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REGULAR ARTICLES

Meat retail conditions within the establishments of Kigali city (Rwanda): bacteriological quality and risk factors for *Salmonella* occurrence

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Abstract Meat constitutes one of the major vehicles for human foodborne infections. This study aimed to assess the retail conditions and to determine the microbiological quality and safety of meat retailed within the establishments of Kigali (Rwanda). A questionnaire survey was carried out in 150 retail outlets to characterise meat retail conditions. Additionally, 270 retail meat samples were analysed for the enumeration of hygiene indicator bacteria (total mesophilic bacteria and *Escherichia coli*) and for the qualitative detection of *Salmonella*, using conventional culture methods. The results revealed that beef was the predominant meat sold within the retail premises of Kigali city, while meat from non-bovine animal species was mainly sold in large establishments. *Salmonella* was detected in 19.6% of all the retailed meat samples evaluated, whereas the mean loads for total mesophilic bacteria and *E. coli* were 7.3 and 3.5 log cfu/g, respectively. Three factors, namely the temperature conditions of the meat under retail, the cleanability of the used meat cutting boards, and the training of personnel in hygienic meat handling practices, were found to be significantly ($p \leq 0.05$) associated with the risk of *Salmonella* occurrence in the retailed meat. The findings from this study highlight the need for improvements in hygienic meat handling practices, particularly, in small and medium meat retail establishments in Kigali.

Keywords Meat · Retail conditions · *Salmonella* · Hygiene indicator bacteria · Risk factors · Rwanda

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Introduction

Meat is known to be an important source of valuable proteins and nutrients for human nutrition. However, its chemical composition favours the proliferation of a wide range of microorganisms. (de Carvalho et al. 2014; McAfee et al. 2010; Sans and Combris 2015). Consequently, meat constitutes one of the major vehicles for microbial pathogens, responsible for foodborne infections in humans (Doulgeraki et al. 2012; Nychas et al. 2008).

Human salmonellosis constitutes one of the leading foodborne diseases (Centers for Disease Control and Prevention 2013; European Food Safety Authority (EFSA) and European Centre for Disease Prevention and Control (ECDC) 2015), and the consumption of contaminated meat is reported to be one of the major pathways of *Salmonella* transmission. In a study conducted in the United States (US) and European countries, Greig and Ravel (2009) reported that 20.7, 11.5, and 7.2% of *Salmonella* outbreaks with an identified vehicle were respectively associated with the consumption of poultry, beef, and pork products. Nevertheless, it should be noted that the proportion of human salmonellosis

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linked to the consumption of meat is difficult to estimate accurately, principally because only a limited number of illness cases are officially reported to competent authorities; and even within the declared cases, very few allow the identification of the food vehicle (Newell et al. 2010; Scallan et al. 2011; Stevens et al. 2006).

The contamination of meat by microbial pathogens, such as *Salmonella*, can occur at any stage along the meat chain, from the farm to consumption (Niyonzima et al. 2015). However, the retail level constitutes an important stage, regarding the ultimate quality and safety of meat, as it represents the last checkpoint where contaminated products can be identified (Wong et al. 2002). Therefore, the microbiological quality of meat, at the retail stage, constitutes a notable food safety concern for consumers.

In Rwanda, the microbiological quality of meat consumed within the households, as well as meat-based meals consumed outside the home, was thoroughly investigated by Niyonzima et al. (2016, 2017). However, to the best of our knowledge, no study has yet assessed the occurrence of bacterial pathogens such as *Salmonella*, in earlier stages of the meat chain, particularly at the retail level within Kigali city. In a baseline study conducted in the markets of Kigali, the levels of hygiene indicator bacteria (namely, the total mesophilic bacteria and *Escherichia coli* counts) in the retailed meat were found to lie outside the European microbiological standards acceptable range (Niyonzima et al. 2013). This would suggest the possible contamination of retailed meat by bacterial pathogens such as *Salmonella* that are generally associated with poor hygienic practices in meat processing units (Carrasco et al. 2012; Rhoades et al. 2009).

The present study aimed to assess the meat retail conditions in Kigali city, as well as to determine the bacteriological quality and safety of retailed meat in Kigali. Data gathered in this study will be helpful in designing a microbiological risk assessment model for *Salmonella* in the Rwandan meat chain.

Material and methods

Survey on meat retail conditions

The survey was conducted to characterise the retail conditions within the establishments selling meat in Kigali city. From the list of registered establishments in different districts of Kigali city provided to us by the district authorities, 300 establishments were first selected and approached, to request their willingness and consent to participate in the present study. From those who accepted to participate in the study (n = 272), a second selection was carried out to retain only 150 retail establishments, in which the survey and the collection of meat samples were performed. The selection of establishments was performed by using the random selection function of Microsoft Office Excel 2007 (Microsoft Corporation, Redmond, WA, USA).

For the survey, each selected establishment was visited once. Through the interview with the manager of the establishment, information regarding the type of meat used, meat handling and storage conditions, equipment and staff hygiene, cleaning and disinfection procedures, and pest control measures within the establishment was collected through a structured questionnaire. After the interview, the responses were verified on the site and corrections were made when necessary.

In the present study, retail establishments were classified into three categories, depending on their meat production capacity. Establishments with a daily production below 100 kg were considered as small establishments, whereas those with a production between 100 and 200 kg/day and beyond 200 kg were considered as medium and large, respectively.

Microbiological analyses

Collection of meat samples

Meat samples were collected from 75 establishments, selected randomly from those selling beef, and in the totality of establishments selling meat from animal species other than bovines (24 for goat/mutton, 18 for chicken, 12 for pork, and 6 for rabbit). At each establishment, two samples (portions of approximately 50 g) were aseptically collected for each meat type and placed in separate sterile stomacher bags (VWR, Belgium). A total of 270 samples were collected. The meat samples were transported to the laboratory, within approximately 2 h, in a cold box with freeze packs. At the laboratory, samples were stored frozen at − 30 °C and microbiologically analysed within 24 h.

Analytical methods

Meat samples were analysed for the enumeration of hygiene indicator bacteria (namely total mesophilic bacteria and *Escherichia coli*) and for the qualitative detection of *Salmonella*. The International Organisation for Standardisation protocol ISO 7218:2007 (ISO 2007) was followed for the preparation of meat samples. The enumeration of total mesophilic bacteria (TMC) was performed by using the pour plate method on plate count agar (VWR, Belgium), as described in the ISO 4833:2003 standard protocol (ISO 2003), whereas the *E. coli* counts (ECC) were determined on tryptone bile X-glucuronide agar (Bio-Rad, France), as defined by the ISO 16649-2:2001 standard protocol (ISO 2001). In the case the levels of TMC or ECC were found to be below the bacterial enumeration threshold, subsequent calculations were done with the value of the detection limit of the used analytical method. The ISO 7218:2007 standard indicates that the enumeration of total

mesophilic bacteria and *E. coli* in solid samples, by using ISO 4833:2003 and ISO 16649-2:2001 standard protocols, respectively, has a detection limit of 1 log cfu/g (ISO 2007).

Salmonella was qualitatively detected in the meat samples by following the ISO 6579:2002 standard protocol (ISO 2002). The non-selective enrichment step was performed in buffered peptone water (VWR, Belgium), whereas Rappaport–Vassiliadis with soya (Sigma-Aldrich, Belgium) and Müller–Kauffmann tetrathionate-novobiocin (Sigma-Aldrich, Belgium) broths were used for the selective enrichment phase. Xylose lysine deoxycholate (Sigma-Aldrich, Belgium) and brilliant green (Bio-Rad, France) agars were used for the isolation of characteristic or suspected colonies of *Salmonella*, whereas the API 20E gallery (bioMérieux, France) was used for their biochemical confirmation.

Statistical analyses

Statistical analyses were performed using SPSS 16.0 software (IBM, USA). One-way analysis of variance (ANOVA) was used to test the equality of means for normally distributed variables, whereas the Kruskal–Wallis H (KWH) and Mann–Whitney *U* (MWU) tests were used for non-normally distributed variables. The normality of the distributions was assessed by the Shapiro–Wilk test, while Pearson's chi-square (PCS) test was used to compare the proportions of different variables.

The results from bacterial counts were transformed into log cfu scale base 10 before subsequent calculations and statistical treatments. Correlation between TMC and ECC (continuous variables) was determined using Spearman's rank correlation (r_s), whereas the point-biserial correlation (r_{pb}) was used to determine a correlation between ECC and *Salmonella* occurrence (binary variable).

A binary logistic regression analysis was used to determine the risk factors for *Salmonella* occurrence in retailed meat. The outcome variable was the occurrence of *Salmonella*-positive meat in the retail establishment. Meat sold in a retail establishment was considered contaminated by *Salmonella*, when at least one sample was found to be *Salmonella*-positive. Potential risk factors were first screened, to assess their association with the outcome variable, by PCS test, and only significant factors ($p \leq 0.05$) were considered eligible for the logistic regression analysis. The assessed potential risk or protection factors included the processing of meat from various animal species within the establishment; the origin of the processed meat; the temperature conditions for the transportation, the storage, and the exposition of meat within the establishment; the control of meat temperature during transportation, storage, and exposition within the establishment; the coating of walls and floor of the establishment with an easy to clean and sanitise material; the use of meat cutting boards that are easy to clean and sanitise; the sanitation of meat cutting equipment; the cleaning and disinfection frequencies within the establishment; the use of insect traps within the establishment; the conduct of a regular medical check-up for personnel to assess whether they are carriers of pathogens susceptible to be transferred to meat they are handling; the wearing of protective clothes by meat handlers; and the training of personnel in hygienic meat handling practices.

Results

Meat retail conditions in Kigali city establishments

Retail marketing of meat from various animal species

Bovine meat was found to be the main type of meat sold in retail establishments of Kigali city. The sale of non-bovine meat was predominantly practiced in large meat retail premises. The level of utilisation of meat derived from various animal species in retail establishments of Kigali city is described in Table 1.

Distribution conditions for meat carcasses

Table 2 describes the procurement places for various types of meat in the retail premises of Kigali city. Public slaughterhouses were found to be the main procurement place for retail establishments, particularly for bovine and small ruminant meat, whereas meat from other animal species was supplied

Table 1 Utilisation of meat from various animal species within retail establishments of Kigali city

	n	Animal species				
		Cow	Goat/mutton	Chicken	Pork	Rabbit
Small-scale	39	39 (100.0^{a})	0 (0.0^{a})	0 (0.0^{a})	0 (0.0^{a})	0 (0.0^{a})
Medium-scale	69	69 (100.0^{a})	6 (8.7^{b})	3 (4.3^{b})	0 (0.0^{a})	0 (0.0^{a})
Large-scale	42	42 (100.0^{a})	18 (42.9^{c})	15 (35.7^{c})	12 (28.6^{b})	6 (14.3^{b})
Total	150	150 (100.0$^{[w]}$)	24 (16.0$^{[x]}$)	18 (12.0$^{[xy]}$)	12 (8.0$^{[yz]}$)	6 (4.0$^{[z]}$)

Values are numbers (percentage) of retail establishments selling meat of a given animal species. In the same column, different superscript letters (a, b, c) indicate a significant ($p \leq 0.05$) difference. Values with the same superscript letters (w, x, y, z) are not significantly different ($p \leq 0.05$)

Table 2 Meat procurement places for retail establishments in Kigali city

	Animal species				
	Cow (n = 150)	Goat/mutton (n = 24)	Chicken (n = 18)	Pork (n = 12)	Rabbit (n = 6)
Slaughterhouse	129 (86.0[a])	21 (87.5[a])	0 (0.0[a])	0 (0.0[a])	0 (0.0[a])
Other butcheries	21 (14.0[b])	0 (0.0[b])	0 (0.0[a])	0 (0.0[a])	0 (0.0[a])
Farmers	0 (0.0[c])	0 (0.0[b])	18 (100.0[b])	12 (100.0[b])	6 (100.0[b])
Slaughtering in place	0 (0.0[c])	3 (12.5[c])	0 (0.0[a])	0 (0.0[a])	0 (0.0[a])

Values are numbers (percentage) of retail establishments supplied in meat from a given procurement place. In the same column, different superscript letters indicate a significant ($p \leq 0.05$) difference

directly from farmers, predominantly located in the peri-urban area of Kigali city. The transportation of meat carcasses from the slaughtering facility to the retail establishment was found to be mainly carried out under ambient temperature conditions. The average duration of carcass transportation was estimated to 29 min in the establishments where carcasses were transported under ambient temperature conditions and to 46 min in the establishments where the refrigeration of carcasses during the transportation was practiced (Table 3).

Retail and storage conditions for meat

Sixty-nine percent of the studied establishments reported to be exposing retail meat to ambient temperature, and the maximal duration of meat exposition was estimated to 8 h. The average duration of meat exposition (Table 4) was found to be significantly higher in medium establishments compared to small or large retail outlets (small versus medium establishments: MWU test = 531.5, degrees of freedom [df] = 1, $p < 0.001$; small versus large establishments: MWU test = 1217.5, df = 1, $p = 0.381$; medium versus large establishments: MWU test = 536.5, df = 1; $p < 0.001$). All the studied establishments reported to be storing the non-exposed meat carcasses in the freezer, and the average maximal storage duration was estimated to 37.7 h. No significant difference was noted between the storage durations of meat carcasses in different categories of meat retail establishments (KWH test = 3.6, df = 2, $p = 0.146$).

Professional training and hygiene of workers

The overall proportion of retail establishments with trained personnel in meat handling and hygiene was found to be relatively low. No trained staff were reported in all small meat retail establishments, whereas 13.0 and 50.0% of medium and large establishments, respectively, employed trained personnel. In 94% of the 150 studied establishments, personnel in the production area were found to be wearing clean coats, whereas head covers, gloves, and masks were regularly worn by staff in only 66.0, 18.0, and 10.0% of the visited meat retail outlets, respectively (Table 5). Nevertheless, regular staff medical check-ups were reported in all small and large meat retail establishments and in 91.3% of the 69 medium retail outlets.

Hygiene of the establishment

In all retail establishments, the walls and the floor of the production area were found to be covered with an easy to clean material, in most of the cases, porcelain tiles. However, 62.0% of the retail facilities were found to use wooden cutting boards with rough surfaces that are difficult to clean and disinfect.

Table 3 Transportation conditions for meat within retail establishments of Kigali

	n	Transport under refrigeration conditions		Transport under ambient temperature conditions	
		Number (%) of establishments	Duration of meat transportation	Number (%) of establishments	Duration of meat transportation
Small-scale	39	0 (0.0[a])	0.0 ± 0.0[a]	39 (100.0[a])	23.9 ± 13.1[a]
Medium-scale	69	7 (10.1[b])	14.3 ± 13.4[b]	62 (89.9[b])	25.7 ± 16.8[a]
Large-scale	42	14 (33.3 [c])	62.5 ± 46.3[c]	28 (66.7[c])	43.8 ± 29.6[b]
Total	150	21 (14.0)	46.4 ± 44.6	129 (86.0)	29.1 ± 20.7

Temperature conditions: values are numbers (percentages) of establishments transporting meat under the indicated temperature conditions. Transportation duration: values are means (±standard deviation) of the estimated transportation duration (in minutes) for meat from the procurement place to the retail establishment. In the same column, different superscript letters indicate a significant ($p \leq 0.05$) difference

Table 4 Meat retail conditions within the establishments of Kigali

	n	Retail under refrigeration conditions		Retail under ambient temperature conditions	
		Number (%) of establishments	Duration of meat exposition	Number (%) of establishments	Duration of meat exposition
Small-scale	39	3 (7.7[a])	18.0 ± 6.0[a]	36 (92.3[a])	7.0 ± 2.9[a]
Medium-scale	69	16 (23.2[b])	23.3 ± 3.0[a]	53 (76.8[b])	9.0 ± 2.2[b]
Large-scale	42	27 (64.3[c])	22.7 ± 3.8[a]	15 (35.7[c])	8.3 ± 2.3[a]
Total	150	46 (30.7)	22.6 ± 3.8	104 (69.3)	8.2 ± 2.6

Temperature conditions: values are numbers (percentages) of establishments exposing meat under the indicated temperature conditions. Exposition duration: values are means (±standard deviation) of the estimated maximal exposition duration (in hours) for meat within the retail establishment. In the same column, different superscript letters indicate a significant ($p \leq 0.05$) difference

The use of meat cutting boards made of an easy-to-clean material was observed in only 38.5, 27.5, and 54.8% of the small, medium, and large retail outlets, respectively.

Though all retail establishments have indicated to regularly clean the retail and production area of the facility, the disinfection was found to be rarely practiced. Only 2.0% of the 150 studied establishments (7.4% of the large establishments and 0.0% of both the small and medium retail premises) reported disinfecting the production and retail area of the establishment. Nevertheless, pest control measures, by use of insect traps, were applied in all medium and large meat retail facilities and in 61.5% of the small retail establishments.

Bacteriological quality of the retailed meat

Table 6 describes the levels of hygiene indicator bacteria, namely the TMC and EEC, as well as the occurrence of *Salmonella* in various types of meat sold in retail outlets of Kigali city. The mean TMC ranged from 6.3 to 9.6 log cfu/g and the mean ECC ranged from 2.9 to 4.4 log cfu/g, whereas *Salmonella* was isolated in 19.6% of all meat samples. The hygiene indicator bacteria loads were found to be significantly ($p \leq 0.05$) higher in pork and chicken compared to meat from other animal species, whereas the prevalence of *Salmonella* did not vary significantly ($p \leq 0.05$) among the types of meat in which *Salmonella* was detected. For the same sample, Spearman's rank correlation between TMC and ECC was found to be positive and significant ($r_s = 0.454$, $n = 270$, $p < 0.01$) as well as the point biserial correlation between ECC and the occurrence of *Salmonella* ($r_{pb} = 0.350$, $n = 270$, $p < 0.01$).

Table 5 Composition of the working cloth in the studied meat retail facilities

	n	Components of the working cloth			
		Coat	Head cover	Mask	Gloves
Small-scale	39	30 (76.9[a])	15 (38.5[a])	6 (15.4[a])	6 (15.4[a])
Medium-scale	69	69 (100.0[b])	54 (78.3[b])	6 (8.7[a])	15 (21.7[a])
Large-scale	42	42 (100.0[b])	30 (71.4[b])	3 (7.1[a])	6 (14.3[a])
Total	150	141 (94.0)	99 (66.0)	15 (10.0)	27 (18.0)

Values are numbers (percentage) of the establishments in which the personnel wear the indicated working cloth. In the same column, different superscript letters indicate a significant difference ($p \leq 0.05$)

Risk factors for *Salmonella* occurrence

Three variables, namely "meat retail under refrigeration conditions", "use of easy-to-clean meat cutting board in the establishment", and "the training of personnel in hygienic meat handling practices" were found to be significantly ($p \leq 0.05$) associated with a decreased risk of *Salmonella* occurrence in retailed meat (Table 7).

Discussion

Meat handling conditions in retail establishments of Kigali city

Beef was found to be the type of meat primarily sold in retail establishments of Kigali. This could be attributed to the cultural considerations of the Rwandan population, as cows are of great socio-cultural importance in Rwandan society (Adekunle 2007). Another reason would be the lack of public infrastructure available to slaughter other animal species in Kigali city. Consequently, many households in Kigali are unable to afford meat from animals other than bovines that are generally slaughtered in private small-scale plants (Niyonzima et al. 2016). Available statistics indicate that in 2013, bovine meat alone counted for 48.7% of the global meat production in Rwanda [Food and Agriculture Organisation (FAO) 2015]. The reported procurement of raw meat from animals other than bovines directly from farms, by meat retail establishments, appears to be a direct consequence of the lack of public slaughtering facilities for these animal species.

Table 6 Bacteriological quality of meat at retail

	n	Hygiene indicator bacteria		*Salmonella* occurrence	
		TMCs	ECCs	Positive samples (num.)	Positive samples (%)
Beef	150	7.0 ± 1.2^{a}	3.4 ± 1.3^{a}	35	23.3^{a}
Goat/mutton	48	6.3 ± 0.6^{b}	2.9 ± 1.2^{b}	6	12.5^{a}
Chicken	36	9.3 ± 1.3^{d}	4.3 ± 1.2^{cd}	8	22.2^{a}
Pork	24	9.6 ± 1.0^{cd}	4.4 ± 0.5^{d}	4	16.7^{a}
Rabbit	12	6.3 ± 0.6^{abc}	3.7 ± 0.3^{abc}	0	0.0^{b}
Total	270	7.3 ± 1.5	3.5 ± 1.3	53	19.6

Hygiene indicator bacteria: values are means (±standard deviation) of bacteriological counts. *Salmonella* occurrence: values are numbers and percentages of *Salmonella*-positive samples. In the same column, different superscript letters indicate a significant difference ($p \leq 0.05$)

TMCs total mesophilic counts, *ECCs E. coli* counts

In most of the studied establishments, the transportation of carcasses or meat cuts from the slaughtering place to the retail points was found to be carried out under non-refrigerated conditions. This can be explained by the low financial capacity of a number of meat retail establishments in Kigali, which cannot afford the purchase of meat refrigeration vehicles. The high cost of cold storage equipment has been identified as one of the key factors hampering the transportation of meat cuts and/or carcasses under refrigeration conditions in developing countries (Kago et al. 2014). Our findings agree with the results from previous studies conducted in various developing countries, such as Ghana (Adzitey et al. 2011) and Kenya (Roesel et al. 2014), where the transportation of meat under non-refrigerated temperature conditions was reported. The average duration of carcass transportation under ambient temperature conditions was found to be about 29 min. As the generation time for *Salmonella* in optimal temperature conditions (35–37 °C) is known to be 25 min (Delhalle et al. 2009b), the recorded duration of carcass transportation under ambient temperature might allow the proliferation of *Salmonella* cells initially present on carcasses or meat cuts. Several studies have reported bacterial proliferation during the carcass transportation stage, when the temperature was not successfully controlled (Wong et al. 2002; Niyonzima et al. 2015).

As during the carcass transportation stage, numerous establishments (69.3%) were found to be exposing retailed meat under non-refrigerated conditions, for an average maximal duration of 8 h. In these establishments, meat cuts were kept frozen and meat to be retailed was hung on hooks at ambient temperature everyday. At the end of the day, the leftovers were frozen and sold the following day. These retail practices might favour the proliferation of microorganisms present in meat cuts, particularly during the period which meat is kept at ambient temperature. Several studies have reportedly associated the proliferation of microorganisms to the repeated freezing and thawing of meat products (Oranusi et al. 2014; Wu et al. 2017).

The exposition of meat at ambient temperature observed in some retail establishments can be attributed to the low financial capacity of retailers to afford the purchase of meat refrigeration cabinets, as well as their limited knowledge in

Table 7 Risk factors for *Salmonella* occurrence in meat retail establishments of Kigali city

Variable	Percentage of *Salmonella*-positive establishments[a]	Binary logistic regression		
		Odds ratio	95% CI	*p* value
Retail temperature condition for meat				
Ambient temperature (*n* = 104)	71.4	1.0		
Refrigeration (*n* = 46)	17.0	0.082	0.032–0.211	0.000
Easy to clean (and disinfect) meat cutting board				
No (*n* = 93)	88.9	1.0		
Yes (*n* = 57)	7.0	0.009	0.002–0.037	0.000
Training of personnel in meat handling and hygiene				
No (*n* = 120)	57.8	1.0		
Yes (*n* = 30)	18.4	0.165	0.063–0.430	0.000

[a] Meat retailed in a given establishment was considered contaminated by *Salmonella* if at least one meat sample was found to be *Salmonella*-positive

hygienic meat handling practices. The meat retail conditions observed in our study are comparable to the practices reported in other developing countries, such as the Democratic Republic of Congo (Kabwang 2013), Ethiopia (Haileselassie et al. 2013), and Ghana (Adzitey et al. 2011), where they were associated with an increased risk of microbial contamination in the retailed meat.

The knowledge of butcher workers in meat handling and hygiene was found to be relatively low, as only 20.0% of the studied establishments reported to employ personnel trained in meat handling and hygiene. Our results corroborated the findings from the study conducted in Ethiopia, where trained butcher workers were reported in 38.5% of 26 retail outlets in Mekelle city (Haileselassie et al. 2013). Comparable observations were also recorded in western Romania, where only 30.9% of 168 meat handlers reported to have received professional training (Jianu and Goleț 2014). Nevertheless, a relatively higher training rate of personnel was recorded in Serbian meat retail establishments, where 52.8% of 116 meat workers were reported to be trained in meat handling and safety (Smigic et al. 2016).

The wearing of protective clothes other than aprons was found to be rarely practiced, particularly within small meat retail establishments. This could be explained by the limited knowledge of meat handlers in meat hygiene practices. The proportion of hairnet usage (66.0%) recorded in the present study appears to be low compared to that observed in Romanian establishments, where 89.3% of 168 meat handlers reported to regularly wear a hairnet, during the meat production and retail activities (Jianu and Goleț 2014). Nevertheless, our findings are comparable to the results from the studies conducted in Ethiopia (Haileselassie et al. 2013) and Uganda (Muyanja et al. 2011), where hairnets were reported to be regularly worn by 49.3 and 50.2% of meat handlers, respectively. The study conducted in the Democratic Republic of Congo revealed that hairnets were not worn at all, by meat retailers in the markets of Lubumbashi (Kabwang 2013). Protective clothes, such as proper aprons, hairnets, and gloves, are barriers against microorganisms that may be transferred from handlers to meat and should always be worn during the handling of meat, to prevent microbial contaminations from the handler. Previous studies have identified bare hands (Heinz and Hautzinger 2007), dirty clothes (Cardinale et al. 2005), and worker's hairs (Lues et al. 2006) as probable sources of meat microbial contamination.

Meat handlers may also be carriers of bacterial pathogens, such as *Salmonella* (Gopinath et al. 2012). Hence, it is important that food handlers carry out a regular medical check-up, to ensure that they are not pathogen carriers. In the present study, the proportion (96.0%) of meat retailers with a medical certificate attesting that they do not carry illnesses susceptible to be transferred to meat was found to be relatively high. Comparable findings were recorded in Ethiopia, where 84.6% of 26 meat retailers in Mekelle city reported to have medical certificates (Haileselassie et al. 2013). However, lower compliance rates were reported in other developing countries. The study conducted within street food retailers in Sudan revealed that only 64% of 54 vendors had a health certificate (Abdalla et al. 2009), whereas meat retailers in Tanzania (Kago et al. 2014) and the Democratic Republic of Congo (Kabwang 2013) were found to be working without any medical certificate.

Meat retail establishments in Kigali city showed important efforts to prevent meat contaminations from the processing environment, as most of the retail outlets were found with infrastructures, such as easy-to-clean walls and floors, within the production area, and reported to be applying pest control measures by using insect traps in both the production area and retail premises. However, these efforts appear to be hampered by the limited knowledge of meat professionals in basic hygienic practices. Indeed, the sanitisation of retail premises and butcher equipment was found to be rarely practiced and a relatively high proportion of retail establishments (62.0%) reported to be using wooden cutting boards (in most instances, pieces of tree trunks) that are not easy to sanitise (Carrasco et al. 2012). The lack of knowledge in basic meat hygiene practices within meat retailers has been reported in other countries, such as the Democratic Republic of Congo (Kabwang 2013), Ethiopia (Haileselassie et al. 2013), Kenya (Kago et al. 2014), Pakistan (Hassan Ali et al. 2010), and Romania (Jianu and Goleț 2014), and was found to be associated with an increased risk of microbial contamination in the retailed meat.

Microbiological quality of the retailed meat

The willingness of the managers to participate in the present study was the principal criteria to select retail outlets, from which meat samples were collected. Consequently, this might have introduced a bias in the observed results. However, as a large percentage (90.7%) of the establishments accepted to participate in the study, and their selection was carried out randomly, the introduced bias is relatively minimal.

The bacteriological quality, particularly the levels of hygiene indicator bacteria in meat sold in retail outlets of Kigali city, was found to vary significantly ($p \leq 0.05$) among the establishments. The observed variability could be explained by the level of hygiene, as well as meat handling practices within the establishment that differ among the retail outlets. Some authors have reportedly associated the microbiological quality of meat at the retail stage to the hygiene of meat workers and the processing environment (Wong et al. 2002; Carrasco et al. 2012). Furthermore, factors, such as the quality of the used raw material, as well as the transportation conditions for carcasses from the slaughtering place to the retail premises, could have also contributed to the variation of

ultimate hygiene indicator bacteria loads, as they are likely to differ among the establishments.

The levels of hygiene indicator bacteria were found to be significantly ($p \leq 0.05$) higher in pork and chicken, compared to meat from other animal species. As meat handling practices within retail establishments were found to be comparable for all types of meat, the higher bacterial loads observed in pork and chicken samples could be attributed to the bacterial quality of the pork and chicken carcasses. Studies have indicated that pork and chicken carcasses generally present higher bacterial loads than carcasses from other animals because their hides are not removed during the slaughtering operations. Furthermore, they undergo a scalding process, which is known to favour the proliferation of microorganisms present on carcasses (Bolton et al. 2002; Borch et al. 1996).

The mean TMC recorded in the present study (7.3 log cfu/g) appears to be relatively high and indicates deficient hygienic practices within the studied meat retail establishments and/or in earlier stages of the meat chain. Our findings corroborate with studies conducted in other developing countries, where the lack of hygienic practices in meat handling was reported. In a study conducted in the markets of Accra (Ghana), for example, the TMC levels recorded in bovine meat samples (2.3–4.4 log cfu/g) were attributed to unhygienic practices and poor handling of meat by butchers (Soyiri et al. 2008). Comparable findings were reported in Pakistan, where a mean TMC of bacteria of 10.2 log cfu/g was recorded in meat sold in retail shops of Karachi city (Hassan Ali et al. 2010).

The average *E. coli* load in meat sold within retail outlets of Kigali was found to be 3.5 log cfu/g. Similar values have been documented previously. For instance, Soyiri et al. (2008) reported a mean ECC of 3.3 log cfu/g in bovine meat sold in the Ghanaian retail premises and Kabwang (2013) recorded mean *E. coli* loads of 4.50, 4.54, 4.43, and 4.44 log cfu/g, respectively, in bovine, goat, pork, and chicken meat, retailed in the markets of Lubumbashi (the Democratic Republic of Congo). However, in a study conducted in Belgian meat retail outlets, relatively lower ECC levels (0.21–1.23 log cfu/g) were recorded in pork (Delhalle et al. 2009a).

As for the hygiene indicator bacteria, the prevalence of *Salmonella* recorded in the present study (19.6%) appears to be relatively high when compared with the prevalence observed in developed countries, where hygienic practices in meat handling are reported to be strictly practiced. In the US, for example, a *Salmonella* prevalence as low as 1.02% was recorded in muscle beef cuts collected in retail premises (Vipham et al. 2012), whereas in the European Union countries, a recent report on zoonotic agents and foodborne outbreaks revealed an average *Salmonella* prevalence of 2.3, 0.5, and 0.1%, respectively, in chicken, pig, and bovine meat at retail (EFSA and ECDC 2015). European regulations indicate that *Salmonella* must be absent in 25 g of food products destined for human consumption (European Commission 2005).

The correlation between TMC and ECC and the correlation between ECC and the presence of *Salmonella* were found to be positive and significant ($p < 0.01$). This indicates that the prevalence of *Salmonella* increases with the levels of hygiene indicator bacteria in meat and would suggest that efforts to improve hygiene in meat retail units can significantly reduce the risk of *Salmonella* occurrence in the retailed meat.

Risk factors for *Salmonella* contamination in the retailed meat

Three risk factors were found to be associated with the risk of *Salmonella* occurrence in meat sold within retail outlets of Kigali. The risk of *Salmonella* occurrence in retailed meat was high in the establishments where meat was exposed to ambient temperature compared to the establishments where meat was exposed in refrigerated cabinets. This could be explained by the proliferation of microorganisms including *Salmonella*, initially present in retailed meat pieces, during the time meat is exposed at ambient temperature and the dissemination of these microorganisms through cross-contaminations. Previously, the rupture of the cold chain was reportedly associated with the proliferation of microorganisms including pathogens, such as *Salmonella*, on stored meat (McEntire et al. 2014).

The utilisation of wooden cutting boards, with rough surfaces, which are not easy to sanitise, was also associated with an elevated risk of *Salmonella* occurrence. This could be explained by the fact that materials, such as wood, generally present numerous pores that may trap microorganisms (Carrasco et al. 2012). These pores are not easily accessible by the sanitising agents. Consequently, trapped microorganisms may proliferate and disseminate to the processed products through cross-contaminations. Contaminated equipments are generally recognised as major sources of cross-contaminations in meat processing units (Small and Buncic 2009; Warriner et al. 2002). Nevertheless, the risk of *Salmonella* occurrence was found to be significantly reduced within retail establishments, whose personnel were trained in hygienic meat handling practices. These findings highlight the important role of meat handling personnel within retail establishments, in assuring the microbiological quality and safety of the processed products.

Conclusion

The findings from this study indicate that beef constitutes the main type of meat sold in retail outlets of Kigali. The hygiene indicator bacteria loads in various types of retailed meat, as well as the prevalence of *Salmonella*, were found to be relatively high, indicating the need for hygiene improvements in meat retail establishments and/or in earlier stages of the meat

chain. The meat retail conditions, particularly, the exposition of meat to ambient temperature, as well as the lack of professionally trained meat handlers, were identified as the key factors hampering the quality and safety of retailed meat in Kigali, predominantly in small and medium retail establishments. Further studies addressing the occurrence of *Salmonella* in earlier steps of the chain are needed, to design an accurate risk assessment model for *Salmonella* in the Rwandan meat chain.

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Compliance with ethical standards The authors declare that all procedures involving human participants performed in this study have been approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Helsinki declaration and its later amendments.

Conflict of interest The authors declare that they have no conflict of interest.

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