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REVIEW ARTICLE

Transmission of *Salmonella* in Humans and Animals and its Epidemiological Factors

Oladapo O. Oludairo[1*], Jacob K. P. Kwaga [2], Junaid Kabir [2], Paul A. Abdu [2], Arya Gitanjali [3], Ann Perrets [3], Veronica Cibin [4], Antonia Lettini [4], Julius O. Aiyedun [1], Oluwafemi B. Daodu [5], Isaac D. Olorunshola [5], and Uduak Akpabio [6]

[1]Veterinary Public Health and Preventive Medicine Department, University of Ilorin, Nigeria
[2]Veterinary Public Health and Preventive Medicine Department, Ahmadu Bello University, Zaria, Nigeria
[3]OIE Salmonella Reference Laboratory, National Microbiology Laboratory, Public Health Agency of Canada, Guelph, ON, Canada
[4]Salmonella Reference laboratory,
IstitutoZooprofilatticoSperimentaledelleVenezieVialedell'Università, Legnaro (PD), Italy
[5]Veterinary Microbiology Department, University of Ilorin, Nigeria
[6]Veterinary Public Health and Preventive Medicine Department, Michael Okpara University of Agriculture, Umudike, Nigeria
*Corresponding author: oludairo@hotmail.com

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Abstract

Over 2,500 *Salmonella* serovars cause typhoidal and non-typhoidal salmonellosis, which has economic and public health importance worldwide. The routes, modes, and vectors of *Salmonella* transmission in humans and animals, including the factors that affect them are important in the understanding of the epidemiology, prevention, and control of the disease. This study aims to identify the routes, modes, and vectors of transmission of *Salmonella*, including the factors that enhance the spread, maintenance, and persistence of the organism in humans and animals. This was achieved by using a Google search engine to obtain peer-reviewed articles on the keywords of this study. The major route of transmission of *Salmonella* in humans is faecal-oral, while the transovarial route has also been reported in poultry. Ingestion of contaminated food or water, contaminated materials from pets/wildlife, infected persons, and transmission to the young through the placenta are described as modes of transmission of *Salmonella* in humans. *Salmonella* Typhimurium (*S.*Typhimurium), *Salmonella* Enteritidis (*S.* Enteritidis) and *Salmonella* Senftenberg (*S.* Senftenberg) attach efficiently to vectors like fruits and vegetables with the aid of *AgfD*-regulated-adhesin, biofilms, and flagella. The organism can also invade plant tissues before transmission to humans and animals. *Phytophagous hemipteran* and cynanthropia/coprophagic insects serve as vectors of transmission by forcibly excreting ingested *Salmonella* and through their intermittent habitat and diet changes, respectively. Lice serve as vectors by ingesting viable strains of the organism, after they reach a maximum titre of 0.5–5.0 $\times 10^7$ within 6–8 hours; *Salmonella* is thereafter shed and transmitted through their faeces. Factors that affect the transmission of *Salmonella* include pathogen, host and environment-related factors like increased antimicrobial resistance, intermittent shedding of the organism and rainfall, respectively. The knowledge of the routes, modes, vectors, and factors that affect the transmission of *Salmonella* will contribute to the body of knowledge on the epidemiology, prevention, and control of salmonellosis.

Keywords: *Salmonella* serovars, Routes, Vectors, Mode of transmission.

Introduction

Salmonella is a significant foodborne pathogen that causes 115 million human-infections and 370,000 deaths globally every year [1]. *Salmonella enterica* serovar Enteritidis (*S.* Enteritidis) and *Salmonella enterica* serovar Typhimurium (*S.* Typhimurium) are the most common causes of human non-typhoidal salmonellosis all over the world [2-4]. The rapid spread of *Salmonella* across the world has remarkably affected human and animal-health [5]. *Salmonella* is broadly spread in domestic and wild animals such as pigs, poultry, cattle, and turtle as well as pets such as cats, dogs, birds, and reptiles. The organism can traverse the whole food chain from animal feed/primary production to households or food service institutions [6]. In humans, *Salmonella* is usually contracted through the consumption of contaminated food of animal origin such as egg, meat, poultry, and milk [6].

Invasive *Salmonella* infection causes a significant burden of disease in Africa and the world at large, it presents as either typhoid or paratyphoid fever or invasive non-typhoidal salmonellosis [7, 8]. *Salmonella*-caused foodborne gastroenteritis is characterized by bloody diarrhoea, fever, headache, abdominal pain, nausea, and vomiting [9]. The outbreak of the disease had been associated with domestic/wild animals [6], chocolate products [10], peanut butter [11] and many more animate and non-animate objects.

The disease had been reported to affect both humans and animals, accounting for millions of cases and causing a significant social impact globally [12-14]. The public health significance of salmonellosis is of global concern due to foodborne outbreaks, illnesses, and food poisoning as well as significant economic losses [15-18].

Person-to-person transmission of salmonellosis can occur through the faecal-oral route [6]. This could occur especially when infected people with diarrhoea fail to wash their hands thoroughly after defecation; it had been particularly reported in preschool children in day care facilities or among neighbourhood/home playmates [12]. Human contact with infected animals that do not show signs of disease can lead to infection of the disease [16]. The majority of infections in animals and humans are foodborne, but about 3% are acquired through indirect and direct contact with animals [6].

By having the intestines and/or reproductive tracts as targets, the organism in animals is spread between animals in high numbers, resulting in a maximum level of transmission and disease [19].

Vectors of transmission are living organisms that can transmit infectious pathogens, while vehicles of transmission of salmonellosis are non-living objects/materials contaminated with the organism that can transmit the pathogen between humans or from animals to humans [20]. Carnivorous amphibians like frogs, toads and salamanders feed mostly on earthworms, crickets, flies, moths, cockroaches, fish or mice that may be contaminated with *Salmonella* [21]. They thereafter become asymptomatic carriers contaminating other wild/domestic animals, water bodies they inhabit, humans that come in contact with them or their contaminated materials through touch or consumption [22, 23].

Vectors and vehicles that have been reported include reptiles [24], insects [25], food sellers [26, 27], wildlife [13, 28] and other domestic animals. This study aims to investigate the routes, modes and vectors of transmission of *Salmonella* serovars and the epidemiological factors that affect their spread and maintenance in humans and animals.

Published articles detailing the routes, modes, vectors (especially the role of fruits/vegetables, lice and insects) and the factors affecting the transmission of *Salmonella* were obtained online by typing these keywords into the google search engine. The results of the search were examined and evaluated for relevance to the study. Relevant articles were saved in computer hardware and subsequently retrieved for use in the study.

Transmission of *Salmonella*

For non-typhoidal salmonellosis, the incubation period varies from 6 -72 hours but is usually about 12-36 hours. Incubation periods that are longer than 3 days have also been documented [29, 30]. The incubation period of typhoid fever caused by *S.* Typhimurium depends on the infecting dose but is usually between 3 days to 1 month, the common range is however, 1-2 weeks, while it is 1-10 days for paratyphoid fever [31, 32].

After the establishment of *Salmonella*, the host may transmit the organism. Transmission is a complex process including components of both the pathogen and the host [33, 34]. The host-to-host pathogen transmission ensures the successful spread and maintenance of the organism within a host population [33, 35]. There are several hurdles a pathogen must overcome to colonize a host, which includes the resident microflora, the host's innate immune system and its ability to multiply within the new host and repeat the cycle of multiplication [36, 37]. The inherent and acquired factors of both the host and the pathogen will determine the level of colonization and transmission of the organism [33, 38-40].

Routes and modes of *Salmonella* transmission in humans and animals

The major route of transmission of salmonellae in humans is the faecal-oral route; however, the transovarial route had been reported in poultry [29]. In humans and animals, the most common mode of transmission is the ingestion of any food and water that have been contaminated with human or animal faeces [41]. Such foods include raw fruits and vegetables [29, 31]. In addition, pets and wildlife including lizards and turtles could be chronic carriers of Salmonella [29, 42]. Person-to-person transmission can also occur especially among members of the same household and preschool children in day-care. Certain types of sexual contact for example oral-anal contact play important role in the transmission of Salmonella [29, 43]. Vertical transmission is a result of reproductive organ colonization and had been recorded in the S. Enteritidis dissemination from laying hens to eggs/chicks [44-46].

Fruits and vegetables as vectors of transmission of *Salmonella*

The attachment of the organism to fruits and vegetables is a pre-requisite for *Salmonella* to colonize and be subsequently transmitted to humans and animals. Once it is attached to the fruits and vegetables it is very difficult to remove by washing [6, 47-49].

Several serovars of *S. enterica* like *S.* Enteritidis, *S.* Typhimurium and *S.* Senftenberg adhere efficiently to fruits and vegetables, while others like *S.* Arizona, *S.* Agona and *S.* Heidelberg do not attach well to fruits and vegetables [50, 51].

Pilus curli or Tafi encoded by *agfB* gene, O antigen capsule encoded by *yihO* gene, and cellulose synthesis encoded by *bcsA* gene, together with other adhesins play important roles in the adhesion of *Salmonella* to fruits and vegetables [52-54]. Curli, capsule, and cellulose are regulated by *agfD* gene, suggesting a role in the environmental persistence of *Salmonella* [55-57]. Biofilms are formed by cellular matrix which has been consistently found to be created by curli and cellulose [58]. Strains of *Salmonella* that form extensive biofilms were found to have stronger adhesion to fruits and vegetables compared to those that produce weak biofilms [59, 60].

Salmonellae possess at least 15 different 'fimbriae or pili'. 'Curli' on the other hand are thin aggressive fimbriae detected throughout *S. enterica* associated with cell-to-cell aggression and formation of adhesive colonies [61-66].

It has been reported also that the flagella of *S.* Senftenberg play a major role in its adherence to fruits and vegetables [50, 67]. This has been reported to be true for *S.* Typhimurium though it is only able to invade leaves' mesophyll in the presence of light and not in darkness, resulting in bacterial aggression round the stomata and invasion of the inner part of the leaf's tissue [68, 69]. *S.* Montenegro inoculated into bean sprout seeds were found to be present inside the growing plant after germination suggesting that *Salmonella* strains can infect plant tissues, adhere to their surfaces and thereafter be transmitted to humans and other animals [49, 70].

Other creatures serve as vectors that aid the transmission of *Salmonella* to different plant hosts. Since vectors are generally defined as organisms, usually arthropods or fomites that carry a disease agent from a reservoir to a susceptible host [71, 72]. Concerning food safety, a vector has been defined as a living carrier that serves as a vehicle of transmission of an infectious agent, but not necessarily as a reservoir and facilitates the exposure of a host to the pathogen [73-75]. Regarding plants, pathogen vectors are loosely defined as organisms that can introduce a pathogen into a plant to cause infection by carrying the pathogen internally and externally [76].

Phytophagous hemipteran insects as vectors of transmission of *Salmonella*

This group of insects include *Macros teles quadrili* (Aster leaf hopper), *Hemiptera aphididae* (Green peach aphids), *Helicoverpa, armigera*, white fleas, grasshoppers, crickets, leaf miners, *Spodoptera* and *Littoralis* [77, 78]. They mostly feed on green leaves like lettuce that could be infested with *Salmonella* by man and through other means. They have been reported to harbour a huge *S. enterica* population after coming incontact with contaminated plant materials [79, 80].

By the adhesion of the organism on the exoskeleton of the insect, they can dispense the pathogen along the same leaf or adjacent onesor spread *Salmonella* species (spp.) to the abaxial part of the leaf which contain higher densities of stomata. *Salmonella* gain access and penetrate leaves using stomata sentry points [81,

82]. This directly influences the persistence and spatial distribution of *S. enterica* on leaves [83]. Insects' excretion of the ingested *Salmonella* represents another important mechanism of transmission [83]. They usually survive the passage through the insect's alimentary canal and are subsequently dispersed on plants by the insects. Since all leafhoppers and some aphids forcibly direct droplets of their excretion or honeydew (aqueous solution containing several sugars and amino acids) away from themselves to prevent self-contamination [84]. Uninfected insects, animals, and humans could also be infected by coming in contact with *S. enterica*-contaminated honeydew [84, 85].

Cynanthropic and coprophagic insects as vectors of transmission of *Salmonella*

Belonging to this group of insects are houseflies. They are documented as vectors of human enteric pathogens and have been implicated in the survival, dispersal, and multiplication of *S. enterica* [86, 87]. This group of insects are associated with unsanitary conditions. They have the ability to change their habitats indiscriminately from livestock to produce fields or from urban to rural areas.

They also have multiple dietary sources, ranging from faecal materials, fruits, plants, and vegetables that all play important roles in the epidemiology of *Salmonella* [88, 89].

Lice as vectors of transmission of *Salmonella*

The possible role of lice in the transmission of *Salmonella* has been studied using human-body lice fed experimentally with fresh chick skin membrane and maintained on rabbits [90-92]. It has been established that lice ingesting one viable unit of *S. enteritidis* strain S-795 became infected and eventually developed 0.5-5.0 × 10^7 bacteria in their bodies reaching maximum titre in 6-8 h. Viable *Salmonella* spp. survived in lice faeces in considerable numbers for more than 1 year and about 4 years in experimental cases [90, 93]. Lice, therefore, appear not to transmit the organism through a bite but rather through their faeces [90, 94].

Factors that maintain/affect the transmission of *Salmonella*

The factors that maintain the transmission of *Salmonella*, especially in a food processing environment are increased antimicrobial resistance, the ability of cross-contamination of animate and non-animate materials and long-term survival of the organism [95, 96]. Intermittent shedding of *Salmonella* spp. by infected hosts is another important factor in the transmission of the organism. *Salmonella* may have a mean shedding duration period of 8 months or more after host infection [97, 98]. The mild infectiousness and long infection period contribute to the dynamic pattern of disease transmission [99. 100]. Humans may serve as chronic carriers as in the case of the study of *S.* Paratyphi A in which infected migrant patients and carrier workers spread the organism in the course of their movements especially given the combination of hygiene with hot humid climate, poor food, and water [99].

Other factors that have been reported to significantly affect the carriage of *Salmonella* in wild animals are rainfall, sex, and the ability of the organism to survive in the environment. A negative association was recorded between the occurrence of *Salmonella* in racoons and

rainfall [101]. The report also indicated female animals might have a lower prevalence of *Salmonella* compared to male animals due to reduced contact with the environment, reduced activity, and lower distance coverage resulting in less activity [101]. The ability of *Salmonella* to survive in the environment may play an important role in its transmission between host animals, dissemination, and persistence in animal and human populations [102]. In humans, additional factors reported to affect the occurrence of *Salmonella* include nutritional status, social, economic, and environmental factors including race and ethnicity. Black race and people of Hispanic origin were reported to exhibit more resistance to *Salmonella* infections compared to other races [103].

This was reportedly due to varying food preferences or methods of food preparation among these races [104]. Furthermore, an association between altered nutritional status and acute gastroenteritis have been established in AIDS patients [105]. The highest occurrences of *S. enteritidis* were observed in more prosperous areas of the United States. It was advanced that the population living in such areas more frequently ingested vehicles harbouring *S. enteritidis* [106].

Conclusion

Transmission of *Salmonella* is a complex process in which inherent and acquired host and pathogen factors determine the level of colonization and transmission. Resident microflora, host innate immune system, difficulty multiplying in new host cells and repeat multiplication cycles are hurdles pathogens must overcome to colonize hosts. The main route of transmission of *Salmonella* is the faecal-oral-route in humans and the transovarial route in poultry, while the common modes of transmission are ingestion of contaminated water/food, contamination from infected pets/wildlife, persons, and anus, including placental mode of transmission.

S. Typhimurium, *S.* Enteritidis and *S.* Senftenberg unlike *S.* Arizona, *S.* Heidelberg, and *S.* Agona efficiently attach to fruits and vegetables and must colonize them before they are transmitted to humans and animals. Attachment to these fruits and vegetables by *Salmonella* is enhanced by the formation of biofilms, presence of flagella and AgfD-regulated adhesins like pilus curli/tafi, O antigen capsule and cellulose encoded by the *agfB*, *yihO*, and *bcsA* genes, respectively. Invasion of plant tissues by *Salmonella* could also occur before transmission to humans and animals.

Phytophagous hemipteran insects, such as grasshoppers feed on *Salmonella*-infested green leaves and excrete ingested organisms forcibly away from themselves to the same/other leaves, uninfected leaves, insects, animals and humans, contributing to the spatial distribution and persistence of the organism. Cynanthropic and coprophagic insects like houseflies with a special ability to change their habitant indiscriminately and alternate their diet from faeces, plants, fruits, vegetables and human-cooked and uncooked foods contribute significantly to the dispersal, survival and multiplication of *Salmonella* spp. When lice ingest a viable unit of *S. enteritidis* S-795 strain, the organism reaches a maximum titre of 0.5-5.0 ×107 within 6-8 h and thereafter sheds or transmits the bacteria in or through their faeces to humans and animals.

Increased antimicrobial resistance, the ability of vectors to cross-contaminate, long-term survival of the organism in the host, intermittent shedding of the organism by the host, mild infectiousness/long period of infection and other physical, demographic and climatic factors affect the maintenance and transmission of *Salmonella* in plants, animals, humans, and the environment.

Recommendations

Further research work should be carried out to cover the routes, modes, vectors, and factors affecting them more extensively. Other areas not included in the study such as other vectors of transmission of *Salmonella* should be studied to further understand the way those vectors transmit the organism. This may include studies to determine other factors that affect and maintain the transmission of *Salmonella*. These studies are of importance because their knowledge will afford researchers, veterinary/medical officers and epidemiologists the knowledge of the stage at which intervention for prevention and control could be instituted.

Conflict of Interest

The authors have no conflict of interest to declare.

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الملخص العربي

إنتقال السالمونيلا في الإنسان والحيوان وعواملها الوبائية

أولودايرو أولودايرو 1 * ، جاكوب ك.ب.كواغا 2 ، جنيد كبير 2 ، بول إيه عبده 2 ، آريا جيتانجالي 3
آن بيريتس 3 ، فيرونيكا سيبين 4 ، أنتونيا ليتيني 4 ، يوليوس أو.أيدون 1 ، أولوفيمي ب.داودو 5
إسحاق د. أولورنشولا 5 ، وأودواك أكبابيو 6
1 قسم الصحة العامة البيطرية والطب الوقائي ، جامعة إيلورين ، نيجيريا
2 قسم الصحة العامة البيطرية والطب الوقائي ، جامعة أحمدو بيلو ، زاريا ، نيجيريا
3 المعمل المرجعى للسالمونيلا (OIE) مختبر الأحياء الدقيقة الوطني ، وكالة الصحة العامة الكندية ، جيلف ، أونتاريو ، كندا
4 مختبر السالمونيلا المرجعي
5 قسم الأحياء الدقيقة البيطرية ، جامعة إيلورين ، نيجيريا
6 قسم الصحة العامة البيطرية والطب الوقائي ، جامعة مايكل أوكبارا للزراعة ، أوموديك ، نيجيريا

يوجد أكثر من 2500 من الانواع المصلية للسالمونيلا تسبب امراض السلمونيلا التيفوئيدى وغير التيفوئيدى والذى له أهمية اقتصادية وصحية عامة فى جميع أنحاء العالم.كما تعتبر طرق وأنماط وناقلات انتقال السالمونيلا في البشر والحيوانات ، بما في ذلك العوامل التي تؤثر عليهم ، مهمة في فهم علم الأوبئة والوقاية والسيطرة على المرض. تهدف هذه الدراسة إلى تحديد طرق وأنماط وناقلات انتقال السالمونيلا ، بما في ذلك العوامل التي تعزز انتشار ، والحفاظ ، واستمرار الكائن الحي في الإنسان والحيوان. تم تحقيق ذلك باستخدام محرك بحث جوجل للحصول على مقالات تمت مراجعتها من قبل الأقران حول الكلمات الرئيسية لهذه الدراسة. الطريق الرئيسي لانتقال السالمونيلا في البشر هوعدوى البراز- الفموي ، بينما تم تسجيل أيضًا الطريق عبر المبيض في الدواجن. توصف ابتلاع الطعام أو الماء الملوث ، والمواد الملوثة من الحيوانات الأليفة / الحيوانات البرية ، والأشخاص المصابين ، والانتقال إلى الصغار عبر المشيمة ، على أنها طرق لانتقال السالمونيلا في البشر.تلتصق السالمونيلا تيفيموريوم (S.Typhimurium) و سالمونيلا انتريتديس (S. Enteritidis), وسالمونيلا سينفينبرج (S. Senftenberg) بكفاءة مع ناقلات مثل الفواكه والخضروات بمساعدة مادة لاصقة منظمة AgfD والأغشية الحيوية والأسواط. يمكن للميكروب أيضًا أن يغزو أنسجة النبات قبل انتقاله إلى الإنسان والحيوان.كما تعمل الحشرات النصفية المأخوذة بالنباتات و cynanthropia / coprophagic الحشرات كنواقل انتقال عن طريق إفراز السالمونيلا المبتلعة بالقوة ومن خلال تغير موطنها / نظامها الغذائي المتقطع ، على التوالي. ايضا يعمل القمل كنواقل عن طريق تناول سلالات حية من الكائن الحي ، بعد أن تصل إلى حد أقصى يبلغ 5.0-0.5 × 107 في غضون 6-8 ساعات ، يتم التخلص من السالمونيلا بعد ذلك وتنتقل عن طريق البراز. العوامل التي تؤثر على انتقال السالمونيلا تشمل العوامل الممرضة والمضيف والعوامل المتعلقة بالبيئة مثل زيادة مقاومة مضادات الميكروبات ، واالافراز المتقطع للميكروب وهطول الأمطار ، على التوالي. ستساهم معرفة الطرق والأنماط والنواقل والعوامل التي تؤثر على انتقال السالمونيلا في تكوين اساس المعرفة حول علم الأوبئة والوقاية والسيطرة على داء السلمونيلا.