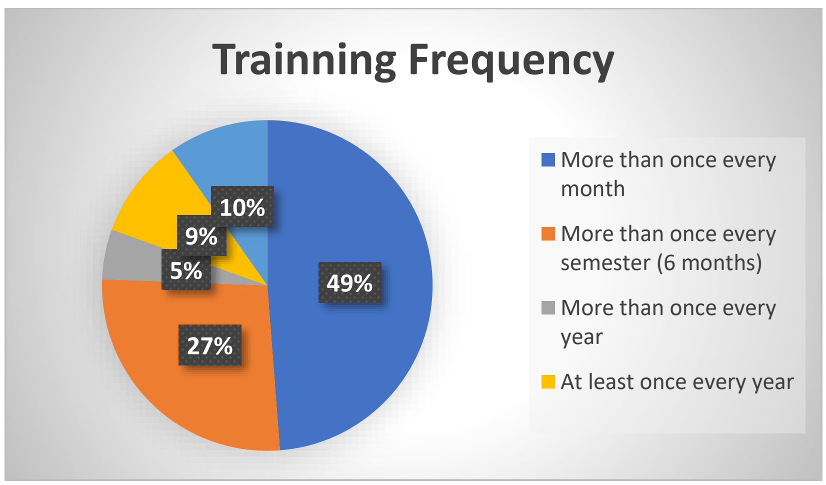

Figure 16 Percentages of participants recalling the training frequency they have received.

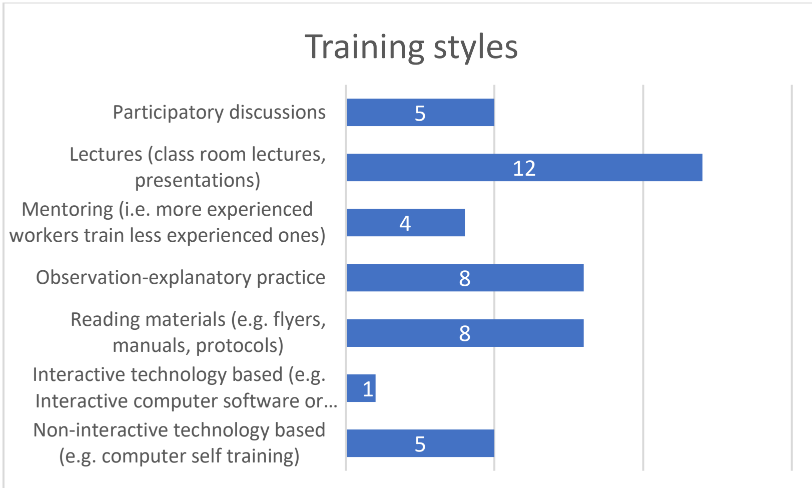

Figure 17 Percentages distribution of training styles reported.

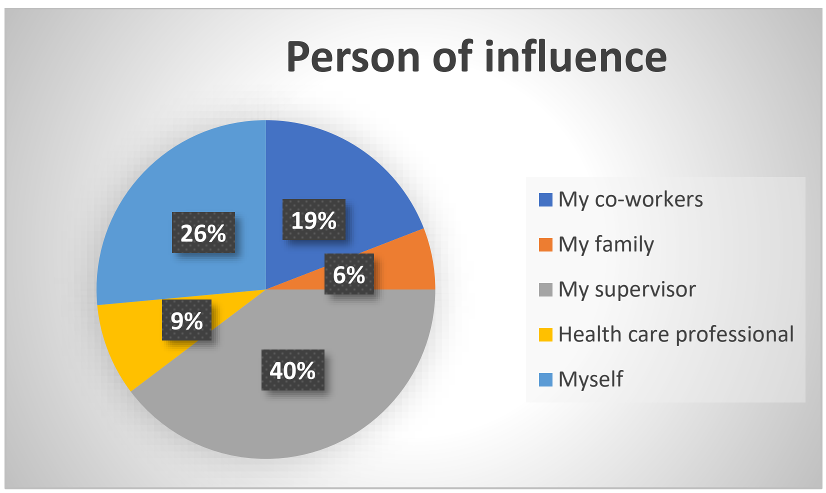

Figure 18 Percentages of reported person of influence for getting new prevention practices instructions.

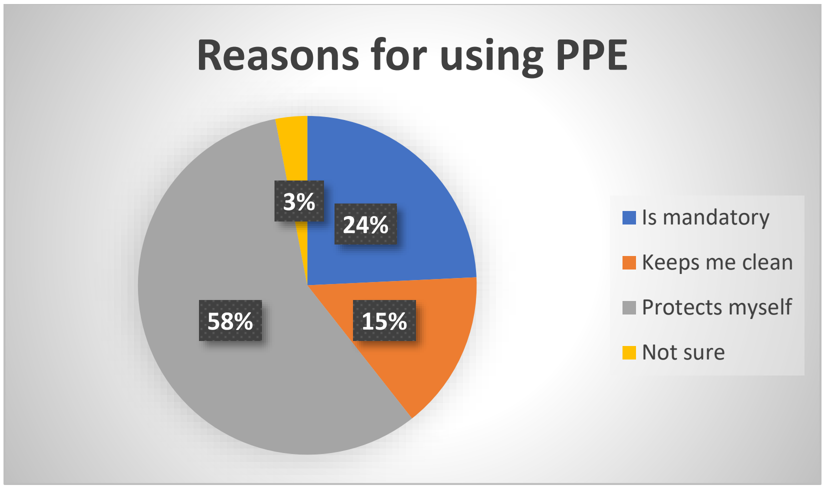

Figure 19 Percentages of main reasons reported for wearing PPE

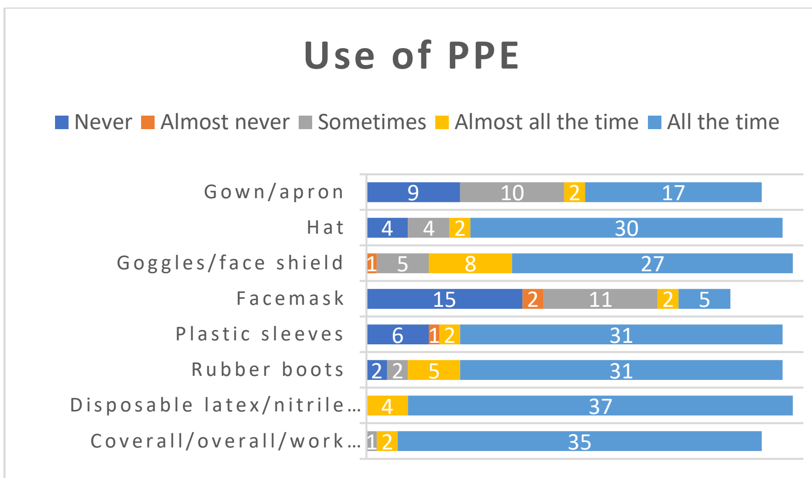

Figure 20 Frequencies of reported use of PPE at work

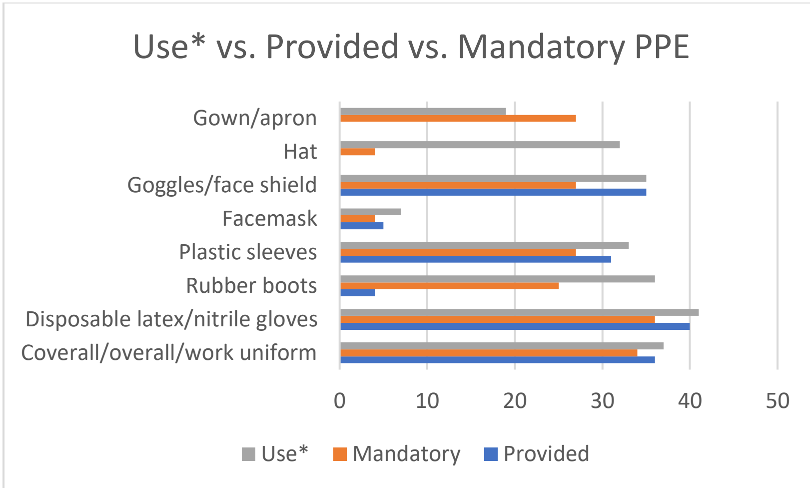

*Figure 21 Comparison of frequencies of reported use (*Almost all the time + All the time), mandatory by the farm, and provision of PPE elements.*

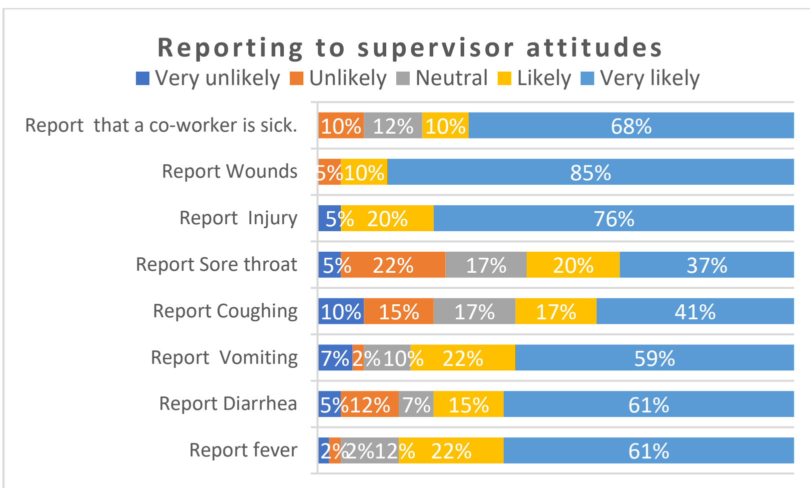

Figure 22 Percentages distribution of the intentions of reporting to supervisor in case of a health event.

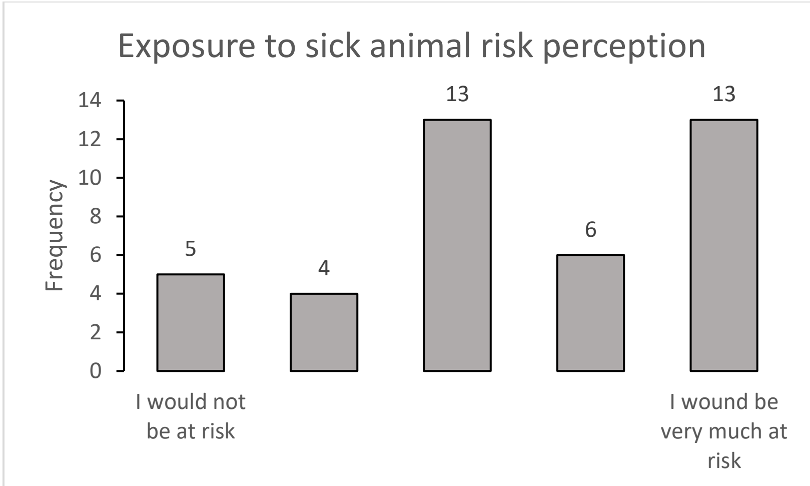

Figure 23 Reported perception of risk when exposed to a sick animal.

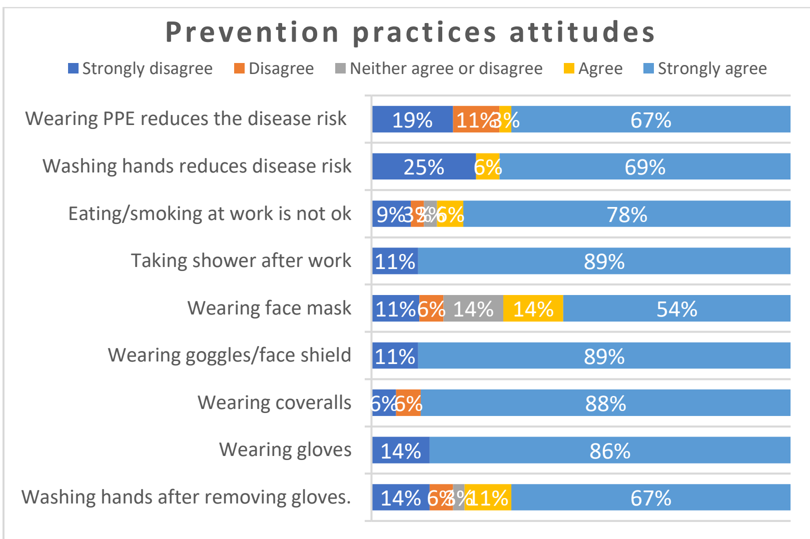

Figure 24 Percentages distribution of scale measuring attitudes toward prevention practices.

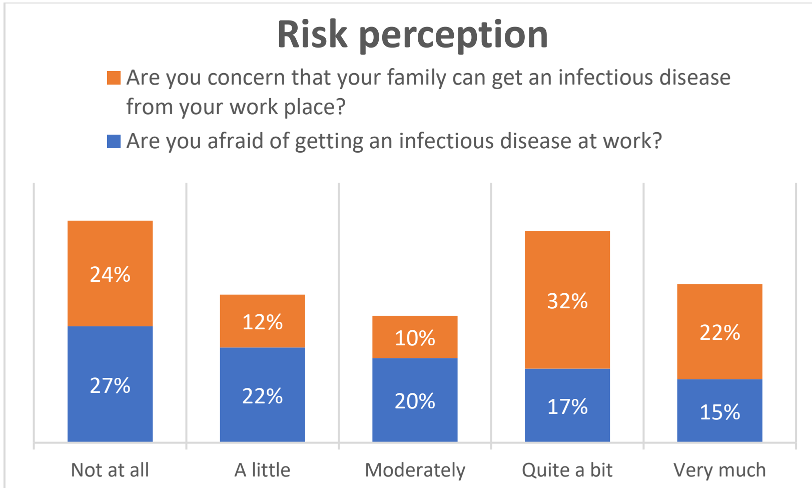

Figure 25 Percentages distribution of the risk perception measures.

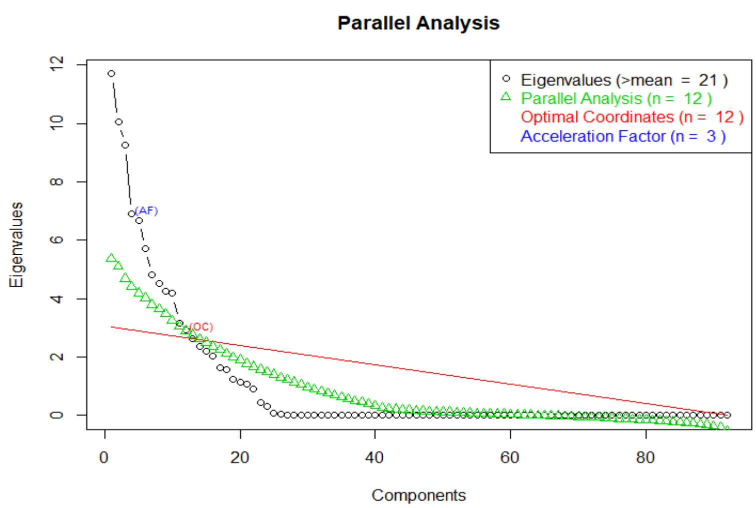

Figure 26 Parallel scree test for determining the number of principal components to retain.

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Chapter 5. FINAL CONSIDERATIONS

It is just logical to use the social ecological model to organize the final considerations of this dissertation. Based on the evidence and findings of the research conducted, we emphasize the potential actions that can be implemented to improve the prevention of zoonotic diseases exposure on a dairy farm. In addition, we want to pinpoint the limitations and pitfalls of this research as a valuable outcome.

As we have highlighted along this dissertation, the SEM is organized in different compartments arranged in layers within one another; they portrait different degrees of interdependence and interactions between them. According to this, the statements and propositions here exposed are not isolated and should be taken integrally because, indeed, an action in one layer will affect the underlying layers as well.

5.1 Intrapersonal level

In this complex level, we can find characteristics of an individual that influence behavior change, including knowledge, attitudes, behavior, self-efficacy, developmental history, gender, age, religious identity, racial/ethnic identity, sexual orientation, values, goals, expectations, literacy, stigma, and others.

We found evidence of intrapersonal factors affecting the exposure to zoonotic diseases in dairy farms. Based on our factor analysis results we found that knowledge and risk perceptions join into one common factor, indicating orthogonal covariability. Alongside, we found that this combined factor of knowledge score and high-risk perceptions is a protective factor of exposure to zoonotic diseases. Oppositely and surprisingly, self-efficacy appeared to be a risks factor.

Another interesting finding is that there is a lack of zoonotic diseases prevention knowledge recall in the participants. This is reflected in a few obvious knowledge deficiencies such as lack of basic understanding of the causes, transmission, and potential consequences of infectious diseases. We also observed that in our sample there was no association of knowledge with educational level or none of the training variables measured. This supports in part the premise that the existent knowledge could have been acquired from other sources such as supervisors and co-workers. Based on this evidence we can interpret that including potential consequences of zoonotic diseases infections, and basic concepts of transmission and causes of infections would decrease the risk of exposure to zoonotic diseases.

5.2 Interpersonal level

This level includes formal and informal social networks and social support systems that can influence individual behaviors, including family, friends, peers, and co-workers.

Supporting the results reported elsewhere, in our study we found indications and evidence that supervisors and coworkers play an important role as agents of prevention. Concretely, we found that most of the participants (40%) consider that the supervisor is the most influential for transfer of preventive information. We hypothesized that the lack of association between training variables and knowledge on prevention of infectious diseases is an indication that safety knowledge of infection prevention is flowing through other channels; perhaps through interpersonal interactions with supervisors and experienced coworkers. This hypothesis is supported by the findings from the factor analysis; we found supervisor perception variables about knowledge and perception of risks from infectious diseases. Additionally, the interpersonal factors such as perceptions of supervisors and coworkers are protective of exposure to *Campylobacter*. There is enough evidence exposed here and in other studies to affirm that this level plays an essential role in the flow of prevention information, practices, and transfer of safety. The potential for interventions in this level is significant, since focusing on a few key members of this level would have a very substantial effect with a supporting organizational environment in place.

5.3 Organizational level

This level encompasses essential social ecological determinants of infectious diseases prevention. Decision-making power regarding allocation and availability of prevention resources such as information, PPE availability, safe facilities, protocols and standards, and access to health prevention services, are the most relevant for prevention of zoonotic disease at the farm.

We found evidence of several organizational level factors affecting the exposure to zoonotic diseases in dairy farms. Positive attitudes and perceptions towards farm management were found to be a protective factor of exposure to *Salmonella*, and similarly, negative workplace perceptions were found as a risk factor. The farm management perceptions compiled variables such as organizational commitment perception, trust in management, and absence of discrimination perception, while negative workplace perceptions contained variables such as role overload, lack of job control, and safety concerns from coworkers. This is an indicator of the positive effect that a supportive work environment has on the prevention of zoonotic diseases for the workers. Due to the limited number of farms that we sampled, we advise caution on the extrapolation of these results. We encourage the continuous scientific exploration of these factors on random samples of farms to confirm their external validity.

Based on our observations, we also found other less tangible yet very important social ecological factors that would improve the prevention of diseases at work. Some of them, are good communication and language, promotion of safety culture, a favorable work climate, and endorsement of leadership roles among supervisors and coworkers.

5.4 Outer layers

In the scoping research conducted our findings indicated that several social ecological factors with research and intervention potential. Based on these results we provide a few critical considerations.

Comunity level: At the community level, we can find the organizations, institutions, and informational networks including associations, community leaders, and health care centers. Our scoping research identified critical information transfer sources and pathways that affect the prevention of infectious diseases. Social media, mass information media, associations and guild publications, and health and extension outreach services are essential tools for dissemination of prevention. Considering the importance of these tools, it is relevant to maintain the flow of accurate disease prevention and safety information through these available dissemination paths

Enabling level (policy level): The enabling level encompasses the administrative and legal instances of the local, state, national and global laws and strategies, including policies regarding the allocation of resources for access to health care services, research priorities, restrictive policies, or lack of policies. We found evidence that the actions taken in this level are effective in reducing public health threats.

Some policies and regulations affect the prevention of infectious diseases as occupational hazards. Taking into account that the dairy environment is a contaminated workplace, biological hazards regulations and policies applied to other workplaces should reach dairy production workplaces as well.

5.5 Limitations, pitfalls, and improvements opportunities.

We want to clarify that the researchers utilized all the resources they had available in procure of reliable and valid results. However, as in all research projects, we encounter multiple barriers that will be addressed in this section. This project was planned and conducted as a pilot exploration. Thus this section should be taken as one of the important outcomes obtained and used as a reference when planning further research endeavors.

One of our most significant deficiencies was the limited number of farms that we were able to access. Due to this, we could not find evidence of the direct effect that different farms has on the exposure to zoonotic diseases. Despite this, we found several organizational factors that can be theoretically linked to the farm.

The worker sample size is also small and was not probabilistically selected. This has implications on the external validity of the interpretation of the results. It is probable that the results here displayed are only valid to the accessed population. Despite this, and based on the concept of external ecological validity, these results have the potential to be applied using comparability characteristics. The ecological external validity theory states that the results obtained can be applied to another set if the conditions are similar to those of the accessed sampled population [6]. The small sample size also limited the

[6] Gliner JA, Morgan GA, Leech NL. Sampling and Introduction to External Validity. In: *Research Methods in Applied Settings: An Integrated Approach to Design and Analysis*. Second edition. New York: Routledge; 2009.

use of multivariable regression model to address the multivariable effect of social ecological factors on the exposure to zoonotic diseases. We expect that these annotations serve for a reference point when planning further research on these topics.

5.6 Final thoughts

The social ecological approach serves as a framework to measure, understand, and intervene underrated host and environmental epidemiological determinants of zoonotic diseases. We provide evidence of the effect of intrapersonal, interpersonal, and organizational factors on exposure to zoonotic diseases in dairy farms. And presented potential important community and enabling level factors that are worthy of exploration an intervention. These results can be used right away as a reference for informing the design, improvement, and implementation of prevention intervention programs in the farms, and as a reference point for further research aimed to expand the concepts here exposed.

APPENDIX 1

Letter of invitation for farm owners or managers

Dear [name of contact person]

My name is Jairo Palomares, and I represent a group of researchers that are working on identifying the social and ecological factors that may affect the exposure of dairy workers to zoonotic diseases. As a dairy producer in Colorado, we would like to invite you to participate in this important study.

Zoonotic pathogens can cause disease, production losses, and increased veterinary and replacement costs in the dairy herd. These diseases can be passed between animals and humans and cause disease, lower productivity, missed work days and increased medical expenses among the farm's personnel. Zoonotic diseases can also be passed between animals by dairy personnel. Although effective prevention strategies for transmission of these diseases are well known, many dairy workers do not follow them. Our primary goal is to understand what factors increase or decrease the exposure of workers to these diseases.

To identify these factors, we would like to enroll dairy workers from the milking parlor, maternity, hospital, and calf rearing areas of the operation. After obtaining consent, we would like to interview several workers. The survey is confidential, and questions relate to safety training, knowledge, perceptions, and practices. The interviews would not interrupt work in any way and will only be conducted outside of working hours. Additionally, we would like to collect microbiological samples from the dairy environment and the protective equipment worn by the participating workers. The samples will be analyzed for the presence of common zoonotic pathogens.

Data will be gathered confidentially and will only be shared after being combined with data from other participating operations. With your participation, we hope to gain more knowledge about the factors that affect the prevention of exposure to zoonotic diseases at dairy farms.