zoonotic diseases

Review

Zoonotic Significance and Antimicrobial Resistance in *Salmonella* in Poultry in Bangladesh for the Period of 2011–2021

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Abstract: Antimicrobial resistance (AMR) in *Salmonella* in poultry poses a serious human health threat as it has zoonotic importance. Poultry is often linked with outbreaks of *Salmonella*-associated foodborne illness. Since antimicrobials are heavily used in poultry in Bangladesh, multidrug-resistant (MDR) *Salmonella* is quite frequently found there. MDR *Salmonella* is challenging to treat with antimicrobials and often causes a severe economic loss in the poultry sector. By horizontal gene transfer and/or evolutionary mutations, antimicrobials primarily exert selection pressure that contributes to antimicrobials resistance. In addition, resistance patterns can vary with variations in time and space. Without having prior knowledge of resistance patterns, no effective drugs could be prescribed. Therefore, it is crucial to have updated knowledge on the status of AMR in *Salmonella* in Bangladesh for effective treatment and management of the flocks against salmonellosis. There are several review articles on AMR in *Salmonella* in poultry in Bangladesh; they lack the whole scenario of the country and particularly do not have enough data on the poultry environment. Considering this scenario, in this review, we have focused on AMR in *Salmonella* in poultry in Bangladesh (2011–2021), with particular emphasis on data from the poultry and farm environments on a divisional zone basis.

Keywords: AMR; *Salmonella*; poultry; zoonotic; antimicrobials; Bangladesh; MDR; resistance; environment

1. Introduction

The poultry sector has turned into a symbol of a profitable business among the people of Bangladesh [1]. Reports from the Department of Livestock Services (DLS) denote that the poultry population in Bangladesh is more than 350 million, contributing to the advancement of the national economy and employment generation [2]. In addition, the poultry sector provides cheaper and easily reachable sources of nutrition and protein in terms of egg and meat to all classes of people [3]. The poultry sector contributes almost 40% of the total meat supply and more than 25% of Bangladesh's total human protein demands [4,5]. Furthermore, this sector has shown adequate support to the nation in gaining the sustainable development goals (SDGs) of eliminating malnourishment and securing improved health by supplying protein-containing foods. However, the poultry sector is attacked regularly with the introduction of bacterial infections. Salmonellosis is one of them. Many serovars of the genus *Salmonella* under the Enterobacteriaceae family are responsible for salmonellosis [6]. In the chicken business, salmonellosis is amongst the most dangerous bacterial infections, resulting in significant financial loss due to death and reduced productivity [7,8]. Salmonellosis also causes pullorum disease, fowl typhoid and other contaminations developed from poultry herds (intense systemic malady and gastrointestinal issues) to incubator (embryonic issue) [9]. The genus of *Salmonella* is isolated into two species: *S. enterica* and *S. bongori*; among them, *S. enterica* can cause devastating consequences. Serovars Typhimurium and Enteritidis of *Salmonella enterica* are the common causes of salmonellosis. Infantis is a serovar that affects people all around the world [10]. More than 20 million humans and animals are infected with *Salmonella* each year. It decreases animal productivity and causes 150,000 human and animal fatalities each year [10]. Typhoid infection is most common in the south-central and south-east Asian regions (more than 100/100,000 people per year) [10].

AMR has become a severe global challenge by affecting all health components [11,12]. It is assumed that AMR problem will cause hundreds of millions of human deaths along with severe financial crisis and severe damage in livestock productions by 2050 [13,14]. Furthermore, the consequences will be disastrous for low and middle earnings countries, such as Bangladesh [15]. The AMR attributes a threatening situation in food security by developing production losses in the poultry sector. A global action plan (GAP) with a "one health" approach has been put in place by the World Health Organization (WHO) to fight against the emerging global threat in an extensive system. Recently, Bangladesh has developed a national action plan that aligns with AMR-oriented GAP rules [16–18].

For simple cases of salmonellosis (watery diarrhea), antimicrobial agents are not recommended. Antimicrobials are usually administered for severe cases of salmonellosis, and also for typhoid fever. However, antimicrobials resistance in *Salmonella* is becoming a major threat for the public health around the globe. Human activity has contaminated the poultry farm environment (air, water and soil) with antimicrobial residues and resistant organisms [19]. The elevation of antimicrobial-resistant *Salmonella* is connected in many cases with the haphazard use of antimicrobials in poultry farming. *Salmonella* has become less susceptible to different kinds of antimicrobials in poultry farming because of their indiscriminate use therefore it develops treatment failure [20–22]. Salmonellosis is a significant threat to poultry farming in Bangladesh by causing severe economic losses every year. It has become more devastating due to the AMR. The mortality rate in poultry due to antimicrobial-resistant *Salmonella* is much higher than that of infections due to non-antimicrobial-resistant *Salmonella* strains. In this case, it is pivotal to have an adequate idea of antimicrobial-resistant *Salmonella* in poultry farming. Nevertheless, there is no sufficient review data on antimicrobial-resistant *Salmonella* in poultry in Bangladesh in recent years. The purpose was to give references for future work as well as a request to intervene in the AMR by implementing a One Health program.

2. Materials and Methods

We used PubMed, Web of Science, Google Scholar, ResearchGate and Crossref databases to perform a written survey on the AMR *Salmonella* situation in Bangladesh's poultry health division and around the world. To begin with, we centered the primary segment on the foundation of AMR *Salmonella* circumstance around the world, its impacts on poultry and open wellbeing segments, the potential source of AMR in poultry and present patterns in antimicrobial utilization in Bangladesh.

Keywords used to search databases were "AMR *Salmonella* situations in poultry from 2010 to 2021 in Bangladesh" and "AMR *Salmonella* in different divisions of Bangladesh;" "AMR *Salmonella* organisms in poultry production of Bangladesh;" "Antibiotic-resistant" or "antimicrobial-resistant" in poultry farm environment in Bangladesh". Antimicrobial resistance in *Salmonella* in Bangladesh chickens was the subject of all key discoveries from studies conducted between 2011 and 2021. The AMR situation in individuals, agribusiness, aquaculture or banned scenarios that were supposed to be unimportant to the display were investigated in this study. The major findings connected to this study (initial writers, launched period, poultry ranch category with geographic area, sample type, array of resistance with antimicrobial groups and resistance genes) were extracted from the papers in Table 1.

Table 1. Major findings of studies (2011–2021) focused on antimicrobial resistance in *Salmonella* in poultry in Bangladesh.

Study Year/Study Location	Sample Category	Sample Size	Sample Type	Isolation Method Culture/Confirm by PCR	Resistance Phenotype	Detection Disk Diffusion/Genotype by PCR	Resistance Genotype	References
2010/Dhaka	Layer	100	Egg surface	Culture	Amoxicillin (87.50%), Ampicillin (87.50%), Erythromycin (62.50%), Cephalexin (50%), Doxycycline (50%), Ceftazidime (37.50%), Nalidixic acid (25%)	Disk diffusion	-	[23]
2008–2010/Dhaka	Layer	300	Cloacal swab, intestinal fluid, egg surface, hand wash and soil	Culture	Penicillin (100%), Tetracycline (100%), Erythromycin (82%), Ampicillin (88%), Rifampicin (60%), Cephalexin (65%), Chloramphenicol (58%), Cefixine (50%), Norfloxacin (20%), Ciprofloxacin (20%), Nalidixic acid (20%)	Disk diffusion	-	[24]
2011/Mymensingh	Broiler	60	Dressing water, devices and environmental swabs	Culture	Ampicillin (100%), Chloramphenicol (100%), Streptomycin (100%), Nalidixic acid (100%), Tetracycline (100%), Erythromycin (100%), Azithromycin (81.25%), Gentamicin (81.25%)	Disk diffusion	-	[25]
2009–2010/Savar	Layer	67	Poultry samples	Culture/PCR	Rifampicin (88%), Clindamycin (84%), Oxacillin (84%), Vancomycin (78%), Doxycycline (52%), Levofloxacin (50%), Azithromycin (25%), Ceftriaxone (10%)	Disk diffusion/PCR	-	[26]
2012/Chittagong	Layer	30	Dead birds	Culture	Amoxicillin (100%), Tetracycline (100%), Enrofloxacin (87.50%), Ciprofloxacin (87.50%), Pefloxacin (87.50%), Doxycycline (50%), Colistin (50%), Kanamycin (50%)	Disk diffusion	-	[27]
2014/Mymensingh	Broiler	50	Cloacal swabs	Culture/PCR	Amoxicillin (87.50%), Cloxacillin (87.50%), Erythromycin (87.50%), Colistin (50%), Ciprofloxacin (31.25%)	Disk diffusion/PCR	-	[28]
2015/Mymensingh, Gazipur and Sherpur	Broiler	60	Dressed broiler carcass	Culture/PCR	Amoxicillin (82%), Erythromycin (82%), Tetracycline (68%), Streptomycin (38%), Azithromycin (22%)	Disk diffusion/PCR	-	[29]
2013/Chittagong	Layer	310	Eggs, egg surface, and trays	Culture	Ampicillin (100%), Amoxicillin (100%), Erythromycin (90%), Tetracycline (94.50%), Ciprofloxacin (49.50%), Colistin (60%), Enrofloxacin (60%), Pefloxacin (12.50%)	Disk diffusion	-	[30]
2015/Mymensingh	Layer	150	Droppings and Cloacal swabs	Culture/PCR	81.81% isolates were resistant to Amoxicillin, Doxycycline, Kanamycin, Gentamicin, and Tetracycline and 45.46% isolates to Ciprofloxacin	Disk diffusion/PCR	-	[31]
2012/Mymensingh	Layer	60	Cloacal swabs, intestinal fluid, egg surface, feces, air and hand washings	Culture	Erythromycin (100%), Tetracycline (100%), Nalidaxic Acid (100%) and 40% to Ampicillin, Amoxicillin, Sulfamethoxazole, Kanamycin and Chloramphenicol	Disk diffusion	-	[32]

Table 1. *Cont.*

Study Year/Study Location	Sample Category	Sample Size	Sample Type	Isolation Method Culture/Confirm by PCR	Resistance Phenotype	Detection Disk Diffusion/Genotype by PCR	Resistance Genotype	References
2015–2016/Gazipur and Tangail	Broiler	153	Chick meconium, cloacal swabs, dead birds, feed, water and floor and vehicles swabs	Culture/PCR	Erythromycin (100%), Tetracycline (100%), Azithromycin (47.22%), Amoxicillin (38.89%)	Disk diffusion/PCR	-	[33]
2016–2017/Gazipur and Mymensingh	Broiler	51	Chicken Meat	Culture/PCR	Erythromycin (100%), Doxycycline (79.31%), Sulfamethoxazole (75.86%), Azithromycin (72.41%), Oxytetracycline (66.67%), Amoxicillin (44.83%)	Disk diffusion/PCR	-	[34]
2017/Jamalpur, Tangail, Kishoreganj and Netrokona	Broiler	20	Dressed broilers	Culture	Tetracycline (85.71%), Erythromycin (64.28%), Streptomycin (50%), Amoxicillin (28.57%), Azithromycin (28.57%)	Disk Diffusion	-	[35]
2017/Naogoan	Layer	180	Egg samples	Culture	Ciprofloxacin (7.14%),Ceftriaxone (14.29%), Gentamicin (21.43%), Chloramphenicol (28.57%), Ampicillin (71.42%), Amoxicillin (92.86%)	Disk diffusion	-	[36]
2019/Chattogram	Sonali Chicken	50	Fecal sample	Culture	Ceftriaxone (96.42%) and Ciprofloxacin (71.42%)	Disk diffusion	-	[37]
2017/Mymensingh	Broiler	100	Cloacal swabs, litter and feeds	Culture/PCR	Tetracycline (97.14%), Chloramphenicol (94.28%), Ampicillin (82.85%), Streptomycin (77.14%)	Disk diffusion/PCR	*tetA* (97.14%), *floR* (94.28%) *bla*$_{TEM-1}$ (82.85%), *aadA1* (77.14%) and *intI1* (20%) genes	[38]
2017/Dhaka, Gazipur, and Tangail	Broiler	352	Clocal swabs, whole carcass, feed, water and hand washes	Culture/PCR	Erythromycin (81.72%), Tetracycline (80%), Amoxicillin (42.73%), Azithromycin (47.27%).	Disk diffusion/PCR	-	[39]
Dhaka/2017	Pigeon	40	Oral and cloacal swabs	Culture	Tetracycline (100%), Nalidixic acid (81.82%), Erythromycin (45.45%), Amoxicillin (36.36%), Ampicillin (27.27%), Azithromycin (27.27%), Levofloxacin (18.18%)	Disk diffusion	-	[40]
2018/Mymensingh	Broiler	75	Droppings, litter, feed, hand wash, water and air	Culture	Oxacillin (100%), Ampicillin (66.67%), Colistin (54.55%), Chloramphenicol (42.42%), Gentamicin (42.42%), Ciprofloxacin (27.27%), Oxytetracycline (27.27%)	Disk diffusion	-	[41]
2018–2019/Mymensingh and Tangail	Turkey	55	Feces and intestinal contents	Culture/PCR	Erythromycin (100%), Tetracycline (100%), Ciprofloxacin (44.44%), Meropenem (40.74%)	Disk diffusion/PCR	*tetA* gene (92.59%)	[42]

Table 1. *Cont.*

Study Year/Study Location	Sample Category	Sample Size	Sample Type	Isolation Method Culture/Confirm by PCR	Resistance Phenotype	Detection Disk Diffusion/Genotype by PCR	Resistance Genotype	References
2019/Dhaka, Sylhet, Mymensingh, Chattogram, and Rajshahi	Broiler	113	Frozen Chicken Meat Sample	Culture/PCR	Oxytetracycline (100%), Sulfamethoxazole (89.20%), Tetracycline (86.50%), Nalidixic acid (83.80%), Amoxicillin (74.30%), Pefloxacin (70.30%), Imipenem (48.60%)	Disk diffusion/PCR	$bla_{\text{CTX-M-1}}$ (2.7%), $bla_{\text{NDM-1}}$ (20.3%), *qnrA* (4.1%) and *qnrS* (6.8%) genes	[43]
2019/Gazipur, Narsingdi, Tangail and Brahmanbaria	Layer	82	Blood, Liver and Intestine	Culture/PCR	Colistin (92.68%), Oxytetracycline (86.59%), Co-Trimoxazole (76.83%), Ciprofloxacin (73.17%), Enrofloxacin (65.85%)	Disk diffusion/PCR	mcr^{-1} gene (6.09%)	[44]
2016/Rajshahi	Broiler and Layer	120	Cloacal swabs	Culture	Penicillin (100%), Nalidixic acid (100%), Sulfamethoxazole (55%), Ampicillin (40%), Amoxicillin (25%)	Disk diffusion	-	[45]
2018–2019/Mymensingh, Jamalpur	Broiler	70	Feces, meatand visceral organ	Culture/PCR	Amoxicillin (100%), Tetracycline (90.48%), Ceftazidime (61.90%), Chloramphenicol (38.10%) and Colistin (33.33%)	Disk diffusion/PCR	-	[46]
2019/Dhaka	Broiler, Sonali and Native	870	Cecal contents	Culture/PCR	100% to Ciprofloxacin, Streptomycin and Tetracycline. 86.70% to Nalidixic acid and Gentamicin. Ampicillin (72.70%), 20% to Amoxicillin, Chloramphenicol, Sulfamethoxazole, Cefixime and Ceftriaxone	Disk diffusion/PCR	bla_{TEM} (73.3%), *tet*A (100%), *sul*1 (80.2%) and *str*A/B (33.3%) genes	[47]
2020/Dhaka, Mymensingh, Rangpur, Sylhet, and Chattogram	Layer	765	Cloacal swabs (535), visceral organs (50), and droppings (180)	Culture/PCR	Amoxicillin (49.70%), Sulfamethoxazole (47.70%), Erythromycin (43.70%), Azithromycin (31%), Oxytetracycline (79.70%), Doxycycline (61.40%), Ciprofloxacin (30%), Gentamicin (32%)	Disk diffusion/PCR	-	[48]

3. Salmonellosis in Poultry

Salmonellosis having zoonotic potentiality could be frequently detected in poultry flocks [49]. Salmonellosis can be contracted by eating contaminated, unsanitary food contaminated with *Salmonella*. In the summer, the sickness is more common than in the winter [50]. Salmonellosis could be a common illness in numerous developing nations, counting Bangladesh [51]. *Salmonella* contamination restricts the production of poultry in Bangladesh. Multidrug-resistant *Salmonella* is a significant threat for this poultry across the globe, including Bangladesh [26]. In addition, *Salmonella* can be a widespread food-borne pathogen with serious consequences for public health [52]. *Salmonella* from chickens can transmit to humans through contaminated meat and crude eggs. In Bangladesh, where medium-sized economic ranches are dominant, salmonellosis is spreading at the farm holding level [53].

Salmonella is one of the most serious concerns for Bangladesh's poultry sector, with significant public health implications [54]. The infection pullorum is caused by *S.* Pullorum which is passed down vertically from parent to descendent [55]. *Salmonella* Gallinarum causes fowl typhoid, is a serious or persistent infection that typically affects older chickens, providing a substantial rate of death and lowering reproductive performance. Furthermore, *S.* Gallinarum can cause damage to newborns that is different from that caused by pullorum disease [56].

Clinical signs of fowl typhoid include increased risk of death and inferior quality in chicks born from contaminated eggs, which are typical of a septicemic infection in poultry. Anemia, sadness, labored breathing, and diarrhea in older birds cause excrement to cling on the vent. Pullorum disease has the highest fatality rate in 2–3-week-old birds. The sickness may be minor or undetectable in older birds. Susceptibility increases at the point of lay in both breeding and laying flocks [57]; however, pullorum disease may have no symptoms other than decreased egg production and hatchability. Among the most important transmission channels for illnesses is trans-ovarian infection, which causes infection of the egg and newborn chicks or poults [58]. Reported antimicrobial resistance in *Salmonella* in different divisions of Bangladesh is presented in Figure 1.

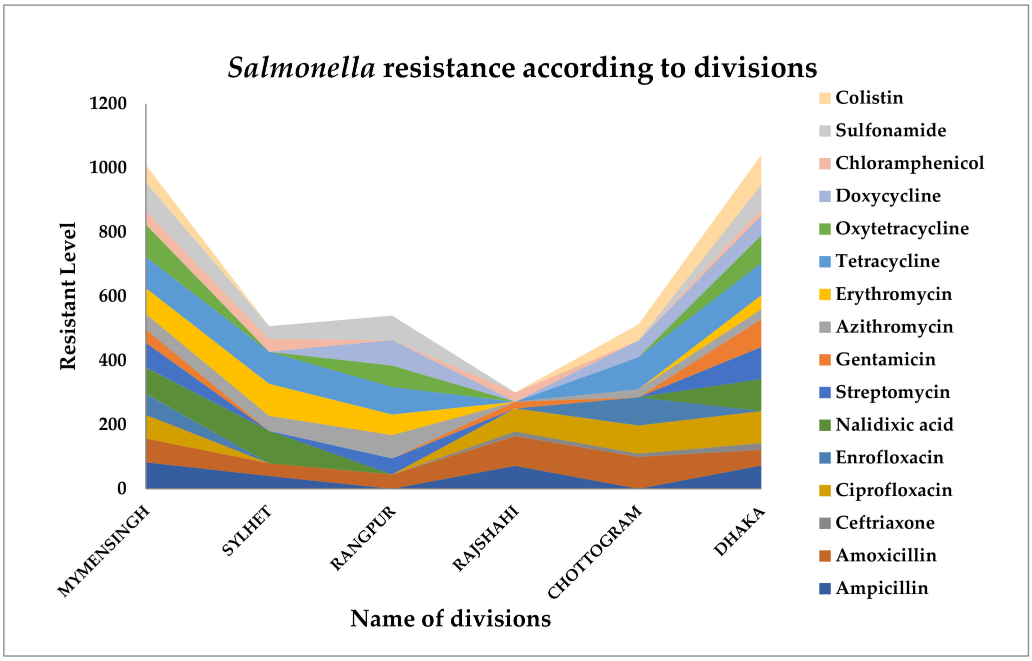

Figure 1. Antimicrobial resistance profiles of *Salmonella* in poultry in different divisions of Bangladesh.

4. Transmission of *Salmonella*

Salmonella is widely dispersed and survives in arid conditions, although it may survive for months in water. *Salmonella enterica* can cause both human and animal illnesses [59]. *Salmonella* can induce clinical or sub-clinical infection in symptomless animals that are called "carriers". *Salmonella* can continually and routinely be excreted in feces from these carrier birds to contaminate the surrounding environment without clinical symptoms. *Salmonella* can transmit both horizontally and vertically [59].

In *Salmonella* contamination in chickens induced by serovar Enteritidis with a unique preference for the chicken reproduction cycle, vertical transmission is of particular concern. In this situation, transovarian contamination occurs when the mother fowl is exposed to systemic contamination, which causes ovarian illness and egg production within the oviduct [60]. Serovar Enteritidis contaminates eggs in part due to microbes moving from the cloaca to regenerative organs [60]. Aerosol or fecal transfer may occur. *Salmonella* can be spread through fomite, polluted drinking water, infected food and filthy cages [61,62].

A few of the salmonellosis outbreak trials were kept separate from those that used live chickens, and there was also some indirect contact with contaminated food vendors [63]. A foodborne illness spread by handlers infected by direct contact with farm chickens is another example of an epidemic caused by indirect contact with live poultry [64,65]. Possible transmission routes of salmonellosis in poultry in Bangladesh are presented in Figure 2.

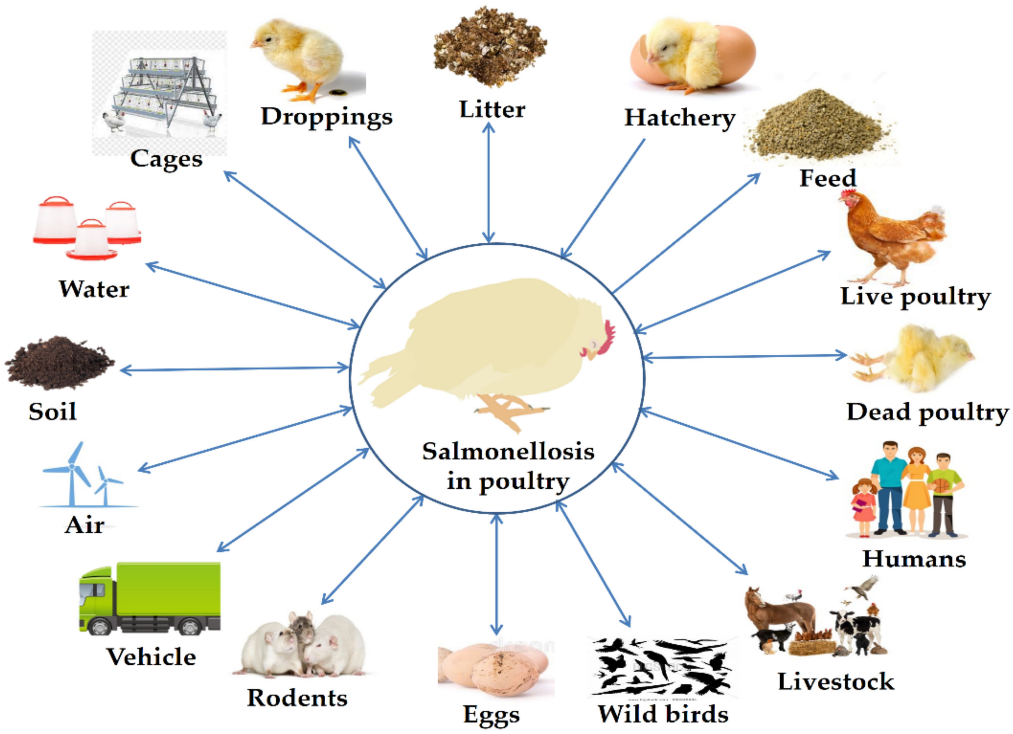

Figure 2. Possible transmission routes of salmonellosis in poultry in Bangladesh.

5. Zoonotic Importance of *Salmonella*

Salmonella is a major zoonotic pathogen. It is responsible for severe economic losses and also has a public health concern. Most common *Salmonella enterica* serovars in humans and animals are listed in Table 2.

Table 2. Most common *Salmonella enterica* serovars had seen in humans and animals (Adapted from [66]).

Host.	Serovars	Major Symptoms	Zoonotic Importance
Human	*Salmonella enterica* serovar Typhi (*S.* Typhi)	Typhoid fever	Yes
	Salmonella enterica serovar Paratyphi (*S.* Paratyphi)	Paratyphoid fever	Yes
	S. Typhimurium	Non-typhoidal Salmonellosis/Enteritis	Yes
	S. Enteritidis	Non-typhoidal Salmonellosis/Enteritis	Yes
Poultry	*S.* Gallinarum	Fowl typhoid	Yes
	S. Pullorum	Pullorum disease	Yes
	S. Typhi	Salmonellosis	Yes
	S. Enteritidis	Salmonellosis	Yes
Ducks	*S.* Anatum	Keel disease	Yes
Sheep and goats	*S.* Abortusovis	Salmonellosis	Yes
	S. Anatum	Salmonellosis	Yes
	S. Montevideo	Salmonellosis	Yes
Cattle	*S.* Dublin	Salmonellosis	Yes
	S. Typhimurium	Salmonellosis	Yes
	S. Newport	Salmonellosis	Yes
Horses	*S.* Anatum	Salmonellosis	Yes
	S. Agona	Salmonellosis	Yes
	S. Enteritidis	Salmonellosis	Yes

Salmonella can be transmitted from animals to people, as well as the other way around. Infection spreads from animals to people most commonly through contaminated food. Contaminated meat and eggs, as well as contaminated lettuce and other leafy vegetables, sprouts, spices and seeds, are also potential sources of infection. Contact with infected persons is another source of infection [67].

The infectious dosage of *Salmonella* is relatively high; however, it varies with the strain characteristics, age and immune status of the individual. A healthy adult with a normal immune system needs up to 100,000 bacteria to become unwell. On the other hand, too little bacteria can make children or the elderly unable to resist the disease. Salmonellosis has a 1–3-day incubation period (6 h to 10 days) [68].

The disease outcomes also vary with the age and immune status of the individual. It usually causes dehydration as a result of diarrhea, nausea and vomiting. Fever is also fairly common. In immune-compromised persons, it can progress to septicemia or localized infection. Although the disease usually does not cause mortality in humans, the costs incurred as a result of the condition are often staggering. It has the potential to kill vulnerable people, such as infants, the aged and those with impaired immune systems [69].

6. Overall Prevalence of *Salmonella*

Poultry appears to be a general reservoir of *Salmonella* [70]. *Salmonella* contamination at an increased level is concerning for both poultry farming and public health. Since the egg surface may have been contaminated with *Salmonella* via excrement during lay in an unsanitary environment from tainted fowl, the average *Salmonella* content is 18.09% [23,30,32,36]. In this review, we found that 17.19%, 28.57% and 30% of salmonellae were present in water, transport swab and air samples from poultry farm environments in Bangladesh [25,33,39,41]. This study also observed that average 26.30% of the cloacal swab samples, 42% of the visceral organ samples and 60% of intestinal fluid samples were infected with *Salmonella* [24,32,38,44,45,48]. *Salmonella* infection in poultry farm samples has been documented from many regions of the world, with rates of 17%, 35%, 36%, 39% and 53% in the United States, Spain, Korea, Brazil and Vietnam, respectively [71,72]. *Salmonella* was found in 23.44% of poultry handlers, indicating a possible breakdown in personal hygiene during bird handling and shipment of chicken products [24,32,39,41]. Poultry droplets and litters in various chicken farms in Bangladesh were found to contain an average of 26% and 25.71% *Salmonella*, respectively [31,38,41]. Commercial poultry feed should be free from *Salmonella* but average 18.75% *Salmonella* was found within poultry feeds in different farms due to accidental contamination with feces or litter [33,38,41]. Locally processed fish by-products were a substantial source of bacterial contamination of chicken feeds among the animal protein sources and common ingredients of poultry feed. *Salmonella* has also been found in feed and feeding materials of poultry and animals as a natural microflora [73]. Figure 3 shows the total prevalence of *Salmonella* in poultry, feed farm components, etc. in Bangladesh by sample types.

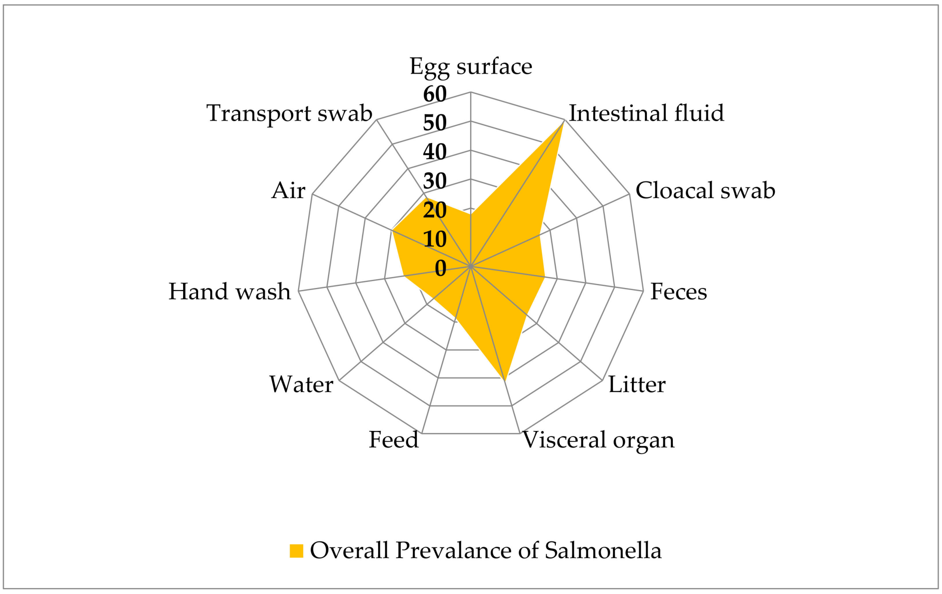

Figure 3. Samples wise overall prevalence of *Salmonella* in poultry in Bangladesh.

7. Antimicrobial Resistance Profile of *Salmonella*

7.1. Resistance to Penicillins

Penicillins are antimicrobials that are classified as β-lactams [74]. Ampicillin, amoxicillin, oxacillin and cloxacillin are broadly utilized semi-synthetic antimicrobials within the penicillin class.

Akond et al. [24] reported 100% penicillin-resistant and 88% ampicillin-resistant *Salmonella* in hand wash, intestinal fluid, cloacal swab, egg surface and soil samples from a layer farm in Dhaka. Sarker et al. [45] reported similar results ten years later, both in broilers and layers in Rajshahi. Ampicillin was the first broad-spectrum antibiotic of the penicillin group. Ahmed et al. [23] reported that 87.50% of *Salmonella* exhibited resistance to ampicillin and amoxicillin in egg surface samples from laying hens at different markets in Dhaka city. Additionally, Mahmud et al. [30] and Talukder et al. [46] observed 100% resistance to ampicillin and amoxicillin in Chittagong and Mymensingh. Furthermore, *Salmonella* was found to be 40% to 92.86% resistant to ampicillin and amoxicillin in broilers and layers [32,34,36,48]. Jahan et al. [25] detected 100% ampicillin- and amoxicillin-resistant *Salmonella* from dressed broilers, water and device surface samples, whereas Alam et al. [38] and Hossain et al. [41] reported 66.67% to 82.85% ampicillin-resistant *Salmonella* in cloacal, fecal, litter, feed, water, air and handwashing samples collected from different broiler farms in Mymensingh. Previously, Mir et al. [75] showed that 100% *Salmonella* were resistant to penicillin and oxacillin, and Sharma et al. [76] found 95.71% ampicillin-resistant *Salmonella* from poultry samples in India.

Several genes are known to be linked with resistance against penicillin. A study in Bangladesh has recently confirmed the presence of the β-lactam-resistant bla_{TEM} gene in 73.30%, 63.60% and 50% of *S.* Typhimurium isolates from broilers, sonali and indigenous chickens, respectively [47]. Parvin et al. [43] also detected the $bla_{\text{TEM-1}}$-resistant gene of *Salmonella* from chicken in Bangladesh. Previously, Alam et al. [38] detected the $bla_{\text{TEM-1}}$ (82.85%) gene in *Salmonella* from broiler samples in Bangladesh. Likely, in Egypt, Sabry et al. [77] reported the β-lactam-resistant bla_{TEM} gene from healthy and diseased chickens. Earlier, Wajid et al. [78] detected the $bla_{\text{TEM-1}}$ (72.70%) gene in *Salmonella* from the layers in Pakistan. In addition, Giuriatti et al. [79] detected the $bla_{\text{TEM-1}}$ (83.33%) gene from chickens in Brazil. Similarly, the $bla_{\text{TEM-1}}$-resistant gene of *Salmonella* from poultry was detected in Brazil and China by Souza et al. [80] and Wang et al. [81], respectively. Therefore, the exhibition of higher resistance patterns of *Salmonella* to penicillin group of antimicrobials in poultry may well relate to the longtime use of these antimicrobials.

7.2. Resistance to Cephalosporins

Cephalosporins are a class of β-lactam antimicrobials [82] that might be broadly utilized as crucial drugs to treat important bacterial diseases in people and animals [83]. For a long time, there seems to be an increment in records of resistance in *Salmonella* to cephalosporin in people and food producing animals universally. In Bangladesh, cephalosporins are also used in poultry.

Cephalexin, a class of first-generation cephalosporins, was found to be not utterly effective against *Salmonella.* For example, in Dhaka city, *Salmonella* isolated from egg surface, hand wash, cloacal swab, intestinal fluid and soil samples were found about 50% to 65% resistant to cephalexin [23,24]. Similarly, Akond et al. [24] in Dhaka and Chaudhary et al. [37] in Chittagong observed 50.00% to 96.44% resistance of *Salmonella* to ceftriaxone and cefixime since they are used as the third generation of cephalosporins. Dutil et al. [84] and Jeon et al. [85] recorded ceftiofur-resistant *Salmonella* from poultry meat in Canada and Korea, respectively. The use of ceftiofur (a third-generation cephalosporin) in farm animals has severe public health concerns since it leads to resistance to extended-spectrum cephalosporins such as ceftriaxone and cephamycins [86]. These findings point to the need for a better monitoring scheme and guidelines for the prudent use of antimicrobial medicines in Bangladesh's poultry sector.

7.3. Resistance to Carbapenems

Ertapenem, imipenem and meropenem belong to carbapenem group of antimicrobials. Imipenem features a wide range of action against aerobic and anaerobic microbes. Parvin et al. [43] reported 48.60% resistance to imipenem in *Salmonella* isolates from chicken frozen meat. Tawyabur et al. [42] also observed 40.74% resistance of meropenem in healthy and diseased turkeys. These findings demonstrate that we must be concerned since antibiotics from carbapenem group are frequently used as "last-line agents" to cure diseases caused by MDR Gram-negative bacteria [87–89]. Earlier, Wajid et al. [78] also reported resistance of *S.* Typhimurium for imipenem (79.40%), doripenem (61.70%), and meropenem (54.50%) in poultry in Pakistan. Carbapenems are generally considered to be last-line antimicrobials to treat hospitalized patients affected by different bacterial infections. However, it has been unclear how this sort of resistance has entered the poultry, as these sorts of antimicrobials are not allowed for use in the poultry industry. Higher rates of carbapenem resistance are in poultry is very much alarming, so it is important to ensure quality control and confirmation measures for the poultry processing and production industry.

7.4. Resistance to Fluroquinolones

Fluoroquinolones are a group of antimicrobials that are used universally. Ciprofloxacin, a sort of fluoroquinolone antimicrobials, is commonly used to treat a vast extend infections of humans, poultry, and other animals. As a result, *Salmonella* isolated from broilers, layers and turkeys showed periodical increase in resistance to ciprofloxacin, ranging from 20% to 100% [24,28,30,37,42,44,47] in different districts of Bangladesh in between 2012 to 2021. The scenario is similar in neighboring countries. Hassan et al. [27] revealed 87.50% resistance of *Salmonella* to pefloxacin inlayer chickens, whereas Parvin et al. [43] reported 70.30% resistance in the broilers. Sharma et al. [76] observed 82.86% resistance of *Salmonella* to ciprofloxacin in chickens in India. Similarly, in Pakistan, 92.60% of *S.* Typhimurium and 100% of *S.* Enteritidis were resistant to pefloxacin in poultry birds [78]. Furthermore, 60% of *S.* Typhimurium and 65.85% *S.* Enteritidis showed resistance in layers in Chittagong, Gazipur, Narsingdi, Tangail, and Brahmanbaria [30,44]. Nalidixic acid (NA) is the first of the synthetic quinolone antibiotics. Various degrees of resistance found against NA have been reported in *Salmonella* in Bangladesh. About 20% to 100% resistance found in *Salmonella* to NA secluded from poultry and environmental samples at a different region of Bangladesh [23–25,32,40,43,45,47]. Early, Nikolić et al. [90] observed 95.50% resistance of *Salmonella* to NA in broiler isolates in Serbia. These discoveries highlight the requirement for the execution of reconnaissance frameworks that center on nourishment cleanliness, utilize antimicrobials in poultry farming and continuously check the quality of retail meat items.

7.5. Resistance to Aminoglycosides

Aminoglycosides are antimicrobials that repress bacterial protein synthesis [91]. Streptomycin is one of the primary aminoglycoside antibiotics presented in human medication. It is additionally utilized in animals and poultry. *Salmonella* resistance to streptomycin has been documented in chicken in Bangladesh, ranging from 38% to 100% [25,29,35,38,47]. Similarly, Souza et al. [80] reported 98.30% resistance in *Salmonella* to streptomycin from poultry in Brazil. Gentamicin, a broad-spectrum aminoglycoside antibiotic, has long been used to treat Gram-negative and Gram-positive microbes in poultry in Bangladesh. Extremely recently, Siddiky et al. [47] reported 86.70% resistance in *Salmonella* to gentamicin in the broilers, sonali, and indigenous chickens in Bangladesh. Previously, Wajid et al. [78] observed 64.70% resistance to gentamicin from *S.* Typhimurium isolates in poultry in Pakistan. Earlier, Hassan et al. [27] and Paul et al. [32] also observed significant amount of resistance to other aminoglycosides in *Salmonella* such as kanamycin in the layers. Alam et al. [38] reported the aminoglycoside-resistant gene *aadA1* (77.10%) in *Salmonella* isolates from cloacal swabs and a litter of broilers in Mymensingh. Siddiky et al. [47] observed the *strA/B* (33.33%) resistance gene in *S.* Typhimurium isolates from broilers ceca at wet markets in Dhaka. Earlier, Wajid et al. [78] reported aminoglycosides *aadA1* (35.20%), *strA* (20.50%) and *strB* (41.10%) resistance genes, respectively, in *S.* Typhimurium from poultry in Pakistan.

7.6. Resistance to Macrolides

Macrolides are bacteriostatic, which means that instead of killing bacteria, they limit or restrain their growth [92]. Azithromycin is an azalide, a sort of macrolide antibiotic. *Salmonella* in Bangladeshi poultry has been found to have varying degrees of azithromycin resistance, ranging from 18.18% to 81.25% [25,26,33–35,39,40,48]. Last year, Tîrziu et al. [93] also reported 88.20% resistance in *Salmonella* to azithromycin was isolated from store raw poultry in Romania. Erythromycin is generally used to cure many diseases of chicken in Bangladesh. About 62.50% to 100.00% resistance found in *Salmonella* to erythromycin in layer samples [23,24,30,32], while 64.28% to 100.00% resistance observed [25,28,29,33–35,39] in case of broiler samples. Cardoso I et al. [94] in Brazil and Sharma et al. [76] in India also reported 100% resistance of avian *Salmonella* to erythromycin. These higher resistances of *Salmonella* to macrolides are not unprecedented since in numerous cases, many individuals of Enterobacteriaceae are found resistant to these compounds.

7.7. Resistance to Lincosamides

Clindamycin is an antibiotic that is used to treat a variety of bacterial infections. It belongs to the lincosamides family and operates by preventing bacteria from producing protein [95]. Sultana et al. [26] reported 84% resistance in *Salmonella* to clindamycin in poultry in Bangladesh. Similarly, Yildirim et al. [96] in Turkey and Mir et al. [75] in India detected 97% and 100% resistance in *Salmonella* isolated from poultry as resistance to clindamycin, respectively. So, it is obligatory to actualize strict control over the man handle of antimicrobials, especially in the poultry segment. Appropriate logical and open wellbeing controls are required to scrutinize the non-judicial utilization of antimicrobials.

7.8. Resistance to Tetracyclines

One of the heavily used antibiotics in veterinary medication is tetracycline. A variable level of tetracycline resistance has been noticed in *Salmonella* to tetracycline in poultry in Bangladesh. Several studies had reported about 65% to100% resistance in *Salmonella* to tetracycline and oxytetracycline in layers and broilers in Bangladesh [25,27,29,30,32–34,38–40,42,43,46,47]. Recently, Alam et al. [38] and Tawyabur et al. [42] detected tetracycline-resistant phenotype and the tetracycline-resistant gene *tetA* in *Salmonella* in poultry in Bangladesh. More specifically, extremely recently, Siddiky et al. [47] identified tetracycline *tetA*gene 80%, 90.90% and 100% *S.* Typhimurium isolates of broilers, sonali, and indigenous chickens' ceca, respectively, in Bangladesh. Earlier, Sharma et al. [76] observed 100% resistance to tetracycline and also detected the *tetA*-resistant gene in *Salmonella* in India.

Doxycycline is a broad-spectrum tetracycline class of antibiotic that is commonly used to treat different infections in humans and animals. A significant number of isolates resistant to doxycycline (50.00% to 79.31%) has also been reported in *Salmonella* in poultry in Bangladesh [23,26,34,48]. Formerly, Waghamare et al. [97] also observed 100% resistance in *Salmonella* to doxycycline in India. Higher rate of detection for the tetracycline-resistant gene in *Salmonella* from poultry environment is threat for both animals and humans. The ability of resistance potential of *Salmonella* to access the food web could expose individuals to life-threatening health risks. To reduce the rise of bacterial resistance in chicken farms in Bangladesh and around the globe, AMR reconnaissance protocols should be implemented.

7.9. Resistance to Phenicols

Chloramphenicol is a broad-spectrum antibiotic not currently used since it is a banned item due to its side effect on the host. However, it has long been used to treat numeric types of bacterial maladies in both individuals and animals [98]. Studies carried out throughout 2012 to 2021 have reported variable degree (20% to 58%) resistance in *Salmonella* to chloramphenicol in layer birds in Bangladesh [23,32,36,41,47]. In broilers, about 94.28% to 100% resistance was reported in *Salmonella* to chloramphenicol [25,38]. Alamet al. [38] also detected chloramphenicol resistance *floR* (94.28%) gene from *Salmonella* isolates of broilers in Bangladesh. Previously, El-Sharkawy et al. [99] reported 100% resistance to chloramphenicol in *S.* Typhimurium isolated from chicken in Egypt. These authors also detected the chloramphenicol-resistant gene *floR* (79.30%) from these isolates [99]. The detection of the chloramphenicol-resistant *floR* gene of *Salmonella* in broiler carrying *intl1* is of severe general well-being issues because their *Salmonella* zoonotic type and conceivable outcomes to access into the food web.

7.10. Resistance to Rifampicin

Rifampicin is used for the treatment of a few sorts of bacterial diseases, counting tuberculosis, *Mycobacterium avium* complex disease, and Legionnaires' disease [100]. In livestock and poultry, it has been used to some extent experimentally. However, reports are available showing resistance in *Salmonella* to rifampicin. Akond et al. [24] reported 60% resistance in *Salmonella* to rifampicin isolated from the egg surface, cloacal swabs, intestinal fluid, soil and hand washing samples of the layers. Later, Sultana et al. [26] also observed 88% resistance in *Salmonella* to rifampicin isolated from the layers in Bangladesh.

Previously Zdragas et al. [101] reported 33.30% rifampicin resistance in avian *Salmonella* in Greece and Ramatla et al. [102] reported 100% rifampicin resistance in avian *Salmonella* in South Africa. Horizontal transfer of rifampicin-resistant genes from human isolates to avian species might be linked with this observed resistance in avian isolates.

7.11. Resistance to Glycopeptides

Vancomycin is a glycopeptide antimicrobial useful to treat skin diseases, circulatory system diseases, endocarditis, bone and joint diseases, and meningitis in humans [103]. Although it is not used in poultry, Sultana et al. [26] reported 78% resistance in *Salmonella* to vancomycin in the layers in Savar. In India, Singh et al. [104] recorded 100% resistance in avian *Salmonella* to vancomycin. Vancomycin works against the Gram-positive cell wall, so it was not unexpected to see resistance in *Salmonella* to vancomycin.

7.12. Resistance to Sulpher Drugs

Sulfonamides such as sulfamethoxazole are a widely used group of antimicrobials in poultry [105]. In Bangladesh, variable degrees of sulfamethoxazole resistance in *Salmonella* in the layers were recorded [32,45,48]. Rahman et al. [34] detected 75.86% resistance to sulfamethoxazole and Parvin et al. [43] also reported 89.20% resistance in *Salmonella* to sulfamethoxazole in the broilers. In Bangladesh, the percentages of resistance to sulfur medicines detected are close to those reported in other studies in Malaysia, which was 67.50% [106], and Ethiopia [107] where resistance was 60%. Extremely recently, Siddiky et al. [47] detected sulfonamide resistance *sul1* gene in 36.40%, 66.70% and 80% *S.* Typhimurium isolated from broiler, sonali and indigenous hens' ceca in Bangladesh, respectively. This gene has also been identified in *Salmonella* in India [108]. The evolution of sulfamethoxazole resistance in hens could be caused by irrational antimicrobial use in the production process or environmental drip. As a result, we should be concerned about developing and implementing an efficient national AMR surveillance strategy in order to assure food safety and market control.

7.13. Resistance to Polymyxins

Colistin is an antibiotic in the reserve group that is used as a last option for curing various MDR bacterial diseases in humans. Despite the fact that there are limits to the utilization of colistin in domesticated fowls in Bangladesh, it has long been used to treat Gram-negative bacterial diseases in this country. A significant level of colistin resistance was observed as ranging from 50% to 92.68% in *Salmonella* in broilers and layers in Bangladesh [27,28,30,41,44]. Similarly, Phiri et al. [109] also reported 78.70% colistin resistance in *Salmonella* in Zambia. The main reservoirs for colistin resistance and transmission have been identified as livestock and poultry [110]. Detection of colistin resistance is extremely concerning for public health. In Bangladesh, Uddin et al. [44] detected colistin resistance *mcr1* gene in *Salmonella* in poultry. Earlier, Quesada et al. [111] and Moreno et al. [112] also identified colistin resistance*mcr1* gene in poultry in Spain and Brazil, respectively. Globally, increased resistance to colistin is quickly growing, posing a hazard to human health. Colistin-resistant genes are found in the plasmid. There are conceivable outcomes for exchanging these resistance genes from resistant to other sensitive isolates, making the situation more aggravated.

Overall antimicrobial-resistant profile of poultry *Salmonella* in Bangladesh as reported in the literature on a yearly basis is presented in Figure 4.

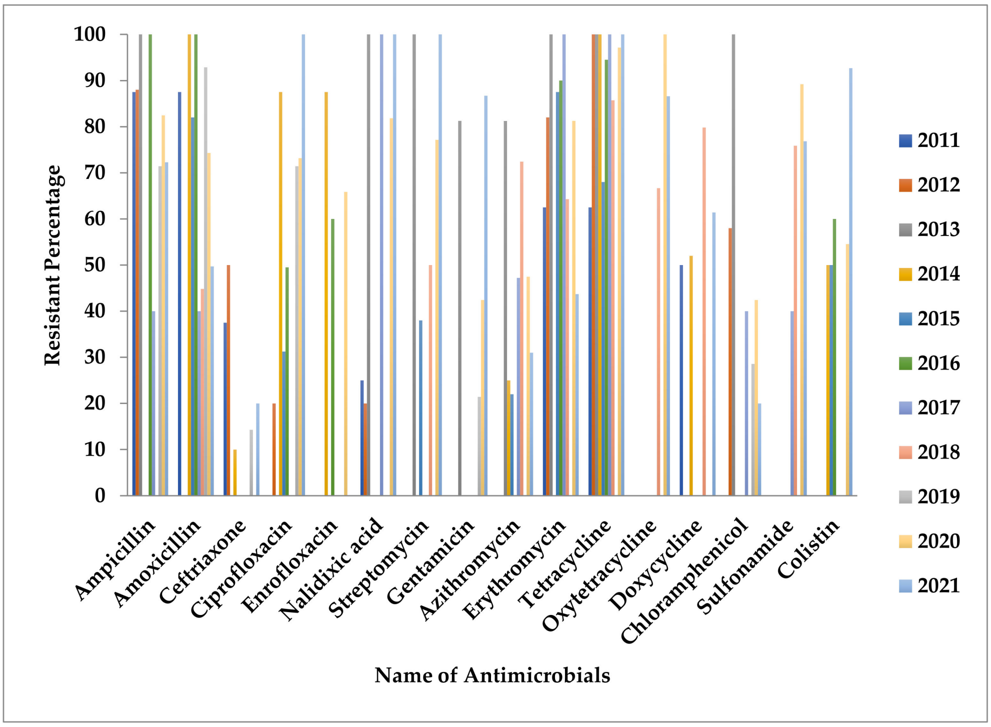

Figure 4. Presents antimicrobial-resistant profiles of *Salmonella* based on year of publications.

8. Public Health Significance of *Salmonella*

Salmonella is a major issue for the public health in many flourishing nations due to the lack of safe drinking water, inadequate hygiene facility and incorrect antimicrobial drug uses. *Salmonella* infection affects nearly 30 million individuals worldwide every year, whereas the scenario in Bangladesh is estimated to be between 292–395 cases per 100,000 persons each year [113–115]. Foodborne zoonoses, such as salmonellas, pose a dangerous threat to the food industry and food safety around the world. All necessary measures must be taken to overcome them in this way, as it entails improving public health and assembling food supply needs. *Salmonella* anticipation can be achieved over time using a holistic methodology that is comprehensive and all-encompassing. Salmonellosis has a substantial social and financial impact as a result of financial costs to the poultry industry, particularly to infected people and their families [116]. Human infection with *Salmonella* that is MDR in nature could be highly expensive to treat due to the cost of effective alternative medicines and longtime patient care in hospitals unless covered by health insurance [117].

9. Economic Impact of Salmonellosis

Salmonella is responsible for great economic impact all over the world. It usually spreads from animal to human and affects the poultry business globally. It also causes economic loss in the poultry sector in Bangladesh; however, the exact data on such economic loss are not well documented. Economic losses are due to high treatment and other management costs, loss of production and mortality. Only some countries submit reports on the financial impact of *Salmonella*, and data on the cost of foodborne illness in under-developed countries are often unavailable [118]. Foodborne infections have a significant impact nearly one out of every ten people becomes ill each year and responsible for loss of 33 million lives per year. According to the Centers for Disease Control and Prevention (CDC), *Salmonella* causes 1.2 million infections, 23,000 hospitalizations, and 450 deaths in the United States every year [119]. Food is responsible for approximately 1 million of these illnesses.

The cost of disease is determined by its frequency, severity and influence on one's health. Estimates of the cost of foodborne diseases are critical in driving federal attempts to stop foodborne diseases in the United States. The first cost estimates for sixteen foodborne illnesses were issued by the USDA's Economic Research Service (ERS) in 1989 [120]. In 2000, the ERS estimated that sickness caused by five important foodborne pathogens, including *Salmonella*, cost nearly USD 7 billion per year.

For the first time in a decade, new full cost of illness estimates was released in 2012. Scharff [121] employed an upgraded tariff of illness design that included a metric for agony, distress, and functional incapacity that is more inclusive. According to Scharff [121], the annual cost of foodborne diseases for all pathogenic organisms could be as high as USD 77.7 billion. In that year, Hoffman et al. [122] calculated that disease caused by fourteen main pathogenic organisms costs USD 14.1 billion in the United States.

The cost per pathogen rankings in the two studies is nearly identical. According to Scharff [121] and Hoffmann et al. [122], the expense of non-typhoidal *Salmonella* is the greatest of all foodborne infections. The entire financial cost of foodborne *Salmonella* in the United States in 2013 was USD 3.7 billion [123]. The annual cost of foodborne *Salmonella* is USD 1.14 billion [121]. According to David Byrne, EU Commissioner for Health and Consumer Protection, the cost of foodborne *Salmonella* alone in EU countries is expected to be up to EUR 2.8 billion per year (EU Commission, 2003) [124]. The yearly cost of foodborne salmonellosis in Denmark was estimated to be USD 15.5 million in 2001 and it is roughly 0.009% of its national GDP. A *Salmonella* management system has already been in operation in the country for some years, with an estimated annual cost of around USD 14.1 million [118]. In the Netherlands, the yearly financial costs of human salmonellae were estimated to be EUR 32–90 million [125].

10. Salmonellosis Prevention and Control

Salmonellosis is a serious concern in the food industry. Since January 2006, the European Union has established standards that include yields, biosecurity indicators, and the ban of the use of antibacterial agents as development promoters across the poultry value chain [126]. Meat and process items of chickens are regularly connected with episodes of salmonellosis therefore significant spread of illness occurred [127]. *Salmonella* avoidance and control can be accomplished by receiving the standards of HACCP [128].

For the poultry farm's general management, hygiene and biosecurity should be required [129]. These means are vital in contamination control. Approaching poultry should be in good health and purchased from reputable sources with assured quality. Moreover, *Salmonella* can be introduced in chicken homesteads by transportation, laborers, apparel, gumboots, gear, water, foods, trash, creepy crawlies, rodents, wild birds, pets, hardware and numerous components. It should be able to prevent *Salmonella* from entering the farm by regulating who enters the property, wearing protective clothing, and wearing cleaned footwear. Laborers should also be aware of important sterile standards, such as keeping hands and feet clean. Cleaning and sterilizing should be done on a regular basis while organizing the administration of the entire homestead. Chicken farms should be sterilized using examples such as floors, dividers, drinking water, dining areas and the temperature. It is believed that if an antimicrobial usage approach is implemented, public knowledge of antimicrobial hazards will rise [130,131]. The cooperation between human health, sanitation, livestock health, One Health access and pollution methodologies along with animals, markets, caterings, and purchasers to limit tainting and decrease spread of *Salmonella* is essential to reduce the threat of foodborne pathogens. Furthermore, constant observing of the degree of *Salmonella* obstruction worldwide is vital for physicians to help useful treatment alternatives for salmonellosis, particularly for sick persons accepting antimicrobial treatment [132,133].

11. Current Status and Future Research

Salmonellosis is one of the most common zoonotic diseases in Bangladesh. Every year millions of people, animals, and poultry are affected by *Salmonella* infection. Salmonellosis is frequently associated with high mortality rates that are closely 90%, resulting in significant economic losses [134]. According to the European Food Safety Authority (EFSA), the overall economic cost of human salmonellosis could be as high as EUR 3 billion per year [135].

In addition, to overcome bacterial AMR, phage therapy could be an alternative way [136]. These phages, also known as bacteriophages, are actually viruses having ability to infect bacterial cells and kill them by lysis. Experimental study in mice showed phages as effective against *Salmonella* [137].

According to the last decade survey in Bangladesh, epidemiological, AMR and few levels of genetic exploration were observed in avian salmonellosis. We need more studies on why *Salmonella* becomes resistant frequently in poultry production, and the foodborne illness is more substantial in Bangladesh. In addition, food hygiene and food safety practices and biosecurity in the poultry production units in Bangladesh are not well standard in many cases, which needs to be properly addressed. Good hygiene and manufacturing practices in the food production units and strict biosecurity is a must to overcome zoonoses and control of Salmonellosis in the poultry production units.

12. Conclusions

Salmonellae are major foodborne pathogenic bacterial organisms. Chicken and processed items are a potential origin for antimicrobial resistance to *Salmonella.* The farm environment could also be a major source and reservoir for MDR *Salmonella.* Treatment of MDR bacteria is complicated, expensive, and often required long-time attention and monitoring. *Salmonella* resistance has already been documented in poultry in Bangladesh. Antimicrobials only have to be applied after conducting the sensitivity test. Law enforcement by the concerned government agencies should be implemented to restrict easy access and use of antimicrobials. It also needs to be ensured that general people are aware of the fatal consequences of AMR through various awareness building programs.

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