Agricultural Sciences Journal
Available online at http://asj.mnsuam.edu.pk/index.php
ISSN 2707-9716 Print
ISSN 2707-9724 Online

Review Article

ESCHERICHIA COLI O157:H7 IN MEAT AND POULTRY: TRANSMISSION, CONSEQUENCES ON HUMAN HEALTH AND IMPACT OF NON-THERMAL DECONTAMINATION TECHNOLOGIES: A REVIEW

Raheel Suleman[1*], Sabahat Zulfiqar[2], Alma Delia Alarcon Rojo[3*], Maimoona Shahid[1]
[1]*Institute of Food Science and Nutrition, Bahauddin Zakariya University, Multan, Pakistan.*
[2]*National Institute of Food Science and Technology, University of Agriculture, Faisalabad-38000, Pakistan.*
[3]*Faculty of Animal Science and Ecology, Autonomous University of Chihuahua, Chihuahua, Mexico.*

Abstract

Food-borne pathogens cause serious health threats to consumers globally. The consumption of contaminated and undercooked meat products obtained from livestock and poultry are the major sources of its transmission. The E. coli O157:H7 is transmitted to meat and its products through poor sanitary environment, improper and unhygienic slaughtering processing and use of contaminated equipment. As a result, outbursts of E. coli O157:H7 have been observed in various regions of the world. This review highlights factors involved in the transmission of E. coli O157:H7, its clinical manifestation, associated health hazards and control measures like cold plasma treatment, high-pressure processing and electrolyzed water treatment must be followed for outbreaks prevention.

Keywords: Food born pathogen, Meat sources, Clinical manifestation, Control measures.

1. INTRODUCTION

Food-borne pathogens cause food spoilage and foodborne diseases. Consumption of contaminated foods of animal origin results in food-borne infections. The occurrence of these diseases and of intoxication have been increasing because of changing lifestyles and the commercial production of foodstuffs (Rawat, 2015). These food-borne infections have a greater influence on the health of humans worldwide. About 600 million people annually suffer from the consumption of food contaminated with pathogens i.e., E.coli, Shigella spp., Salmonella spp. and campylobacter spp. (Odeyemi et al.2020). The World Health Organization report showed that in developed countries 30% people get affected while in developing countries 2 million people die annually due to foodborne diseases. Pervasiveness of E. coli O157:H7 revealed to be 15.3% in under-five years old children in a study conducted in Eastern Ethiopia. Escherichia coli is a gram negative, facultative anaerobic bacteria belongs to Enterobacteriaceae family, found in the gastrointestinal tract of humans as wells as animals but does not cause serious diseases. Most of the strains are non-dangerous while there are some pathogenic strains including O103:H2. O104:H4, O157:H7 and O111 which cause severe gastrointestinal and urinary tract problems. E. coli is categorized into different serotypes following somatic "H" (flagellar) antigens, "O" (lipopolysaccharide) antigens and "K" (capsular) antigens (Guevara et al. 2019). The virulent groups of E.coli includes enteroaggregative E. coli, enterohemorrhagic E.

(Received: 1 April 2022, Accepted: 15 June 2022) Cite as: Suleman. R., Zulfiqar. S., Rojo. S. D. A., Shahid. M., 2022 Escherichia coli o157:h7 in meat and poultry: transmission, consequences on human health and impact of non-thermal decontamination technologies: a review. Agric. Sci. J. 4(1): 52-62.

coli, enter-invasive E. coli, enteropathogenic E. coli and enterotoxigenic E. coli. Depending upon the serotypes, pathogenic or diarrheagenic E. coli causes diseases including respiratory and intestinal diseases (Raeispur & Ranjbar, 2018). Among the pathogenic E. coli strains, O157:H7 is categorized as a prominent and lethal food-borne pathogen. Diseases caused by this strain of E. coli range from watery/bloody diarrhea to lethal conditions such as hemorrhagic colitis, hemolytic uremic syndrome (HUS) and thrombotic thrombocytopenic purpura. E. coli O157:H7 has been emerging as an important foodborne pathogen in humans responsible for outbreaks all over the world (Disassa et al., 2017) including Asia, Europe, Canada, different countries of Africa. In the United States, about 74,000 E. coli cases and 61 deaths are reported each year.

Since the first outbreak of E. coli O157:H7 in Oregon and Michigan in 1982 till today, many advanced and strict measures are adopted for preventing its transmission and adverse effects on human health. Despite all these control measures, there are still cases of its infections, particularly, in developing countries. It is mainly because of least studies carried out in such countries on E. coli O157:H7, its spreads and virulence. The data of cases surfaced is left undocumented. That is why, it is need of time to review this crucial topic to highlight the transmission factors of E. coli O157:H7, its consequences and non-thermal control measures with purpose of bringing about awareness in public.

2. Sources of E. coli O157:H7

2.1 Livestock

Food containing E. coli O157:H7 is deemed unfit for the consumption by humans and it leads to the refusal of products and alarming food safety. Meat is recognized as a rich source of protein, vitamins and minerals (nutrient dense food). Globally, meat consumption has increased in last decades. According to the statistic, 656 million turkeys, 574 million sheep, 479 million goats, 302 million cattle and 69 billion chickens were slaughtered for human consumption. In 2018, consumption of ground beef was associated with cases of E. coli infections. Occurrence of foodborne infections is because of consuming contaminated meat. Data given by WHO subregions on the global incidence of E. coli O157:H7 showed 2.8 million cases per year (Salen and Wasey, 2021.

Studies carried out in Turkey reveal that the percentage of E. coli O157:H7 was high in chicken (31.25%) and meat (19%) while low in vegetables (18%). One of the major natural reservoirs of E. coli O157:H7 is cattle (Abdissa et al., 2017; Abreham et al., 2019) followed by improper cooked beef and spoiled ground beef. However, it has been observed that sheep and goat meat are prime sources of E. coli O157:H7, thus causing diseases in humans. Cattle meat such as cows and buffaloes contained pathogenic strain of E. coli via various factors including fecal to carcass or skin to carcass contamination, improper storage and distribution practices. In arid and semi-arid regions, where camel meat is consumed widely, an analysis was performed to track the presence of E. coli O157:H7 and it was found in two isolates.

Today, chicken meat as a source of pathogenic E. coli is one of the prevalent foods consumed by the people. According to studies, E. coli isolates from poultry and livestock samples had antimicrobial resistance. Duck had the highest rate of methicillin drug resistance (MDR), followed by chicken and cow.. Thus, the rates of E. coli were considerably higher in chicken and duck than in cows. Collectively, it has been observed that chicken meat is the predominant reservoir of pathogenic E. coli O157:H7 that causes harmful effects on human health. E. coli microflora resides in the intestine of broiler chicken, causes fatal diseases and leads to the major losses in poultry farms all over the world. E. coli of poultry origin can cause extra intestinal infections in humans (Mitchell et al., 2015) and has critical significance in public health care, sanitation and hygiene. Study carried out in India showed commercial broiler chicken involved in the channeling of E. coli different strains into the environment. E. coli exists in processed unhygienic foods made of chicken meat and beef. Some studies also revealed that other poultry birds such as ducks carrying E. coli O157:H7 strains.

Turkeys (Meleagris gallopavo) involve in the transference of E .coli O157:H7 causing

Table 1. *E. coli* O157:H7 isolates in meat and poultry

Sources	Factors Involved in Transmission	Clinical Manifestations	References
Raw chicken meat	Unhygienic production and processing, consumption of contaminated chicken meat.	Gastroenteritis	(Afify et al. 2020)
Raw chicken meat	Environmental contamination, unhygienic hand ling of meat.	—	(Aklilu and Raman, 2020)
Broiler chicks	Infected chicks.	Colibacillosis (i.e., weakness, anorexia, off food and diarrhea.	(Kadhum, 2020)
Broiler chicken	Farm fecal contamination of the eggshell, poor hygienic practices at farm.	Intestinal and extra-intestinal disease conditions.	(EL-Sawah et al. 2018)
Broiler chicken	Poor personal hygiene of sellers and dirty market environments.	Watery diarrhea, vomiting.	(Amalia et al. 2020)
Live chicken	Poor housing conditions.	Kidney failure.	(Ningrum et al. 2020)
Ground chicken meat	—	Inflammatory bowel disease, urinary tract infections and meningitis.	(Xu et al. 2019)
Poultry meat	Consumption of raw or undercooked chicken, turkey and duck meat.	Diarrhea, TTP, HC and HUS.	(Aondover et al. 2019)
Poultry meat	Consumption of contaminated meat.	Diarrhea, TTP, HC and HUS.	(Buharshak et al. 2019)
Turkeys (*Meleagris gallopavo*)	Contaminated by fecal materials.	Urinary tract infections, abdominal sepsis, meningitis and colibacillosis.	(Tawyabur et al. 2020)
Chicken, meat and other food products	Improper food processing, improper hygienic measures at household level.	Diarrhea, HC and HUS.	(Lennox et al. 2020)
Chicken and meat	Contaminated transportation vehicles, poor sanitary environment during slaughtering, transportation, usage and hand ling, food contaminated by animal fecal materials. Consumption of contaminated and undercooked ground meat.	HUS and renal failure.	(Albarri et al. 2017)
Chicken and beef	Unhygienic production and processing practices.	Colibacillosis	(M. A. Rahman et al. 2017)
Chicken and mutton	Hand ling, harvesting and processing equipment and transportation. Consumption of microbial contaminated food.	Gastroenteritis (i.e., nausea, vomiting and diarrhea)	(Hemalata and Virupakshaiah, 2016)
Cattle	Unhygienic slaughtering practices. Contaminated meat products.	HC and HUS.	(Al-Ajmi et al. 2020)
Sheep and goat	Slaughtering operations, direct contact of workers with contaminated materials i.e., fecal material, knives, etc. Raw or undercooked minced meat.	HC, HUS and TTP.	(Abreham et al. 2019)
Meat	—	Bloody diarrhea (i.e., HC, HUS and TTP.	(Malvano et al. 2018)
Raw meat and fish	Contaminated by fecal materials. Consumption of contaminated meat.	Food poisoning	(Ayodele et al. 2020)
Beef	Consumption of contaminated and undercooked beef	—	(Lien et al. 2020)
Beef meat	Improper hand ling and processing. Unhygienic environment.	HUS, urinary tract infection, neonatal meningitis, respiratory illnesses and intestinal diseases.	(Samad et al. 2018)
Beef cattle	Poor sanitation at processing plants. Contaminated during slaughtering and dressing processes.	Diarrhea	(Abdissa et al. 2017)
Bovine animals (cow, sheep and goat)	Unhygienic slaughter practices, long distanced food supply transportations. Raw or undercooked meat	Gastroenteritis	(Haile et al. 2017)
Beef, mutton and chicken	Unhygienic slaughtering practices, poor personal hygiene, contaminated equipment. Consumption of contaminated raw beef and meat.	HC, HUS and TTP.	(Assefa and Bihon, 2018)
Ground lean camel meat	Direct contact with animals. Contaminated slaughtering tools and Ingestion of contaminated meat.	Diarrhea, HC and HUS.	(Osaili et al. 2020)

HC: Hemorrhagic colitis; HUS: Hemolytic uremic syndrome; TTP: Thrombotic thrombocytopenic purpura.

infections in human beings after consumption. Turkey farming is a profitable business, more adaptable and less susceptible to diseases than other poultry birds. In the countryside, poultry farming including broilers, layers and turkeys (van Duin and Paterson, 2016), is an additional source of earnings. When they are accommodated altogether then it leads to the

transmission of E. coli in turkeys. Presence of E. coli in conventionally grown turkey and chicken is higher than those which are grown organically.

2.2 Factors involved in the transmission of E. coli O157:H7

Prevalence of E. coli O157:H7 in chicken meat and beef is greater because of unsanitary production and processing. Isolates of E. coli were obtained from raw chicken samples traced the involvement of intestinal contents contamination while hand ling chicken meat. Certainly, improper hand ling and processing cause health risks. Contamination through soil, processing equipment and use of contaminated water during hand ling of meat and animal carcasses, are one of the major sources of transmission of E. coli in chicken meat. Occasionally, knives and the cutter tables used for slaughtering and slicing meat are not sterilized and it leads to the contamination of the meat.

In poultry and livestock, negligence in hygiene during slaughtering, transportation and trading of meat directed contamination of E. coli. Small ruminants are one of the sources of human infection via fecal shedding. Occurrence of transmission of pathogenic E. coli O157:H7 from skin to carcass or fecal to carcass during slaughtering and processing operations of beef has been observed at retail markets.

Transmission of microorganisms between humans and animals is facilitated by interaction with contaminated animals and environment either directly or indirectly. Pathogenic strains of the E. coli such as serotype O157:H7 causes infections, mainly transmitted by consuming contaminated foodstuffs. Raw and undercooked meat consumption commonly transmit E. coli O157:H7 to humans. Because of consuming contaminated ground beef, multistate outbreak of Shiga toxin producing E. coli O157:H7 infected 11 people from five states of USA, out of which 11 people were hospitalized, one person suffered with Hemolytic Uremic Syndrome (Center for Disease Control and Preventions, 2016. In another outbreak, 1 death and 6 hospitalizations were recorded in some regions of USA. In many recorded human cases, cattle and sheep were stated as the main sources of the transmission of E. coli.

2.3 Poor Sanitary Environment

Poor sanitation and unhygienic conditions or measures at household level where the animals are kept before slaughtering, are sources of transmission of various microorganisms (i.e., bacteria, viruses, etc. (Underthun et al. 2018). Some pathogenic groups of E. coli O157:H7 are also transmitted through such unhygienic environment like contamination occurs through fecal material of the animals (Peterson & Hubbart, 2020). The sanitary conditions

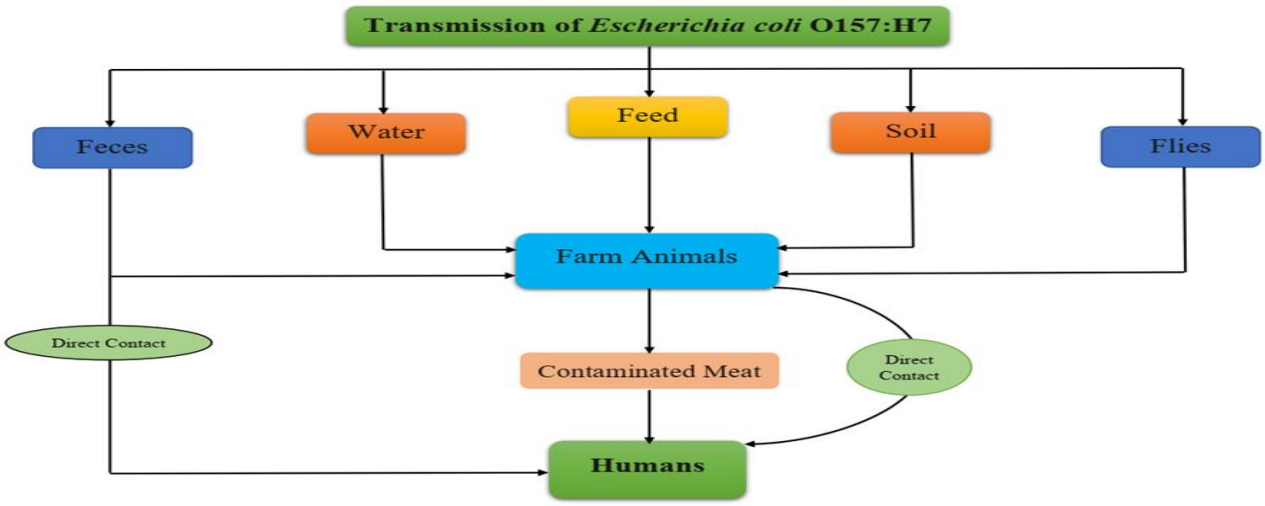

Figure 1. Routes of transmission of E.coli through different sources in humans.

Figure 1 mentioned factors that are involved in the transmission of E. coli O157:H7 to humans, pose serious public health risks and cause life-threatening diseases in human beings. improvement in making the water clean for the poultry and other animals used for meat can help prevent the E. coli transmission moreover these measures would be beneficial for healthy

growth of meat producing animals (Nurliyana et al. 2018).

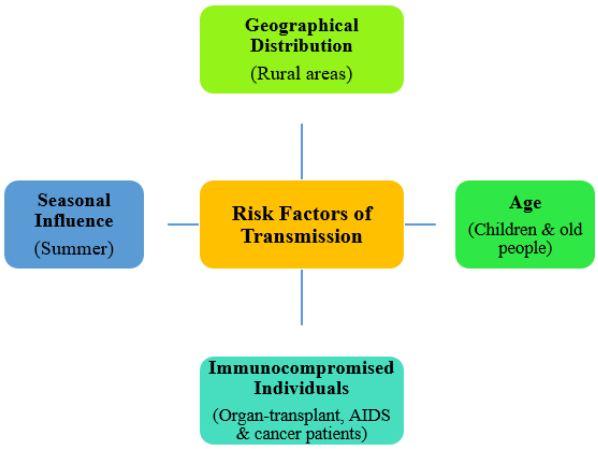

Figure 2. Risk factors of E. coli transmission to people through various sources

2.5 Use of unsterilized or contaminated processing equipment

Introduction of fecal and hide contaminated equipment used for slaughtering and meat processing can ultimately cause contamination of the meat. The traces of microorganisms left behind as a result of improper sterilization contaminate the meat and meat products. Improper sterilization can always cause cross contamination of the meat and therefore it is necessary to sterilize each and every instrument or utensil used for slaughtering and processing of meat to be free of pathogenic cross contamination (Sebsibe & Asfaw, 2020).

2.6 Undercooked chicken meat, beef and mutton

According to the studies carried out in Riyadh showed that the prevalence of E. coli is low at high temperature. Cooking meat at temperature ranging from 70 to 75 o C leads to the denaturation of E. coli (El Ghareeb et al. 2020). People ignorance in consuming undercooked meat leads to serious health concerns. Public awareness among masses to cook the meat properly at the required temperature is very important and thus a reduction in many microbes including E. coli and therefore it is very necessary to make the meat safer for human consumption by just improving the processing conditions (Ma, Glassman & Chui, 2020).

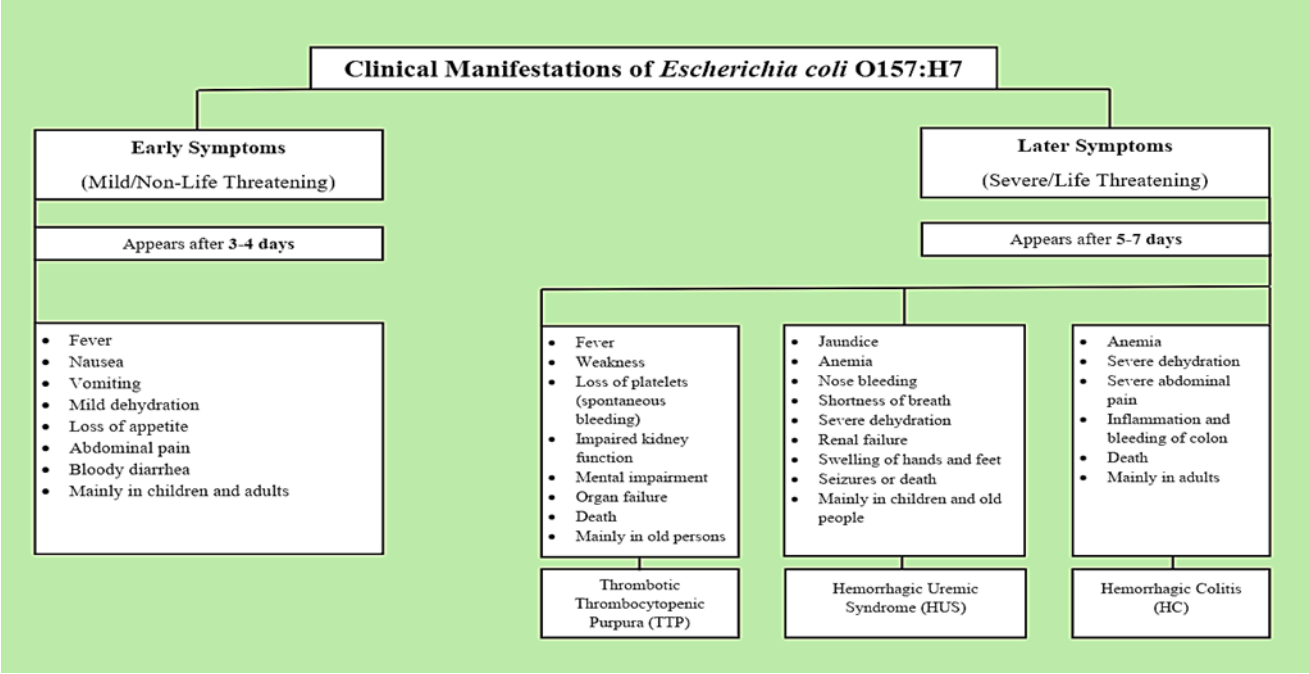

Figure 3. Clinical symptoms of E. coli in humans

2.4 Improper slaughtering, processing, hand ling, transportation and storage practices

Poor personal hygiene of the persons who are handling meat at different stages of meat processing, from slaughtering to transportation, plays central role in the transmission of E. coli O157:H7 to meat and its by-products. Improper processing practices, handling of meat at poorlypoor transportation system, improper and poor hygienic storage practices are major factors involved in transmission of E. coli to beef, mutton and chicken meat (Worku et al. 2022).

2.7 Clinical Manifestations/Health Hazards

E. coli infections range from asymptomatic to severe i.e., hemorrhagic colitis, hemolytic uremic syndrome (Alkeskas et al., 2015; Ameer et al., 2020; Beauvais et al., 2018; Lavrek et al., 2018; Moxley et al., 2020; Tarr et al., 2019) which led to renal failure and death (Mohawk et al., 2010), bloody diarrhea (Ameer et al., 2020; Byrne et al., 2015; Byrne et al., 2018), also cause wide-ranging gastrointestinal symptoms including mild gastroenteritis, abdominal pain and vomiting (Alkeskas et al., 2015; Byrne et al., 2015), urinary tract infection (UTI) (Lavrek et al., 2018; Moxley et al., 2020), hospital-acquired pneumonia (HAP), sepsis, surgical site infection (SSI), meningitis and inflammation of the meninges. It causes infections in cattle which is considered as the principal reservoir and major factor of transmission of E. coli O157:H7 in humans. Figure 3 described the early and later symptoms appear in humans caused as a result of E. coli O157:H7 infection. In 2015, an outbreak of gastrointestinal infection in 47 persons was reported that was associated with intake of contaminated prepackaged salad leaves (Mikhail et al., 2018) while, 800 cases as a consequence of E. coli O157:H7 infections are usually reported in Engl and each year. It was estimated by the Centers for Disease Control and Prevention (2018) that over 63,000 ailments that results more than 2100 hospitalizations and fatalities in U.S.A. Consequently, the medical expenses and fatalities result in economic loss of almost $405 million annually.

Some following common clinical manifestations have observed:

2.8.1 Hemorrhagic Colitis (HC)

Hemorrhagic colitis (HC) is infection of the large intestine; if left untreated, may lead to Hemolytic Uremic Syndrome (HUS. Escherichia coli O157:H7 can cause HC in humans. It occurs when Shiga toxin-producing E. coli O157:H7 infects large intestine causing bloody diarrhea. HC symptoms include severe abdominal cramps, bloody stool and mild or no fever.

2.8.2 Hemorrhagic Uremic Syndrome (HUS)

HUS is critical condition in which blood and blood vessels are affected. One of the major reasons for HUS is infection caused by E. coli O157:H7 (Samad et al., 2018; Abreham et al., 2019; Aondover et al., 2019; Buharshak et al., 2019; Lennox et al., 2020; Osaili et al., 2020) in humans, depicted by hemolytic anemia, renal injury and thrombocytopenia. HUS condition develops when toxins penetrate the intestine, reach blood and damage small blood vessels. There is destruction of platelets which can clog the glomerulus, damaging red blood cells, thereby affecting the kidney's functioning and may lead to renal failure. HUS is usually observed in very old and very young people. Early symptoms of HUS include gastroenteritis, kidney failure and anemia. In UK, the first outbreak of HUS in kids was reported in 1980. Higher number of cases among the children less than 5 years old suffers from infections i.e., hemolytic uremic syndrome as a result of E. coli O157:H7 are reported. HUS almost leads to 1–5% cases of deaths.

2.8.3 Thrombotic Thrombocytopenic Purpura (TTP)

A severe disorder in which blood vessels are blocked with blood clots. If they are left unchecked, they can hinder the blood flow towards major organs. Studies showed that thrombotic thrombocytopenic purpura can be caused by the consumption of contaminated meat with E. coli O157:H7. This life-threatening disease is characterized by the formation of blood clots or red dots under the skin, purplish purpura on skin, fatigue, fever and jaundice. Young women are more susceptible to this disease.

2.8.4 Urinary tract infection (UTI)

Urinary tract infection (UTI) involves the infection of any section of urinary system, it can be cystitis, pyelonephritis, or urethritis. According to the studies, E. coli O157:H7 cause urinary tract infection in humans when bacteria gain access to the urinary tract via the stool excretory route. Prevalence of UTI among the pregnant women vary from 5 to 10% and its symptoms include burning sensation while urinating, fever or chill, pain in back and blood in urine.

2.8.5 Non-Thermal Decontamination Techniques

For preserving food and keeping it free from pathogens, novel decontamination techniques have been introduced to meet the consumer's

needs for better food quality. These techniques are made effective against killing microorganisms and keeping the food quality intact, not bringing any alterations in its nutritional value. Following are mentioned some techniques used in non-thermal decontamination of E. coli O157:H7.

2.8.6 Cold Plasma Inactivation

Cold plasma inactivation is an emerging non-thermal food processing technology directed at inactivating microbes present on food (meat, poultry, fruit, vegetables) using reactive gases like helium, nitrogen, or oxygen. Cold plasma comprises highly energetic species including free radicals, positive/negative ions, excited or non-excited molecules and all these molecules work synergistically in inactivating the contaminating microbes. Atmospheric dielectric discharge cold plasma treatment was tested on chicken breast for checking E. coli O157:H7 decontamination efficacy which was found to be reduced by 0.7 log CFU/cube. Hydroxyl radical (·OH), hydrogen peroxide (H2O2), reactive oxygen species (ROS), peroxyl (ROO·), peroxynitrite ($ONOO^-$), singlet oxygen (1O2) UV photons and electrons produced as a result of cold plasma treatments, which react with the peptidoglycan and lipopolysaccharide present in the cell wall of E. coli O157:H7, breaking C-C, C-N, C-O chemical bonds, disintegrating cell membrane and disrupting the intracellular substances upon entering the cytoplasm, thus ultimately inactivate the bacteria.

2.8.7 High-Pressure Processing (HPP)

It is a non-thermal treatment based on principle of using high-pressure ranges from 400 to 600 MPa with its effect on lethal foodborne microbes like Salmonella, E. coli O157:H7 present in food. It has benefited over cold plasma treatment as it does not break the covalent bonds, thus retaining the food quality and shunning off the use of any food preservative. To avoid the damaging effects of high pressure on food chemistry, this treatment is often combined with natural antimicrobial agents like citral having bactericidal activity present in fruit and leaves of various plants. This bactericidal potency against E. coli O157:H7 enhances the membrane permeability, thereby altering the bacterial cell's morphology leading to its inactivation. Ground beef samples were treated under pressure of 300 MPa, 1% citral, for 15 min and 2.40 log CFU/g initial number of E. coli O157:H7 cells, resulting in 0.40 log CFU/g number of surviving cells. Another study was conducted on chicken meat using the same HPP treatment (350 MPa for 20 min) along with trans-cinnamaldehyde as an antimicrobial agent (0.3%. The number of E. coli O157:H7 cells were reduced to 0.08 log CFU/g from 4.08 log CFU/g.

2.8.8 Electrolyzed Water (EW)

EW is electrically generated hypochlorous acid is among the safe and suitable agents. The acid has strong antimicrobial property, cause the oxidation of bacterial membrane complexes and disturbs the inner cell's electrical discharge and energy production mechanism. This treatment gives good bactericidal results on poultry carcasses, eggshells and vegetables against E. coli O157:H7, Salmonella Enteritidis, Salmonella Typhimurium and L. monocytogenes. The effectiveness of preliminary agent of electrolyzed water i.e., free available chlorine was checked (Veasey and Muriana, 2016) at 250 ppm against E. coli O157:H7 which induced greater than 6 log CFU/g reductions.

3. Disclosure statement

The authors report there are no competing interests to declare.

4. REFERENCES

Abdissa, R., Haile, W., Fite, A. T., Beyi, A. F., Agga, G. E., Edao, B. M., Tadesse, F., Korsa, M. G., Beyene, T., Beyene, T. J., De Zutter, L., Cox, E., Goddeeris, B. M. (2017). Prevalence of Escherichia coli O157: H7 in beef cattle at slaughter and beef carcasses at retail shops in Ethiopia. BMC Infect. Dis., 17(1). https://doi.org/10.1186/s12879-017-2372-2

Al-Ajmi, D., Rahman, S., Banu, S. (2020). Occurrence, virulence genes and antimicrobial profiles of Escherichia coli O157 isolated from ruminants slaughtered in Al Ain, United Arab Emirates. BMC Microbiol., 20(1), 1–10.

https://doi.org/10.1186/s12866-020-01899-0

Albarri, O., Meral, M., Heshmati, B. (2017). Prevalence of Escherichia coli isolated from meat , chicken and vegetable samples in Turkey Prevalence of Escherichia coli isolated from meat , chicken and vegetable samples in Turkey Institute of Natural and Applied Sciences (Fen Bilimleri Enstitüsü), J. Biotechnol. Sci. Res., 4(3), 214–222. http://issrpublishing.com/jbsr/

Alkeskas, A., Ogrodzki, P., Saad, M., Masood, N., Rhoma, N. R., Moore, K., Farbos, A., Paszkiewicz, K., Forsythe, S. (2015). The molecular characterisation of Escherichia coli K1 isolated from neonatal nasogastric feeding tubes. BMC Infect. Dis., 15(1). https://doi.org/10.1186/s12879-015-1210-7

Amalia, A., Apada, A. M. S., Ridwan, R. (2020). Analysis of Escherichia coli O157:H7 contamination in chicken meat sold in traditional markets in Makassar, Indonesia. IOP Conf Ser Earth Environ Sci., 575, 012026. https://doi.org/10.1088/1755-1315/575/1/012026

Ameer, M. A., Wasey, A., Salen, P. (2020). Escherichia Coli (E Coli 0157 H7). In StatPearls. StatPearls Publishing. Available from: https://www.ncbi.nlm.nih.gov/books/NBK507845/

Aondover, G., Charles, O., Moshood, A., Oladipo, O. (2019). Egyp. J. Vet. Sci., 51(1), 43–54. https://doi.org/10.21608/ejvs.2019.17122.1098

Assefa, A., Bihon, A. (2018). A systematic review and meta-analysis of prevalence of Escherichia coli in foods of animal origin in Ethiopia. Heliyon, 4(8), e00716. https://doi.org/10.1016/j.heliyon.2018.e00716

Ayodele, O. A., Deji-Agboola, A. M., Faneye, A. O., Akinduti, P. A. (2020). Characterization and Antibiotic Susceptibility of E. Coli O157:h7 in Meat and Fish Sold in Major Ibadan Markets, Nigeria. Am. J. Biomed. Sci., 12(2), 99–106. https://doi.org/10.5099/aj200200099

Beauvais, W., Gart, E. V., Bean, M., Blanco, A., Wilsey, J., McWhinney, K., Bryan, L., Krath, M., Yang, C. Y., Alvarez, D. M., Paudyal, S., Bryan, K., Stewart, S., Cook, P. W., Lahodny, G., Baumgarten, K., Gautam, R., Nightingale, K., Lawhon, S. D., … Ivanek, R. (2018). The prevalence of Escherichia coli O157:H7 fecal shedding in feedlot pens is affected by the water-to-cattle ratio: A rand omized controlled trial. PLoS One 13(2), 1–21. https://doi.org/10.1371/journal.pone.0192149

Buharshak, O. H., Egah, D. Z., Onyedibe, K. (2019). Isolation of Escherichia coli O157: H7 in Poultry by Culture, Serology and Polymerase Chain Reaction Technique in Jos, North Central Nigeria. Niger. Vet. J., 40(1), 86–94.

Byrne, L., Dallman, T. J., Adams, N., Mikhail, A. F. W., McCarthy, N., Jenkins, C. (2018). Highly pathogenic clone of shiga toxin–producing escherichia coli O157:H7, Englandand Wales. Emerging Infectious Diseases, 24(12), 2303–2308. https://doi.org/10.3201/eid2412.180409

Byrne, L., Jenkins, C., Launders, N., Elson, R., Adak, G. K. (2015). The epidemiology, microbiology and clinical impact of Shiga toxin-producing Escherichia coli in England, 2009–2012. Epidemiol. Infect., 143(16), 3475–3487. https://doi.org/10.1017/S0950268815000746

Centers for Disease Control and Prevention. (2018). Outbreak of Escherichia coli infections linked to ground beef_2018. Outbreak of Escherichia Coli Infections Linked to Ground Beef. https://www.cdc.gov/ecoli/2018/o26-09-18/index.html.

Disassa, N., Sibhat, B., Mengistu, S., Muktar, Y., Belina, D. (2017). Prevalence and Antimicrobial Susceptibility Pattern of E. coli O157:H7 Isolated from Traditionally Marketed Raw Cow Milk in and around Asosa Town, Western Ethiopia. Vet. Med. Int., 2017. https://doi.org/10.1155/2017/7581531

El-Ghareeb, W. R., Abdel-Raheem, S. M., Al-Marri, T. M., Alaql, F. A., & Fayez, M. M. (2020). Isolation and identification of extended spectrum β-lactamases (ESBLs) Escherichia coli from minced camel meat in Eastern province, Saudi Arabia. The Thai Journal of Veterinary Medicine, 50(2), 155-161.

El-Sawah, A. A., Dahshan, A. H. M., El-Nahass, E.-S., El-Mawgoud, A. I. A. (2018). Pathogenicity of Escherichia coli O157 in commercial broiler chickens. Beni-Suef Univ J. Basic Appl. Sci., 7(4), 620–625. https://doi.org/10.1016/j.bjbas.2018.07.005

Haile, A. F., Kebede, D., Wubshet, A. K. (2017). Prevalence and antibiogram of Escherichia coli O157 isolated from bovine in Jimma, Ethiopia: abattoirbased survey. Ethiop. Vet. J., 21(2), 109. https://doi.org/10.4314/evj.v21i2.8

Hemalata, V. B., Virupakshaiah, D. B. M. (2016). Isolation and Identification of food borne pathogens from Spoiled food samples. Int. J. Curr. Microbiol. Appl. Sci., 5(6), 1017–1025. https://doi.org/10.20546/ijcmas.2016.506.108

Kadhum, H. (2020). Experimental infection of escherichia coli O157:H7 with different treatment approaches in chicks. January. https://doi.org/10.13140/RG.2.2.21012.73604.

Lavrek, D., Lava, S. A. G., Milani, G. P., Simonetti, G. D., Bianchetti, M. G., Giannini, O. (2018). Hemolytic-uremic syndrome after Escherichia coli urinary tract infection in humans: systematic review of the literature. J. Nephrol. 31(6), 919–924. https://doi.org/10.1007/s40620-018-0543-x

Lennox, J. A., John, G. E., Echa, C. (2020). Isolation of Escherichia coli 0157:H7 from selected food samples sold in local markets in Nigeria. African J. Food Sci., 14(2), 32–37. https://doi.org/10.5897/ajfs2019.1866

Lien, K.-W., Yang, M.-X., Ling, M.-P. (2020). Microbial Risk Assessment of Escherichia coli O157:H7 in Beef Imported from the United States of America to Taiwan. Microorganisms, 8(5), 676. https://doi.org/10.3390/microorganisms8050676

Luna-Guevara, J. J., Arenas-Hernandez, M. M., Martínez de la Peña, C., Silva, J. L., & Luna-Guevara, M. L. (2019). The role of pathogenic E. coli in fresh vegetables: Behavior, contamination factors, and preventive measures. Inter J Microbiol, 2019

Ma, A., Glassman, H., & Chui, L. (2020). Characterization of Escherichia coli possessing the locus of heat resistance isolated from human cases of acute gastroenteritis. Food microbiology, 88, 103400.

Malvano, F., Pilloton, R., Albanese, D. (2018). Sensitive detection of escherichia coli O157:H7 in food products by impedimetric immunosensors. Sensors (Switzerland), 18(7), 1–11. https://doi.org/10.3390/s18072168

Mikhail, A. F. W., Jenkins, C., Dallman, T. J., Inns, T., Martín, A. I. C., Fox, A., Cleary, P., Elson, R., Hawker, J. (2018). An outbreak of Shiga toxin-producing Escherichia coli O157:H7 associated with contaminated salad leaves: Epidemiological, genomic and food trace back investigations. Epidemiol. Infect., 146(2), 187–196. https://doi.org/10.1017/S0950268817002874

Mitchell, N. M., Johnson, J. R., Johnston, B., Curtiss, R., Mellata, M. (2015). Zoonotic potential of Escherichia coli isolates from retail chicken meat products and eggs. Appl. Environ. Microbiol., 81(3), 1177–1187. https://doi.org/10.1128/AEM.03524-14

Mohawk, K. L., Melton-Celsa, A. R., Zangari, T., Carroll, E. E., O'Brien, A. D. (2010). Pathogenesis of Escherichia coli O157:H7 strain 86-24 following oral infection of BALB/c mice with an intact commensal flora. Microb. Pathog., 48(3–4), 131–142. https://doi.org/10.1016/j.micpath.2010.01.003

Moxley, R. A., Bargar, T. W., Kachman, S. D., Baker, D. R., Francis, D. H. (2020). Intimate attachment of escherichia coli

o157:H7 to urinary bladder epithelium in the gnotobiotic piglet model. Microorganisms, 8(2), 1–9. https://doi.org/10.3390/microorganisms8020263

Ningrum, S. G., Khaerunnisa, I., Wibawan, I. W. T., Wijaya, U., Surabaya, K., Health, V. P. (2020). Molecular detection and phylogenetic analysis of a shiga toxin-producing strain escherichia coli (partial rfbe and flic h7 gene), serotype O157:H7 isolated from a living chicken of a traditional. Bulg. J. Vet. Med., https://doi.org/10.15547/bjvm.2020-0070

Nurliyana, M. R., Sahdan, M. Z., Wibowo, K. M., Muslihati, A., Saim, H., Ahmad, S. A., & Mansor, Z. (2018). The detection method of Escherichia coli in water resources: A review. In Journal of Physics: Conference Series (Vol. 995, No. 1, p. 012065). IOP Publishing.

Odeyemi, O. A., Alegbeleye, O. O., Strateva, M., & Stratev, D. (2020). Understanding spoilage microbial community and spoilage mechanisms in foods of animal origin.

Osaili, T. M., Al-Nabulsi, A. A., Dhanasekaran, D. K., Hasan, F., Rao, S., Fatima, H., Ayyash, M., Holley, R., Obaid, R. S. (2020). Growth behaviour and thermal inactivation of E. coli O157:H7 and Salmonella spp. in ground lean camel meat. Int J Food Microbiol, 316(November 2019), 108423. https://doi.org/10.1016/j.ijfoodmicro.2019.108423

Petersen, F., & Hubbart, J. A. (2020). Physical factors impacting the survival and occurrence of Escherichia coli in secondary habitats. Water, 12(6), 1796

Raeispour, M., & Ranjbar, R. (2018). Antibiotic resistance, virulence factors and genotyping of Uropathogenic Escherichia coli strains. Antimicrobial Resistance & Infection Control, 7(1), 1-9

Rawat, S. (2015). Food Spoilage: Microorganisms and their prevention. Asian J plant sci Res, 5(4), 47-56.

Samad, A., Abbas, F., Ahmad, Z., Tanveer, Z., Ahmad, I., Patching, S. G., Nawaz, N., Asmat, M. T., Raziq, A., Asadullah, Naeem, M., Akhtar, M. A., Pokryshko, O., Mustafa, M. Z. (2018). Multiplex polymerase chain reaction detection of Shiga toxin genes and antibiotic sensitivity of Escherichia coli O157:H7 isolated from beef meat in Quetta, Pakistan. J. Food Saf., 38(6), 1–8. https://doi.org/10.1111/jfs.12540

Sebsibe, M. A., & Asfaw, E. T. (2020). Occurrence of multi-drug resistant Escherichia coli and Escherichia coli O157: H7 in meat and swab samples of various contact surfaces at abattoir and butcher shops in Jimma town, Southwest district of Ethiopia. Infection and Drug Resistance, 13, 3853.

Tarr, G. A. M., Stokowski, T., Shringi, S., Tarr, P. I., Freedman, S. B., Oltean, H. N., Rabinowitz, P. M., Chui, L. (2019). Contribution and interaction of shiga toxin genes to Escherichia coli O157:H7 Virulence. Toxins, 11(10). https://doi.org/10.3390/toxins11100607

Tawyabur, M., Islam, M. S., Sobur, M. A., Hossain, M. J., Mahmud, M. M., Paul, S., Hossain, M. T., Ashour, H. M., Rahman, M. T. (2020). Isolation and characterization of multidrug-resistant escherichia coli and salmonella spp. From healthy and diseased turkeys. Antibiotics, 9(11), 1–14. https://doi.org/10.3390/antibiotics9110770

Underthun, K., De, J., Gutierrez, A., Silverberg, R., & Schneider, K. R. (2018). Survival of Salmonella and Escherichia coli in two different soil types at various moisture levels and temperatures. Journal of food protection, 81(1), 150-157

van Duin, D., Paterson, D. L. (2016). Multidrug-Resistant Bacteria in the Community: Trends and Lessons Learned. Infect. Dis. Clin. North Am., 30(2), 377–390. https://doi.org/10.1016/j.idc.2016.02.004

Veasey, S., Muriana, P. M. (2016). Evaluation of electrolytically-generated hypochlorous acid (‘electrolyzed water’) for sanitation of meat and meat-contact surfaces. Foods, 5(4), 42. https://doi.org/10.3390/foods5020042

WHO. (2020). Food safety. https://www.who.int/news-room/fact-sheets/detail/food-safety

Worku, W., Desta, M., & Menjetta, T. (2022). High prevalence and antimicrobial susceptibility pattern of salmonella species and extended-spectrum β-lactamase producing Escherichia coli from raw cattle meat at butcher houses in Hawassa city, Sidama regional state, Ethiopia. Plos One, 17(1), e0262308.

Xu, A., Scullen, O. J., Sheen, S., Johnson, J. R., Sommers, C. H. (2019). Inactivation of extraintestinal pathogenic E. coli clinical and food isolates suspended in ground chicken meat by gamma radiation. Food Microbiol., 84(July), 103264. https://doi.org/10.1016/j.fm.2019.103264

Yassin, A. K., Gong, J., Kelly, P., Lu, G., Guardabassi, L., Wei, L., Han, X., Qiu, H., Price, S., Cheng, D., Wang, C. (2017). Antimicrobial resistance in clinical Escherichia coli isolates from poultry and livestock, China. PLoS One, 12(9), 1–8. https://doi.org/10.1371/journal.pone.0185326