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Review

Burden of campylobacteriosis in Bangladesh: challenges and opportunities

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Abstract: *Campylobacter* is a prevalent zoonotic bacterial pathogen found in various food animals such as cattle, sheep, goats, and poultry. The increasing production of crossbred cattle in Bangladesh is aimed at meeting the demand for animal protein. However, this trend also poses public health risks associated with emergence of cattle-specific *Campylobacter*. It is probable that there is an increased probability of transmission of pathogenic *Campylobacter* among humans and animals, as well as within the farm environment. Nevertheless, it has been established that *Campylobacter* is also a significant contributor to childhood diarrhea in Bangladesh. The objective of this study is to examine *Campylobacter* in animals and humans, including the risk factors that contribute to its occurrence, patterns of antimicrobial resistance, and measures that can be taken to prevent and control its spread. The study has established predominant maintenance zoonotic *Campylobacter* in source animals and their burden in humans is enormous. Our research is primarily focused on promoting public health by improving cleaning and sanitation practices in animal farms, which can help reduce the amount of *Campylobacter* present in the environment. The data and insights provided in this article can be valuable for policy planners and public health experts who are working to create effective and sustainable strategies aimed at reducing the risks associated with *Campylobacter* infection over the long term.

Keywords: *Campylobacter*; human campylobacteriois; risk factors; livestock and poultry; public health burden; Bangladesh

1. Introduction

Campylobacter comprises a different group of Gram-negative bacteria which cause foodborne diseases in humans throughout the world (Kirk *et al*., 2015; Tack *et al*., 2019). In 2010, more than 95 million people were found to be infected with these foodborne pathogens globally (Kirk *et al*., 2015), and in the United States, each year, an expected 1.5 million people acquire infections with these organisms (CDC, 2019; Tack *et al*., 2019). The livestock species, like poultry, cattle, sheep, pigs, including pets (dogs and cats) and environmental exposure are connected with human *Campylobacter* infection (Mäesaar *et al*., 2020). *Campylobacter* spp. are living in the gastrointestinal tract of various food-producing animals, like ruminants and poultry as commensalism (Sahin *et al*., 2017), and thereby, act as a reservoir (Mäesaar *et al*., 2020). More than 90% of the human intestinal infections are associated with either *C. jejuni* or *C. coli* (Gillespie *et al*., 2002), whereas, C. *fetus* is considered to be a lesser contributor (2.4%) of total confirmed cases of such human infections (Bullman *et al*., 2011).

In Bangladesh, *C. jejuni* is the paramount causative agent of diarrhea in children (25.5%) (Haq and Rahman, 1991). *Campylobacter* infection causes acute flaccid paralysis (AFP) is associated Guillain–Barré syndrome (GBS) has been confirmed in Bangladesh with an expected incidence of 3.25 cases per 100,000 children < 15 years of age group (Islam *et al*., 2011; Islam *et al*., 2012). As many actions have been taken to minimize the burden of *Campylobacter* infection including associated GBS threats without keep in mind the infection sources in low resource settings. Thus, a significant hazard of *Campylobacter* presents in such territories (Platts-Mills and Kosek, 2014) like Bangladesh.

The share of the livestock sub-sector to the GDP at constant prices was 1.43% in FY 2019-2020 with a growth rate of GDP was 3.04% (BER, 2020). Though the share of the livestock sub-sector in the national GDP is scanty, it has huge contribution to the fulfillment of animal source protein, support to the livelihood and food security to the marginalized communities. Since the last decades, numerous initiatives have been tailored by the Government for the development of livestock sectors through different projects and programs. As a part of these activities, the genetic upgradation of native cattle stock through cross breeding using semen from exotic breeds (mostly Holstein Friesian and Sahiwal) has been continuing since the last decades to improve the productivity to fulfilling the growing demand of milk and meat (DLS, 2007). Thus, artificial insemination (AI) is widely practiced in cattle via both government and private interventions for breed up gradation (BER, 2014). Therefore, the number of cross-breed farmed cattle are increasing gradually in Bangladesh. Moreover, the government supports to supplying vaccines for cattle immunization with a subsidized price targeted to prevention of economic important diseases. On the contrary, the poultry sector in Bangladesh is steadily growing since last decade. During, the most recent years, the country has become self-reliant with meat and egg production (DLS, 2020).

Bangladesh is one of the most densely-populated country in the world with a population density of 1240 people /sq. km of area (WB, 2018b). However, the country has the highest dense ruminant (145 large ruminants/ sq. km) (WB, 2018a) and poultry (1,194 birds/ sq. km of area) populations (WB, 2013). Additionally, people dwell with a close contact to animal and birds or even share same premises. Moreover, small proportion of people consume raw milk (Islam *et al*., 2021). Inadequate good agricultural practices (GAP) in livestock farming in combination with lack of food safety and personal hygiene standards in slaughtering and meat processing activities that would facilitate transmission of zoonotic pathogens through the food chains (Islam *et al*., 2020a). In Bangladesh, *Campylobacter* infections have been recorded to be significant public burden like diarrhea to vomition, Guillain–Barré syndrome (Haq and Rahman, 1991; Islam *et al*., 2011; Islam *et al*., 2012).

To mitigate the emerging demand of nutritional requirements of huge human population, intensive livestock production has been taken place since the several decades ago. However, livestock-associated zoonoses are infrequently considered as public health importance (Mourkas *et al*., 2020). Limited research has been conducted in Bangladesh to estimate the true burden of *Campylobacter* in farmed cattle and poultry; and their zoonotic implications. Therefore, the present review highlights *Campylobacter* in food animals and their public health implications as a consequence including risk mitigations measures in the low resource settings like Bangladesh. This will support to the policy planners and public health experts to formulate risk reduction strategies as a long term goal in a low resource settings.

2. Materials and Methods

2.1. Literature search strategy

In this study we conducted review of literature of published articles with special emphasize on studies/ report on livestock data, modality of livestock production and distribution network (PDN), including occurrence of *Campylobacter* both in livestock (cattle and poultry) and humans in Bangladesh. In these regards, we reviewed research articles, book chapters, conference proceedings, and gray literature like government data/ reports, report from international agencies (FAO, WB and WHO), were considered for evaluation under this study.

2.2. Data collection and evaluation method

Data were searched from PubMed via NCBI, Google scholars, and gray literature from respective web-sites. Based on specific key words, “livestock data AND Bangladesh”, “cattle OR poultry production AND Bangladesh”, “poultry OR beef OR dairy value chain AND Bangladesh”, “*Campylobacter* cattle OR poultry

AND Bangladesh", "*Campylobacter* humans AND Bangladesh" were used for searching the pertinent articles spanning from 1980 to 28 July 2021. Additional reports/government documents (gray literature) were searched from the particular websites. Only English language articles/reports were considered for evaluation. Primarily, 139 articles/ reports were identified for review abstract/summary by all authors. We deposited all articles/records via the reference manager EndNote (Thomson Reuters, Philadelphia, P. A. USA), and thus, eliminated duplicates. After screening 53 articles, 48 were included for in-depth evaluation. The first and second authors inclusively reviewed the selected articles, documents/ reports which were informative and to be fit for this research (Figure 1).

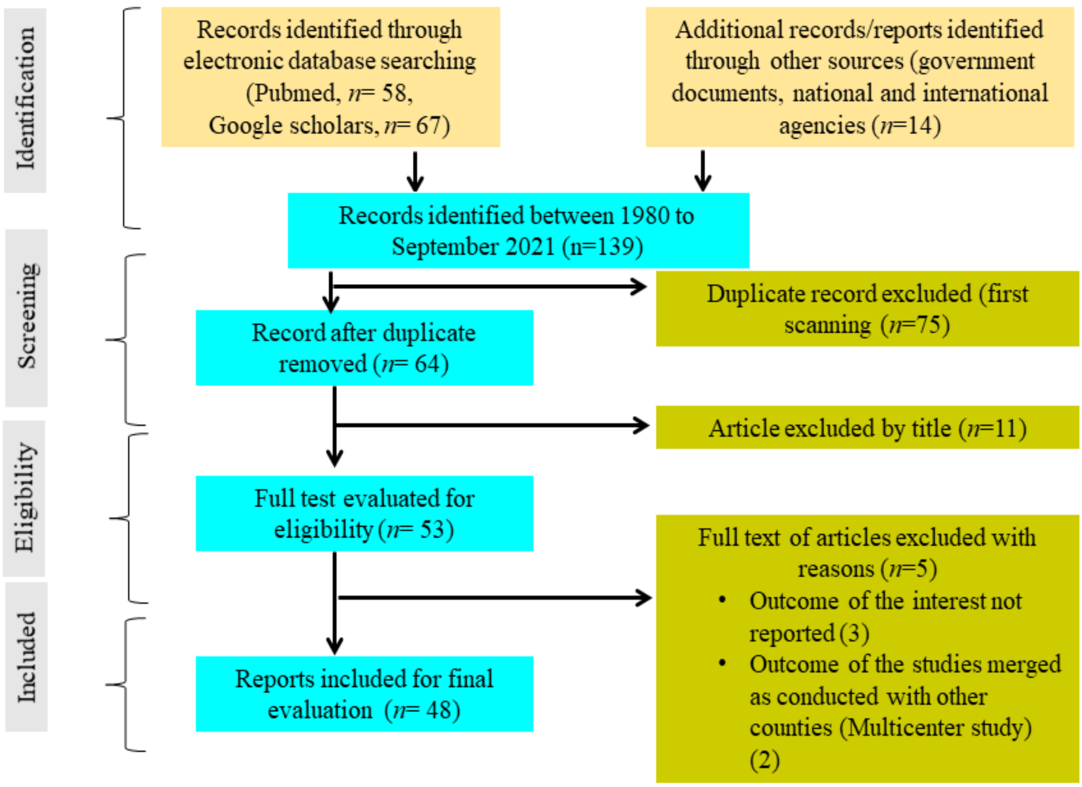

Figure 1. Search and selection strategies used in this study.

2.3. Data extraction and management

We have generated standard extraction format to capture important information for evaluation of excerpts taken from different studies. For studies on *Campylobacter* both in animals and humans we retrieved the following information: author(s) with study year/publishing year, study location(s), study conducted in animal/human, samples taken, prevalence (%) with isolates, risk factors identified for animal/human level occurrence, AMR status of the isolates including laboratory assessment procedure. Lastly, we searched information online on prevention and control options to be pertinent for Bangladesh context.

3. Results

3.1. Cattle production system

Livestock has become as the key farming system in Bangladesh since long before. About 20% people directly and 50% people indirectly depend on livestock due to food security and livelihoods. The country has there are about 24.39 million cattle, 1.49 million buffaloes, 26.4 million goats, and 3.6 million sheep and 296.6 chicken for the year 2019-20 (DLS, 2020). Among the total cattle 15% are high yielding crossbred stocks (Hamid *et al*., 2017). The crossbred cattle are mostly Holstein Friesian, Sindhi, Sahiwal with a small proportion of Jersey breed (Miazi *et al*., 2007), of which nearly 50% are milking cows (Islam *et al*., 2020b). Growing demand for animal origin food especially red meat is estimated to be two-fold by 2050 in low and middle income countries (Agus and Widi, 2018). Annual consumption for poultry meat and eggs per person are projected to be increased

26% and 41%, respectively in upcoming five years (LightCastle Partners, 2020). Therefore, intensification of livestock and poultry production is on-going.

Number of cattle population has been increased 1.3 times over the last 10 years (DLS, 2020). The cattle production system is broadly divided into two categories, viz; beef and dairy based on purpose of cattle rearing. However, each production system is subdivided into four categories, viz, household (Saadullah, 2002), semi-bathan/bathan (Islam *et al*., 2010), and semi-intensive and intensive system (Kamal *et al*., 2019). Usually, conventional system being used for feeding, management, treatment and breeding of cattle in household production system (Datta *et al*., 2019). However, semi-intensive or intensive farming system are practiced modern technologies like artificial insemination (Khan *et al*., 2010; Quddus, 2012), animal health care including disease control and prevention activities (Quddus, 2012).

3.1.1. Beef supply chain

Two systems, viz; traditional and modern are connected with the beef supply chain. The traditional system is dominant in Bangladesh which provides nearly 93% of the beef. The beef cattle supply surges during important religious festival i.e. Eidul Azha. Farmers mainly supply their cattle through the both systems. Usually, male cattle born in their own farms are directly sourced by the smallholder farmers to the butchers/traders for slaughter purpose. For fattening purpose, farmers which are proximate to the bordering districts usually receive cattle/calves from neighboring countries through informal cross-border cattle trade. Both in rural or urban settings, consumers prefer to buy freshly slaughtered beef directly from butchers' shops located in the wet markets (UNIDO, 2019).

The slaughtering facilities (like infrastructure, veterinary inspection, along with hygienic disposal of slaughtering waste etc) are almost absent at the rural slaughtering slabs, and however, these facilities are inadequate in urban slaughtering houses as compliance with the food safety and public health parameters (Yap, 2015b) and these are responsible for transmission of zoonotic pathogens. At present, a few meat processing companies have modern system with infrastructure, veterinary inspection, along with hygienic disposal slaughtering waste) in the light of Good hygienic practices (GHP), good slaughtering practices (GSP) and good manufacturing practices (GMP), but this is not the mainstream beef supply chain in Bangladesh (UNIDO, 2019).

3.1.2. Dairy supply chain

In Bangladesh, majority of the dairy farms in Bangladesh are private which can be classified into five different groups: (a) Cow rearing for home consumption of milk: 1-3 cows, (b) Dual purposes: draft and milk, 2-6 cows including bulls, (c) small-scale dairy farming: 2-5 cows, (d) medium size commercial dairy farming with 6-25 cows, and (f) private large commercial dairy farms with > 26 cows. However, there are also eight government dairy farms, these are mainly used for supplying of heifers to small-scale farmers and production of bull calves used breeding purpose (HIB, 2013). Among of the dairy farms, nearly one third have implemented poor/no cleaning and disinfection practices in dairy rearing in Bangladesh (Hoque *et al*., 2021).

The milk supply chain provides a mixed picture, as milk not consumed by the farm households is supplied to informal traditional markets (>80%), while the rest enters a much smaller, but small portion (5%) goes through commercial processing and distribution network (WB, 2018a). Primarily, milk collector/ milk traders supply milk in urban retail markets and household for consumption or to the chilling plant of milk processing companies. Milk processing company further processes milk pasteurization/UHT milk and other milk type, and milk products for the urban people. The hygienic practices among the milk-man is inadequate and majority (97%) of them do not use protective materials during milking the cows (Islam *et al*., 2021). At present, more than half dozen of milk processing companies utilize 1 million liters of fresh milk daily by Ultra Heat Treatment (UHT)/ pasteurization scheme to supply safe food for the consumer (Parvez, 2018). However, this facility is not sufficient to cover whole production scheme. Majority of farms (94%) use hand-milking and 84% farms wash udder only with water instead of suitable disinfectants prior to milking (Hoque *et al*., 2021). These are responsible for transmission milk-borne zoonotic pathogens even *Campylobacter* through the food chain.

3.2. Poultry supply chain

The poultry production system in Bangladesh is diverse in all aspects with different species, different production and marketing systems. Broiler, layers including other species like duck, goose, quail, pigeon, turkey and guinea fowl are reared in Bangladesh. Nowadays, meat from broiler chicken is preferable in Bangladesh due to easy accessibility for animal protein and accepted from a religious point of view (Light Castle Partners, 2020). The number of poultry population is steadily increasing since the last decade (DLS, 2020). The United Nations of

Food and Agriculture Organization (FAO) categorized the poultry sector into four production sectors on the basis of biosecurity level and marketing and distribution of poultry, of which sector 3 and 4 are comparative less bio-secured, however, maximum contribution (around 90%) of meat production comes from these two production systems. However, commercial poultry farming system with a moderate to high level biosecurity and industrial incorporated farming system with high level of biosecurity and standard SOPs are being practiced under sector 2 and sector 1 production systems, respectively, which contributed nearly 10% of the total poultry production all together (Dolberg, 2008).

3.2.1. Poultry slaughtering and processing

Poultry sale and slaughter onsite mostly (97%) in the live bird markets (LBMs) with some extend in the poultry shops, or through by mobile traders for the consumers/ end users. Unlike the practice in many other Asian countries, there is notable absence of meat stalls in the LBMs or shops selling fresh poultry carcass to the consumers in this country. Usually, hygienic measurement in poultry slaughtering and meat processing activities in the LBMs is considered not to be adequate standard level (Yap, 2015a; Sarker *et al*., 2016; Sayeed *et al*., 2017; Islam *et al*., 2020a), therefore, LBMs are crucial for the drivers of emergence and transmission of zoonotic pathogens (Fournié *et al*., 2012).

A small proportion of poultry meat (< 5%, 10-25 MN) is sold as chilled/ frozen meat at the supermarket supplied from sector 1 and 2 production systems. There are some modern slaughterhouses are active in Bangladesh as per standard requirements. These facilities supply frozen meat to super shops, restaurants including the fast-food industry in Bangladesh. On the contrary, consumers concern on purchase of frozen poultry meat as they are not competent to confirm the health status of slaughtered birds, date of slaughtering and including other traceability issues (LightCastle Partners, 2020).

3.3. Campylobacteriosis in livestock and poultry

3.3.1. Prevalence of *Campylobacter*

Due to limited research conducted in cattle in Bangladesh, the actual burden of the *Campylobacter* could not be estimate. However, a recent study confirmed herd level prevalence of 53.3% (95% CI= 42.5–63.9%) and an animal level prevalence of 30.9% (95% CI=27–35%) through fecal specimen evaluation (Hoque *et al*., 2021) in farmed crossbred farmed cattle. However, another study established 25% (20/80) prevalence in different samples collected from crossbred high yielding cattle (Kabir *et al*., 2018). In poultry, several studies confirmed the prevalence rate of *Campylobacter* that varies prevalences from 26.4% to 75% using poultry and environmental samples (Islam *et al*., 2018; Alam *et al*., 2020; Hasan *et al*., 2020; Neogi *et al*., 2020; Uddin *et al*., 2021). Another study confirmed 62.5% (5/8) *Campylobacter* contamination in broiler meat, frozen chicken nuggets including chicken sausages from super shops of Dhaka city, Bangladesh via conventional methods (culture and biochemical tests) (Sultana, 2017).

3.3.2. Risk factors

Animal level risk factors could not explore properly due to insufficient studies conducted in animals. However, several studies delved risk factors sparsely, like older farms (>5 yrs), absence of cleaning and sanitation practices, animals roam outside were found to be risk factor for herd level *Campylobacter* occurrence in cattle in Bangladesh (Hoque *et al*., 2021). On the hand, older farms (> 5 years, flock size (>1500 birds), no cleaning and disinfection practices, farming experience (< 10 years), poor biosecurity measurement were documented as predictors for flock level occurrence of *Campylobacter* in poultry (Hasan *et al*., 2020). However, some risky practices like disposal of poultry waste in the agriculture (71% farms) field and aquaculture (30% farms) were identified (Hasan *et al*., 2020) as risky practices for environmental contamination and subsequent exposures to humans and animals. Additionally, hygienic parameters like washing hand after contact with poultry (29%) and before taken food (21%) (Hasan *et al*., 2020) can cause infection in humans.

3.3.3. *Campylobacter* antimicrobial resistance status in livestock and poultry

Inadequate data on *Campylobacter* antimicrobial resistance mechanism in livestock and poultry which would create predicament to evaluate the real-time scenario antimicrobial resistance status. Most of the studies conducted in poultry which confirmed the MDR status of *C. jejuni* and *C. coli* varied from 26.7% to 86.36% and 30% to 100%, respectively; and shown resistant against 3 or more antimicrobial agents (Kabir *et al*., 2014; Islam *et al*., 2018; Alam *et al*., 2020; Neogi *et al*., 2020). However, another research confirmed 57.14% *C. jejuni* and 33.33% *C. coli* isolates were presented as MDR to amoxicillin, norfloxacine, azithromycin, and tetracycline, erythromycin and streptomycin in cattle (Kabir *et al*., 2018).

3.4. Transmission pathways

Since the livestock and poultry are considered to be the reservoir animals or amplifying hosts of *Campylobacter* which facilitate to excrete these pathogens via fecal materials with a concentration of ~3×10^4cfu/g (Ogden *et al*., 2009) and exposure to humans from the contaminated settings (environment/water), food chain or even direct contact with animal/birds. Several determinants are responsible human exposures from environments like drinking contaminated water (tube well and ponds), and bathing in contaminated pond/water bodies (tank). However, several risk factors like consumption of raw milk, improper cooked meat or contaminated raw vegetables and fruits may be the contributor of *Campylobacter* infection in humans. Moreover, humans may acquire infections through direct contact with animal for poultry/cattle attendants and abattoir/LBM workers or children playing with cattle (calf) (WHO, 2012) (Figure 2). Additionally, personal hygiene and sanitation practices including involvement of cattle rearing are responsible *Campylobacter* occurrence (Rahman *et al*., 2021).

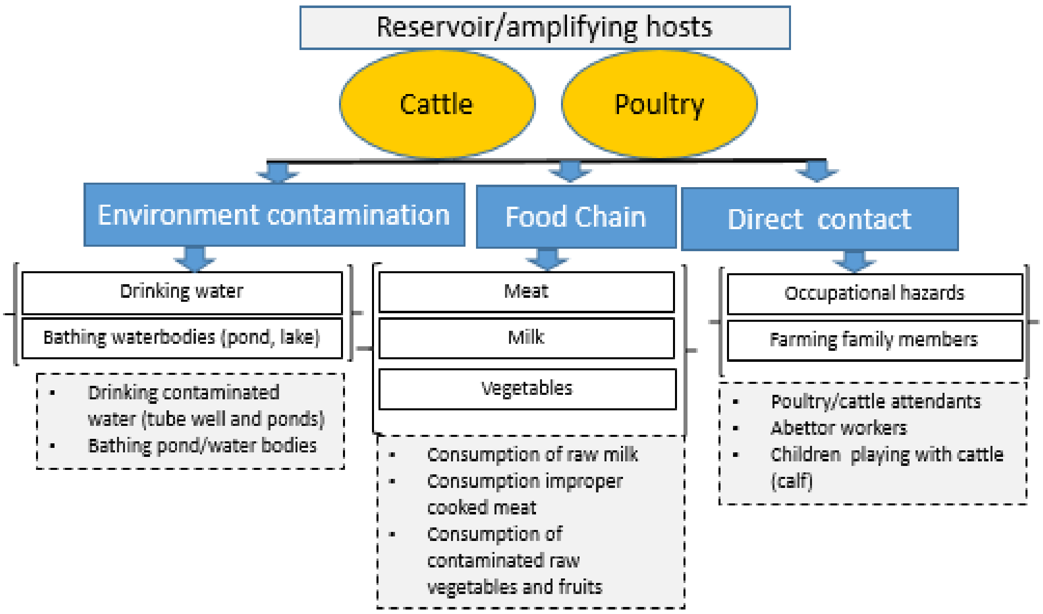

Figure 2. *Campylobacter* exposure pathways (environment contamination, food chain and direct contact) from reservoir host (cattle and poultry) to humans (adapted from WHO, 2012).

3.5. Campylobacteriosis in human

3.5.1. Prevalence of *Campylobacter* in humans

Variable levels of prevalence rate of *Campylobacter* spp. observed in diarrheal patients by different research in Bangladesh from 1983 to 2021. Prevalence rate which varies from 14% to 32.8% confirmed by different studies conducted during 1980s and 1990s established via culture and biochemical tests (Glass *et al*., 1983; Haq and Rahman, 1991; Hoque *et al*., 1994; Albert *et al*., 1999). However, a prevalence of *Campylobacter jejuni* and *Campylobacter coli* was confirmed as 8.5% (n=604) in all age group diarrheal patients, of which 181 isolates serotyped, among them 112 isolates matched with the reference antisera and 45.3% (n=82) isolates matched with a single serotype, 16.6% (n=30) matched with multiple (>2) serotypes, including 38.1% (n=69) were non-typable. Interestingly, one isolate confirmed as serotype O: 41 that connected with GBS (Alam *et al*., 2006). Moreover, the prevalence of *Campylobacter* spp. as 12.16% that comprised of *C. jejuni* as 9.45% and *C. coli* as 2.68% in stool samples and rectal swabs collected from diarrheal patients from 2005 to 2008 in Bangladesh (Ahmed *et al*., 2012). A study conducted in Bangabandhu Sheikh Mujib Medical University (BSMMU), Dhaka confirmed a prevalence of *Campylobacter* spp. as 12.9% in diarrheal children (Huda *et al*., 2015). A malnutrition and enteric disease (MAL-ED) study conducted in 8 low resource settings including Bangladesh which involved with 1892 diarrheal children confirmed a higher prevalence of 84.9% (Amour *et al*., 2016). Additionally, another research confirmed prevalence rate of *C. jejuni* and *C. coli* isolates were as 15.34% and 11.33%, respectively in diarrheal patients admitted in a hospital of Mymensingh district (Karmaker *et al*., 2018). Under a MAL-ED cohort study, established the incidence per 100 child-months of infections of *Campylobacter jejuni*/*coli* and *Campylobacter* spp. during 1–24 month follow up were as 17.7% and 29.6%, respectively

(Haque *et al*., 2019). Moreover, most recent study established prevalence rate increases with age, starting from 18% children with positive fecal specimen at 3 months of age group to 69% children at 24 months of age group (Sanchez *et al*., 2020) and 21.43% prevalence confirmed via fecal specimen examination from the Global Enteric Multicenter Study (GEMS)(Das *et al*., 2021). *C. jejuni* isolated from poultry (n=66) and patients with enteritis (n=39) or GBS (n=10) were used in multilocus sequence typing. The LOS locus classes of A, B, and C were considerably connected with GBS and enteritis related *C. jejuni* strains more than for the poultry strains that substantiated lack of connection amongst the major human and chicken strains. Thus proved that there may be additional causes for campylobacteriosis in Bangladesh (Islam *et al*., 2014).

3.5.2. Risk factors

Animal rearing (chickens, ducks, cats, dogs, sheep, goats and cows) is responsible for human infections. A few serotypes predominate among the animal and human, however, these do not cause clinical manifestations (Neogi and Shahid, 1987). Absence of routine treatment of drinking water, and unimproved sanitation were associated with *C. jejuni/coli* infection (Haque *et al*., 2019). Increased antimicrobial use including treatment of drinking water were found to protective factors for childhood *Campylobacter* infection (Sanchez *et al*., 2020).

3.5.3. *Campylobacter* antimicrobial resistance status in humans

Due to inadequate data the actual burden of antimicrobial resistance status of could not be estimated in humans. A research confirmed 31% and 37% *Campylobacter* isolates were found to be resistant to tetracycline and ampicillin, respectively and, whereas resistance pattern of ciprofloxacin raised up to 88% in 2008 from 65% in 2005 (Ahmed *et al*., 2012). *Campylobacter jejuni* were found to be multidrug resistant (MDR) as shown resistant to tetracycline, ampicillin, norfloxacin and nalidixic acid, however, MDR status of *C. coli* as presented resistant against to tetracycline, ampicillin, erythromycin, norfloxacin and nalidixic acid (Karmaker *et al*., 2018).

3.6. Prevention and control measures

3.6.1. Intervention in cattle production

Since *Campylobacter*s inhibit in the gastrointestinal tract of cattle as reservoir hosts (Mäesaar *et al*., 2020) and these excrete through the fecal material of approximately 20% of cattle with a concentration of around 3×10^4 cfu/g (Ogden *et al*., 2009). Recent study has confirmed significant burden exists in crossbred cattle intensive/semi-intensive farming conditions as source animals (Hoque *et al*., 2021) and number of high yielding cattle population is steadily increasing in Bangladesh (DLS, 2020) to mitigate animal source protein. Intensive cattle farming correlates with the development of host specific *C. jejuni* statins (Mourkas *et al*., 2020). The red meat value chain is the least developed in Bangladesh, as majority animal slaughtering and meat processing activities are traditional (WB, 2018a), and still noncompliance with the food safety indicators considering public health parameters (Yap, 2015b). Therefore, risk reduction measures to be taken each segment of the beef and dairy value chains that would be pertinent in the low resource settings.

3.6.1.1. Farm-level interventions

Control measures i.e. support good agriculture practices including stringent biosecurity and hygienic measurements including better management of cattle manure are needed (Hoque, 2021). Appropriate hygienic measurements in milking parlors, and cleanliness practices of dairy cattle sheds would reduce the growth and subsequent transmission of *Campylobacter* spp. (Ruegg, 2003; Oporto *et al*., 2007; Vissers and Driehuis, 2009). Mixed farming with poultry should be avoided (Klein *et al*., 2013). Personal hygiene of the milk-man and cattle attendants are needed during milking and working in the cattle farms, respectively. Wearing personal protective materials (PPE, gloves. boot and goggles) would be helpful to impede the transmission of pathogens like *Campylobacter* from animal to humans. Washing udder of cattle with suitable antiseptic would minimize the fecal contamination of pathogen to milk contamination.

3.6.1.2. Intervention in animal slaughtering and meat processing

The points should be considered during slaughtering and processing meat, are: (a) animals are slaughtered in a humane manner, (b) in hygienic and sanitary operations with minimal likelihood of contamination or cross-contamination with food hazards, (c) good animal waste management is practiced to prevent polluting the environment with toxic waste and harmful microorganisms, and (d) health hazards are not transmitted to slaughterhouse workers or back to livestock farms (Yap, 2015c). The country has enacted related laws termed animal slaughter and quality control of meat act, 2011 (GoB, 2011), However, lack relevant rules the laws yet to be enforced. Good Slaughter Practice (GSP) is essential to achieve quality animal meat that is clean and wholesome. The primary objective of GSP is to slaughter the animal with complete bleeding, remove the hide or hair, and to remove its gastrointestinal tract and other internal organs with minimal contamination of edible tissues (Heinz, 2008). Workers in the portioning and deboning operations must practice good personal hygiene (wearing PPE and washing hands after visiting toilets and every time before touching any meat) (Yap, 2015c).

3.6.2. Intervention in poultry production

Due to good agricultural practices (GAP) which included arrangement perimeter fencing, netting of the farm, movement control, use of separate footwear, and cleaning of poultry shed with disinfectants, including all in all out practices and use of safe production inputs (feed, and water and DoC) would minimize the occurrence of *Campylobacter*s in poultry farms (Alam *et al*., 2020; Akhter *et al*., 2018). The colonization of *Campylobacter* can occur in all categories poultry (broiler and layers) (Newell and Wagenaar, 2000). *Campylobacter* vertical transmission from parents to offspring via eggs is usually rarely occur (Callicott *et al*., 2006). Therefore, broiler day-old-chicks, should be free from *Campylobacter* that would help to develop a pathogen free flock. After introduction of *Campylobacter* into a flock, rapid transmission and colonization take place among the birds of whole flocks and reach to 10^8 *Campylobacter*/gram caecal content and persists this load until slaughtering stage in a low bio-secured flocks. The intervention measures with the significant control of *Campylobacter* which have focused on-farm and poultry slaughtering and processing facilities (WHO, 2012).

3.6.2.1. Intervention in poultry farms

Good biosecurity measurement is important to prevent introduction of infectious diseases into a farm (Alam *et al*., 2020). Once an infectious disease is introduced it is often difficult to completely eradicate as it symptomless life-long carriers in poultry. Application of stringent biosecurity measurements has demonstrated to prevent *Campylobacter* incursion effectively in poultry farm (Gibbens *et al*., 2001; Newell and Fearnley, 2003). The biosecurity measures include (a) movement control by provision of perimeter fencing and netting of the farm to lessen entree of unauthorized people, predator animals (dog, fox) and birds, (b) rodent and pest control (flies and beetles) (Shane *et al*., 1985; Bates *et al*., 2004; Hald *et al*., 2007; Newell *et al*., 2011); (c) farm worker control by cleaning and disinfection of foot wear before entry into poultry shed/farm (Hansson *et al*., 2007), (d) ensure drinking-water free from biological hazards (sanitation by chlorination or organic acids) (Hansson *et al*., 2007), (e) bury poultry waste with lime, compost or incinerate after a production cycle (Yap, 2015a); (f) cleaning and disinfecting poultry carrying vehicle, poultry cages before entry of the farm (Payne *et al*., 1999); (g) disinfect equipment used between farms/houses, etc. (Hermans *et al*., 2011); and (h) clean and disinfect of entire poultry house/shed and equipment between different production cycles (Newell *et al*., 2011), and (i) use of prebiotics/probiotics for competitive exclusion to prevent the maintenance of pathogens in feed or drinking-water prior to processing or vaccination (WHO, 2012).

3.6.2.2. Intervention during transport of poultry to LBMs

Interventions should be taken to reduce stress to poultry birds during transportation, protect from heat, rain and avoid over stocking, preferably transport poultry at night or early morning (Yap, 2015a). Feed and water should be withdrawn prior to transportation that has a significant impact on *Campylobacter* load in the crop and fecal content are considered to be post-harvest intervention. Inclusion of organic acids (lactic acid) in the last drinking-water may minimize the *Campylobacter* load of in the crop (Byrd *et al*., 2001). Good hygienic measurement is crucial for successful control of *Campylobacter* during post-harvest period (Berrang *et al*., 2001; Hunter *et al*., 2009; Berrang *et al*., 2011). Pertinent measures include hygienic cleaning and disinfection including drying of poultry carrying truck, poultry cages, and adequate bird densities (space) during transportation.

3.6.1.3. Intervention in poultry processing and slaughtering

Appropriate control measures need to be adjusted without major structural changes for LBMs in low-resource settings like Bangladesh. The practice of cleaning and sanitation requirements in poultry slaughtering and processing is needed. Separation of slaughtering activities from other poultry-related processes like dressing, de-feathering of carcasses including decontamination of slaughtering equipment to minimize surface contamination for exposure in human and poultry meat (Islam *et al*., 2020a). Use health-protective equipment like masks, aprons and gloves in poultry shops to lessen the risk of exposure and minimize hazards among LBMs workers (UNICEF, 2013).

3.7. Public awareness and motivational activities among the relevant stakeholders

Farmers' knowledge on how *Campylobacter* is released, exposed, sustained or transmitted is crucial for maintaining biosecurity practices in the farm (Park, 2003). Training of farm attendants/ farmers regarding biosecurity and hygienic requirement has been proved to reduce *Campylobacter* introduction and further subsistence in the farm settings (Newell *et al*., 2011; Sibanda *et al*., 2018). Health education and awareness of relevant stakeholders like poultry farmers, traders/transporters, LBM poultry vendor, processors and consumers on how *Campylobacter* are released, espoused, amplified and transmitted can help prevent incidences linking poultry supply chain. Nevertheless, participatory training on family-level water, sanitation, and hygiene (WaSH) interventions will be prerequisite for successful curb of this burden in humans in low resource settings (Ross *et al*., 2020).

4. Conclusions

This is the first exploratory research that has focused on burden of *Campylobacter* in both farmed cattle and commercial poultry and human. The study has highlighted predominant maintenance zoonotic *Campylobacter* in source animals and their burden in humans is enormous. However, none studies could not strongly confirm the source attribution of human *Campylobacter*. Thus, this is very important to formulate innovative approaches, therapies and interventions to appease growing burden of *Campylobacter*s with the capacity for transmission from animal to humans. Further investigations are necessitated to substantiate which source is responsible for transmission in human through serotyping via MLST is demanding. A "One Health" approach is needed focusing environmental, animal, and human health to mitigate the occurrence of *Campylobacter* in the farm settings and to stop the further introduction to animals and humans.

Data availability

Not applicable.

Conflict of interest

None to declare.

Authors' contribution

Sk Shaheenur Islam, Nazmul Hoque, AHM Taslima Akhter: study design, review of the literature, data collection, interpretation and formulation of draft manuscript; David M. Castellan, Seksun Samosornsuk, Worada Samosornsuk, S. M. Lutful Kabir: review & editing. All authors have read and approved the final manuscript.

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