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Review Article

Microbial Diseases Associated with Consumption of Contaminated Tomatoes and Bell Peppers

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ABSTRACT

Tomatoes (*Lycopersicon esculentum*) and bell peppers (*Capsicum annum*) are two fruits and vegetables that feature widely in the human diet. They are prone to microbial contamination, and spoilage. Bacteria and fungi contamination may go undetected by the food handler or consumer. As such, consumers are at risk of varying disease conditions when these organisms are ingested. Literature has shown certain human pathogens as culprits of fruit spoilage. Known contaminants of these fruits include the genera of *Aspergillus*, *Salmonella*, and *Escherichia* while *Citrobacter*, *Proteus mirabilis* and *Pantoea agglomerans* are reportedly lesser-known contaminants. Diseases resulting from their ingestion could be gastroenteritis, salmonellosis, oesophageal candiditis, haemorrhagic colitis, and mycotoxicosis. This review aimed to highlight the possible infections that could arise from consumption of contaminated tomatoes and bell peppers. A web search was done to determine the human pathogens doubling as spoilage organisms of tomatoes and bell peppers. Elsevier, Pubmed, and other databases were searched using '*food infection, tomatoes, bell peppers, humans, bacteria, and fungi'*. Each selected organism was briefly discussed detailing the infections caused, symptoms, treatment, and epidemiology. Some infections discussed are more common than others, but it is confirmed that tomatoes and peppers can be vehicles of human pathogens associated with infections. More research is required to ascertain the prevalence of these organisms in locally and industrially processed tomato and bell pepper foods and products consumed in Nigeria. Further epidemiological studies are also recommended to determine the disease burden on the populace.

Keywords: Tomato, bell peppers, spoilage, infection, bacterial infection, fungal infection, food poisoning

Introduction

Tomato is an edible fruit and vegetable of the tomato plant *Solanum lycopersicum* L. (*Lycopersicon esculentum*). It is the third most cultivated crop in the world. The vines grow to about 3 feet in height but have delicate stems that cause them to crawl hence they need to be supported. It is botanically classified as a berry, making it a fruit but culinary classifications make it a vegetable.[1,2]
Varieties of tomatoes include beefsteak, plum, cherry, grape, campari, tomberries, and pear tomatoes.
This berry is vulnerable to pests and diseases, but cultivars have been introduced to increase their resistance.[3,4,5,6] The also require cross-pollination to propagate. They provide a great source of umami and savory flavour and are rich in vitamins and sugars, but they are low in fat and protein. They also contain carotenoids like beta-carotene, choline, lutein and lycopene that protect the eye. Tomatoes are rich in folate, calcium, phosphorus, potassium and vitamins A and C.[7]
Commonly eaten raw in sandwiches and salads, tomatoes are also used to make soups and sauces.[6] In vitro studies of Devadas and colleagues demonstrated that consumption of tomatoes can decrease the risk of cancer, maintain healthy blood pressure, and, protect the eyes and skin, while easing constipation due to high fiber and water content.[8]

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Bell Peppers
Bell pepper is also known as Capsicum. It is a fruit of the nightshade family. It is of the species *Capsicum annuum*. The peppers are in varieties of red, purple, yellow, green, and even white. They are also botanically known as fruits and culinary vegetables like tomatoes. The plants are short bushes with woody stems that can grow up to 3ft tall and fruit annually.[9]
Capsaicin is the chemical which causes the 'peppery' feel of heat when peppers are eaten and is measured on a Scoville Scale. Bell peppers do not produce capsaicin due to a recessive gene and so have a heat of zero SHU (Scoville Heat Units).[10]
Bell peppers contain a good amount of fiber, vitamins A, K, C, E and B6. It also contains potassium and folate.[11] They are rich in water, vitamin C and beta-carotene but have much lower content of sugars and infinitesimal fat and protein content. Green peppers have the least nutritional content. Antioxidants like carotenoids are also found in bell peppers. These compounds include lutein, quercetin, capsanthin and luteolin.[12]
Bell peppers possess some health benefits such as improving eye health and preventing anaemia as it is also a source of iron. These fruits may also be an allergen to some people.

Methodology

To conduct this review, previous scholarly works fully accessible online were searched. We combed PubMed, Google Scholar, ResearchGate, and other platforms for reviews and studies related to the aim of this review. Search terms included tomato, bell pepper, humans, infection, and other related terminologies. Papers reviewed were published in English. There was no limit on the age of the reviews and studies evaluated, and no restriction of geographical location was placed on where infections occurred and were documented.

Microbial Food Contamination

Microbiological contamination refers to the unintentional introduction of microbes such as bacteria, fungi, viruses, protozoa or their toxins and by-products. Food contaminants are unwanted microbes found in a certain food which include bacteria and fungi. They can gain access to the food from the air and dust, soil, water and other plants, food handlers and utensils, and cross-contamination.[13]

Actions of food contaminants can lead to food spoilage, which is any change in the condition of food which makes the food become less palatable, or even toxic.[12] The changes may be accompanied by adulteration of organoleptic properties. Mold spoilage is characterized by mouldy growth. Yeasts tend to ferment the fruits, while bacteria spoilage is depicted by souring of the fruits by lactic and acetic acid bacteria.

Microbes gain access to the raw plants during cultivation, growth, harvesting and handling processes if proper measures are not followed but the organism will have to colonize the fruit first by establishing itself on the host before spoilage can ensue.[14]

Contamination may be due to treating soil with organic fertilizers, such as untreated sewage sludge and manure, and from the irrigation water. The ability of pathogens to persist and proliferate in vegetables can also cause contamination. The incidences of the organisms on the fruits may be due to poor market sanitation, unhygienic sellers, dirty vessels, and polluted atmosphere.[15]

In many parts of the world where tomatoes and bell peppers are consumed, recipes require them to be blended, pureed, boiled, fried, juiced or cut into pieces.

For the recipes that call for homogenizing of the fruits, cooks are more likely to select fruits that are undergoing spoilage already even though some spoilt pieces may have been cut out. The healthier looking fruits are kept for foods that require them as close to their whole form as possible. This implies that contaminated fruits are regularly introduced into home and organizational cooking and pathogens can persist at high temperatures.[16] Low-income earners are more likely to select such fruits as sellers are eager to dispose of them at a cheaper price.[17] These factors thus show that infections can arise if cooking methods do not deactivate the spoilage microorganisms and if conditions are right in the host for colonization to take place.

Vectors of microbial contamination of tomatoes and bell peppers

For tomatoes and bell peppers to get contaminated, microorganisms have to gain access to the fruit along the stages of cultivation and right to the moment of consumption. Along this chain is a wide option of contamination routes.[13]

Soil

The soil is a major habitat to myriads of organisms. Effect of irrigation, splashing and rainfall can cause soil particles to adhere to edible plant parts. These particles may contain pathogenic microorganisms which contaminate the fruits.

Water

This is used for a lot of agricultural processes and may be sourced from various options like ground water or wastewater. The quality of water used determines the likely microbial pollution and consequent contamination.

Extreme weather

Heavy rainfall can cause run off of water, soil and waste. Drought also permits some organisms that can survive the dryness such as the Clostridia to survive. In addition, humidity, cold, wind and heat make conditions suitable for microorganisms to persist on the fruits and gain access into the fruit.[13]

Harvest

The method of harvest used may introduce microorganisms into the plant. Picking by hand, use of machinery, shearing or ripping of the fruits may introduce organisms to various degree. The fruits may sustain injuries which allow microbes to access the inside and repeated use of same equipment may transmit organisms among the fruits.

Sorting and processing

Selecting healthy fruits from others can give room for contamination of surfaces of healthy fruits as the workers move the fruits around in the container. All work surfaces and equipment are likely routes of contamination. The final product may be contaminated to some degree if organisms within the seeds and edible plant parts are able to survive the production process.[18]

Transport and packaging

The vessels and vehicles used for transport are likely routes of contamination. Maintenance of optimum conditions for preservation may be challenging, thus allowing microbes to thrive. The material for packaging may inhibit some microbes and permit others on the material or within the product.[19]

Food handlers and consumers

Infected handlers can shed microbes onto the fruits. There is also the risk of fecal contamination if hygienic practices are not duly followed. The method of home and industry preservation of products like salads, sauces and juices also determines the possibility of contamination. Cross-contamination can occur in the course of food preparation and the final product to be consumed becomes contaminated.[20]

Selected Microbial Contaminants of Tomatoes

The highwater activity (> 0.95), and low pH of tomatoes makes them good candidates for microbial contaminants which can in turn harm the unsuspecting human consumers.[6,17] Spoilage of tomatoes is commonly by fermentation due to *Aspergillus, Rhizopus* and *Penicillium*. Fungal rot is caused by *Alternaria, Fusarium,* and *Rhizopus* while *Clostridium butyricum* causes butyric fermentation.

Based on the research by Ugwu *et al*.[21], spoiled tomatoes are contaminated by *Candida tropicalis, Rhizopus stolonifer, Lichtheimia corymbifera, Escherichia coli* and *Salmonella spp*. Obeng *et al*.[15] isolated other organisms causing spoilage of tomatoes including *Citrobacter, Enterobacter, Proteus mirabilis,* and *Shigella.* Ghosh[4] confirmed *Fusarium, Aspergillus,* and *Penicillium* as contaminants of tomatoes. In addition, *Alternaria alternata,* and *Geotrichum candidum* were other fungi detected.[1,22] *Pantoea agglomerans* was isolated by Harding[23]. Obunukwu *et al*.[6] confirmed the bacteria contaminants already listed while also identifying potential diseases that can be contracted from spoiled tomatoes to include meningitis, diarrhea, gastroenteritis, and respiratory infections.

Selected Microbial Contaminants of Bell Peppers

Moist conditions during harvesting and transport make bell peppers prone to soft rot by bacteria and mold growth by fungi. Pepper has a water activity of about 0.99-0.98 which makes it liable to microbial spoilage.

Puran *et al*.[24] identified *Listeria monocytogenes, Staphylococcus aureus, Escherichia coli* and *Clostridium perfringens* as contaminants and spoilage organisms of peppers. Akinyemi and Liamngee[25] isolated *Fusarium oxysporum* and *Aspergillus niger* from peppers. *Geotrichum candidum, Penicillium sp.* and *Fusarium sp.* have been reported by Frimpong *et al*.[26] while *Rhizopus stolonifer* and *Alternaria alternata* were reported by Ademoh *et al*.[12] Ugwu *et al*.[21] found *Candida tropicalis* and *Lichtheimia corymbifera* to be contaminants of pepper. *Salmonella* and *Escherichia coli* were established by Soto-beltran *et al*.[18] as prevalent on bell peppers and *Pantoea agglomerans,* and *Citrobacter sp.* were isolated by Negbenebor *et al*.[27] *Proteus mirabilis* was isolated from green peppers by Al-Mijalli *et al*.[28] and *Shigella* was isolated by Guchi & Ashenafi[29].

Fungal Pathogens and Diseases Associated with Consumption of Tomatoes and Peppers

Candida spp.

This is a dimorphic and opportunistic fungus found in foods and fruits like tomatoes and peppers, as well as on plants and in the gastrointestinal tract of humans. They are commensals but the

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Candida genus can cause harm if overgrowth occurs.[30] Foods with high sugar concentrations can cause overgrowth. Tomato products like candies and purees, can have higher concentrations of glucose, galactose and fructose. The sugars provide over 60% of their dry matter content, thus overgrowth of the fungus can lead to a variety of digestive disturbances. A prominent infection of this organism is Oesophageal candiditis. It is caused by a change in the conditions of the esophagus. Immunocompromised individuals like patients of diabetes, blood cancers, and HIV/AIDS, smokers, antibiotic users, and steroid inhaler users are at risk.[31] Its symptoms include white lesions on the lining of the distal third of the esophagus that resemble cheese, painful swallowing, nausea, vomiting, weight loss, and a dry mouth.[32] Complications include sepsis and fistula. The condition can be diagnosed by an endoscopy. Medical treatment options include Nystatin, Clotrimazole, Itraconazole, fluconazole and Amphotericin B. The thrush can spread to other organs including the liver, lungs and intestines if untreated. Prevalence of the infection varies within the assessed group but HIV-patients, and African Americans over 65 years old are at greater risk of infection.[33,34] The study of Devadas *et al*.[8] revealed antifungal activity of crude tomato extracts against Candida species screened.

Aspergillus spp.

These belong to the Ascomycota and are found in soil, plant detritus and fruits. They cause black rot in many plants and fruits including peppers,[25] and are found in fresh tomato and peppers as well as their pastes.[26] Members can produce mycotoxins which are harmful to the consumers. *Aspergillus niger*, and *A. fumigatus* are common contaminants of tomatoes and peppers and identified by a white to yellow mat bearing black conidia. They may be available in sufficient quantity from cooked food like tomato stews or sauces as most mycotoxins are not destroyed by food preparation methods.[26] Aflatoxicosis could result from ingestion of aflatoxins. Aflatoxins in foods can be due to post-harvest contamination of the food crop with the molds. Improper storage conditions such as high humidity can be a contributing factor.[35] Children and Hepatitis patients are most susceptible to this infection. Acute Severe intoxication and Chronic subsymptomatic exposure are the two forms of aflatoxicosis. The former results in liver damage which can cause complications leading to death. It is characterized by anorexia, fever, vomiting, abdominal pain, jaundice, pulmonary edema, convulsions, liver cancer and hepatitis. Supportive care, stress management, blood transfusion, and therapy for the cancers are common treatment options. Tomatoes assessed by Okigbo and Anene[16] were found to be naturally contaminated by aflatoxins B1, B2, G1 and G2. Gut aspergillosis was established in 21 immunocompromised patients by Kazan *et al*.[36] Aflatoxins have caused significant mortality in Kenya[37] and have been frequently isolated from tomatoes and peppers.[26,38,39] Mwanda *et al*.[41] reported a case of acute aflatoxicosis in a 17year-old boy. In contrast, Mariutti & Soares[40] did not detect aflatoxins in their studies on tomato products.

Penicillium spp.

These are saprophytic molds made up of colourless septate hyphae that reproduce with the aid of ascospores and thrive in low humidity. They have been isolated from tomatoes and peppers as likely spoilage organisms.[12,26,5] Many species produce poisonous mycotoxins such as patulin, citreoviridin, citrinin, penitrem A and ochratoxin A which can cause convulsions, cancers, hepatitis, brain haemorrhage, vomiting, and liver and kidney damage.[42,43] It causes mycotoxicosis. Food poisoning by *Penicillium* presents with dizziness, gastralgia, diarrhea, stomach inflammation and malaise. Patients recover within 3 days. It is worrisome for weakened individuals, causing other infections like endophthalmitis and bronchiolitis.[44] and can be treated by detoxification, surgical debridement, and immune and nutrient therapy. Patulin and citrinin were detected in decaying tomatoes by Harwig[45] obtained from Canadian households. It was postulated that the tomatoes were contaminated during refrigeration. These mycotoxins have been implicated in other foods like cereals, nuts, spices, other fruits and vegetables.[42]

Fusarium spp.

This ascomycetes fungus is harmful to plants. It is ubiquitous in the soil and marine environment and causes fusarium wilt in tomato and pepper. About 15 species of *Fusarium* are known to infect humans and they have a low survival rate particularly among patients with underlying conditions.[46] Nucci & Anaissie[48] reviewed *Fusarium* as a pathogen of skin and eye infections which may be superficial, locally invasive or disseminated. Fusarium causes mycotoxicosis. The mycotoxins include zearalenone, trichothecenes, deoxynivalenol, equisetin and fumonisins. Children are highly susceptible to infection as the toxins target growing cells. Fumonisins have been linked to neural tube defects.[37] Emesis, pulmonary edema, diarrhea, abdominal pain, myalgia and shock are some symptoms. It can also be fatal. Voriconazole and Posaconazole are usual treatment options. Over a hundred people in China contracted *Fusarium* mycotoxicosis on ingestion of mouldy rice.[47] Deoxynivalenol toxin was suspected in the outbreak of gastroenteritis in the US in 1998 from consumption of contaminated burritos; over a hundred children fell ill.[37] *Fusarium* contamination has been most established in wheat and other grains.[46] Nelson *et al*.[49] reported the outbreak of alimentary toxic aleukia from *Fusarium* mycotoxins which was responsible for the death of many soldiers in the USSR within the 1940s and 50s.

Rhizopus spp.

This is a dimorphic, opportunistic black bread mold. It spoils foods stored indoors and is found in the soil, feces and air. It decomposes peppers and tomatoes. Infection with the fungus is rare in healthy individuals as immunocompromised patients, particularly, diabetics, are the most susceptible.[50] Inhalation of the spores when smelling food to ascertain spoilage, and ingestion of spores can cause infection. It causes gastrointestinal zygomycosis in immunosuppressed and malnourished individuals. Abdominal pain, swollen appendix, distension associated with nausea, fever and vomiting are characterizing symptoms. It mostly affects the stomach, colon and ileum. It is diagnosed by an endoscopy or a biopsy. *Rhizopus* infection may be highly fatal. Amphotericin B, antifungal therapy, and surgery which is done to remove the infected tissue to ensure recovery, could manage the disease. Contamination of probiotic dosage by *Rhizopus* led to the fatality of a neonate with gastrointestinal mucormycosis and home-brewed beer was also implicated in this infection.[51] A nosocomial outbreak of *Rhizopus microsporus* infection in Hong Kong was associated with contaminated ready-to-eat food.[52] Gastric ulcer caused by *Rhizopus arrhizus* was reported by Ribes *et al*.[50] as well as other gastrointestinal illnesses caused by *Rhizopus*.

Lichtheimia (Absidia) corymbifera

This is a pale grayish white, saprophytic thermophilic fungus producing small, dark spores within its sporangia. It is found in the soil, air, plant detritus, on food, and farm animals. They are implicated in tomato and pepper contamination. Infection is most commonly by ingestion of spore-contaminated food and inhalation of spores.[50] It can also be transmitted nosocomially. Gastrointestinal mucormycosis in immunosuppressed individuals could occur although infection can arise rarely in healthy people. Symptoms include abdominal pain, nausea, dyspepsia, vomiting, bloody diarrhea, upper GI bleeding, abdominal distension, intestinal obstruction, and perforation peritonitis. The infection has a high mortality rate. Posaconazole, Amphotericin B and surgical debridement are usual treatment options. Mucormycosis has been known to arise when trauma like a road accident, is sustained such as the case reported by Neelaveni *et al*.[53] Benedict *et al*.[51] reported a case of mucormycosis from probiotics. Ribes *et al*.[50] reported *Absidia corymbifera* as an opportunistic pathogen in a cancer patient, and another from injuries with spore-contaminated farm equipment while Choi *et al*.[54] reported the fatal case of *Absidia* zygomycosis mimicking appendicitis.

Alternaria alternata

This mycotoxin-producing saprophytic fungus is a common pathogen of fruits including tomatoes and peppers (internal rot), gaining entrance through injuries and openings.[55] It mainly attacks fruits during transport and storage. Tenuazonic acid (TeA) is a toxic

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metabolite of the fungus detected in tomato juices, sauces and products.[40] TeA is associated with hematological disorders in Central and Southern Africans.[56] Other toxins produced by the genus are alternariol (AOH), altenariol monomethyl ether (AME), altenuene (ALT), and tentoxin (TEN).[57] It is responsible for a major disorder, Onyalai (blood blister) which spans all age groups.[56] Abnormal level of platelets (thrombocytopenia), malaise, general aches, and headaches have been recorded as initial signs. It leads to hematoma on mucus membranes, hemorrhagic lesions on the skin and hematuria. The patient could suffer from petechia, epistaxis and hemorrhagia. Excessive bleeding could result in shock and death as Onyalai is highly fatal. Treatment is by splenectomy, administering blood transfusions, vitamins and increasing platelet count. Tenuazonic acid was detected by Harding *et al*.[23] in tomatoes from Canadian households. Sanzani *et al*.[58] found alternaria toxins in fresh and dried tomatoes. Santos *et al*.[55] assessed tomato pastes, pulps and ketchup for *Alternaria* toxins and detected alongside the toxins, foreign material like rodent hair, insect fragments and mites. *Alternaria tenius* is known to cause convulsions and haemorrhage from contaminated tomato paste.[37] The toxins have also been linked to esophageal cancer in China and have been isolated from tomato sauces, pepper, and other fruits, nuts and seeds.[57]

Geotrichum candidum

This belongs to the ascomycota. It is a human commensal widely found in the environment. It is a common food spoilage organism of tomatoes and peppers. It is soft and creamy in texture.[59] *G. candidum* is implicated in opportunistic infections of animals and humans.[60] It can lead to gastrointestinal geotrichosis. It has high incidence in already weakened individuals and is diagnosed with a blood culture test and microscopy. Loss of appetite and weight, dullness, fever, hemoptysis, diarrhea, abdominal pain, blood and mucus in stool and increased pulse rate are common symptoms. There is also inflammation of the small intestine and colon. Oral geotrichosis is sometimes mistaken for *Candida* thrush. There are white plagues in the mouth that present a burning sensation. Nystatin, clotrimazole, Amphotericin B, and ketoconazole resolve the infection. It is found worldwide and affects both animals and humans of all age groups. It can be fatal on dissemination. Bonifaz *et al*.[60] did a retrospective study of 12 cases of geotrichosis and identified *G. candidum* from almost all patients screened. Keene *et al*.[62] reported a case of geotrichosis in a severely burned patient and speculates that *G. candidum* can be a true pathogen. Gastrointestinal geotrichosis usually follows glutamic acid therapy. Geotrichosis could also be oral, vaginal or bronchial.[59] Cutaneous geotrichosis in an 80year-old man with diabetes mellitus was reported by Sfakianakis *et al*.[63] Amft *et al*.[64] has reported disseminated *G. capitanum* infection in a patient with non-Hodgkin's Lymphoma.

Bacterial Pathogens and Diseases Associated with Consumption of Tomatoes and Peppers

Escherichia coli

These Gram-negative rod-shaped organisms can penetrate tomato and peppers through natural openings or wounds and become internalized pathogens. It is an enteric organism. *E. coli* 0157:H7 is one major virulent strain of the genus which can cause infection in fruits like tomatoes and peppers, and in man on ingestion due to its Shiga toxin.[65,66] It survives for long periods in water, soil, and refrigerators as well as dry areas. Few inoculums of the bacterium is needed for successful infection especially in susceptible people. Tomatoes and peppers become contaminated by *E. coli* from contaminated irrigation water, farms, markets and untreated manure.[67,18] An infection it causes is hemorrhagic Colitis which affects all ages of people. Its symptoms present within three days. They include bloody watery diarrhea, abdominal pain, thrombocytopenia, dehydration and fever. Complications such as Hemolytic Uremic Syndrome may result, causing damage to the excretory organs. HUS can lead to seizures, stroke and coma. It is diagnosed using stool tests. Drinking fluids or administering such intravenously as antibiotics decrease the chances of HUS. No published data on *E. coli* infection associated with tomatoes was found but it has been shown to infect tomato plants and affect their yield,[19] thus posing a likely route of contamination and human infection. Al-Kharousi *et al*.[68] reported an outbreak of Shiga-toxin producing *E. coli* O104: H4 that led to almost 3,000 cases of gastroenteritis from contaminated fenugreek sprouts in Germany. Over 50,000 deaths were attributed to ETEC infections in 2016.[69]

Salmonella spp.

This Gram-negative warmth-loving enteric organism is present in the soil, irrigation water and manure,[70] and can be taken up by the roots of tomato plants during cultivation.[19] It is carried by domestic animals and birds and is also an established contaminant of peppers.[18,29] It causes enteric Salmonellosis. The disease can last for about a week. It may be self-limiting. Diarrhea, abdominal pain, bloody stool, vomiting, nausea and fever are significant symptoms. The complications include dehydration, bacteremia, and reactive arthritis. A stool sample is used for diagnosis as *Salmonella* is shed in feces. Antibiotics and rehydration speed up recovery. At least 82 persons in Sweden were infected with *Salmonella* linked from tomatoes in August of 2019.[71] Seven persons got ill in 2004 after eating *Salmonella*-contaminated Roma tomatoes at a restaurant.[72] Ford *et al*.[73] reported about 990 outbreaks of *S. enterica* of which 778 were food-related. The prevalence of Salmonella on food handlers in Osogbo, Osun state, was researched by Olalekan *et al*.[74] and 4.2% of respondents were positive.

Citrobacter freundii

This is a Gram-negative coliform that has been found to cause food spoilage and food poisoning. Tomato is an implicated food, but pepper has not been firmly established. It is an opportunistic pathogen implicated in septicemia, UTIs, wound infections and meningitis.[75] This enteric organism of humans and animals is also found in water, soil, feces and sewage. Food handlers with poor personal hygiene could be a factor for transmission. Citrobacter may be inhibited by citric acid,[76] when added to tomato products. It can result in Citrobacter gastroenteritis, an intra-abdominal and bloodstream infection that induces diarrhea due to its production of heat-stable and Shiga-like toxins. It presents with diarrhea, abdominal cramps, nausea, vomiting, fever, chills, headache, tenesmus, dizziness, and fainting. A complication is Hemolytic Uremic Syndrome. Cephalosporins, fluoroquinolones, and carbapenems are antibiotics of choice. Citrobacter are mostly implicated in nosocomial infections and can also be transmitted vertically.[77] Citrobacter outbreaks are mostly during summer months and enhanced by dust pollution.[78] Gastroenteritis with HUS occurred in 36 persons who consumed contaminated sandwiches in a nursery school in Germany.[79] There was one fatality.

Listeria monocytogenes

These are Gram-positive bacilli found in meats, dairy, fruits, and vegetables.[80] Infection may be fatal to weakened individuals. It can persist in improperly cooked or raw tomato contaminated from the soil, and in seeds of red bell peppers.[81] It thrives optimally at a water activity of 0.97 thus making tomato fruits a good substrate. Listeriosis could result. Two forms of listeriosis exist. The non-invasive listeriosis may cause mild disease while the invasive kind could cause fatalities. Invasive listeriosis presents with the organism in the blood and CNS fluid. It can infect the uterus and cervix of pregnant women and cause spontaneous abortion.[82] Diarrhea, fever, muscle pain, chills, nausea, vomiting, convulsion, confusion and fatigue indicate infection. Penicillin, Ampicillin, Gentamicin and Amoxicillin are given for antibiotic treatment. In 2016, there were listeria outbreaks linked to contaminated frozen vegetables and packaged salads and some fatalities were recorded.[83,84] Cantaloupe melons, raw sprouts, peppers, onions, stone fruits and apples have also been reported by Desai *et al*.[85] as vehicles of *L. monocytogenes.* Milk and milk products in Nigeria have been identified by the FDA as carriers of Listeria and about 1600 cases of infections are reported annually from the USA.[86]

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Proteus mirabilis
This is a Gram-negative organism that has a unique swarming ability. It is found in urine, soil, feces and water. Proteus has been identified as a potential pathogen in Crohn's disease and Ulcerative colitis.[87,88] Foodborne gastroenteritis could result. Nausea, diarrhea and vomiting are major symptoms. Patients with underlying gastrointestinal infections are more prone to secondary infections by Proteus. The infection is diagnosed by running tests on samples from stool, rectum and vomitus swabs. It is frequently mitigated with penicillin, ciprofloxacin, and gentamicin. Vegetable salad containing *Proteus* and other organisms was implicated in a food poisoning outbreak at Ambrose Alli University, Ekpoma.[89] Eight people were poisoned in 2005 by *P. mirabilis* in tomato puree.[90] Stewed pork contaminated with *Proteus* led to an outbreak in China.[88] In a case report by Cherry *et al*.[91], sliced baked ham was the vehicle of transmission of *P. mirabilis*. The outbreak occurred in a naval officers' mess in 1944.

Shigella spp.
These are Gram-negative rods that infect primates. They are a leading cause of diarrhea worldwide. Tomatoes and peppers[29] fertilized with untreated human waste could have *Shigella* on their surfaces.[92] Food handlers may spread the infection via unsanitary handling of vegetables.[93] Little inoculum is sufficient for the infection, Shigellosis (bacillary dysentery). Cramps in the stomach and lower abdomen, watery/bloody diarrhea, flatulence, vomiting and fever occur about two days after ingestion. It induces inflammation and death of cells in the colon. Dehydration can occur in cases of severe diarrhea and seizures, especially in young children. Individuals with AIDS are also prone to the disease. Shigellosis is self-limiting but rest and increased fluid intake help recovery. *Shigella flexneri* was implicated in a large outbreak of Shigellosis linked to tomatoes in 2001.[93] Tomato salad was the source of an outbreak of *S. sonnei* in India.[94] Shigella is responsible for about 200,000 deaths yearly.[69] Outbreaks of Shigella have been recorded on cruise ships, restaurants and ceremonies. Within 1998 and 2008, 120 outbreaks of food-related Shigellosis were recorded.[95]

Clostridium spp.
These are anaerobic spore-forming Gram-positive organisms notorious in the canned food industry. Home-canned tomatoes are at risk of growing these organisms.[96] They can grow in products with pH of about 4.5 and at warm to cold temperatures. *C. butyricum, C. perfringens and C. botulinum* are implicated in canned tomato spoilage.[97] Canned tomatoes spoiled by *C. butyricum* swell, are frothy, and full of gas and butyric odours. *Clostridium perfrigens* is the most common specie infecting fresh, and dried peppers.[98] *C. botulinum* produces the botulism toxin which is highly fatal. It is the most dangerous specie. *C. botulinum* symptoms present within 6 hours to 10 days. It causes blurred double vision, difficulty swallowing and speaking, gastrointestinal symptoms, heart attack and flaccid paralysis. *C. perfingens* causes diarrhea, nausea, vomiting and severe abdominal pain after large numbers of cells are ingested in food and its Clostridium Perfringens Enterotoxin (CPE) enterotoxin is released.[99] The infection lasts for about two days.
Prevention of *C. butyricum* is by thorough washing of the tomatoes, with pH and temperature control. Spores are destroyed at 93°C for 5-10 mins at pH 4-4.3 and Citric acid should be added to reduce the pH to 4.6 at least.[97] Administration of an antitoxin and intravenous fluids may stimulate recovery. Loutfy *et al*.[96] documented an outbreak of botulism linked to tomato sauce consumed at a family meal. Rennie *et al*.[100] reported an outbreak of *Clostridium perfringens* from a cafeteria meal which was later found to be due to *Klebsiella pneumoniae*. Meat-containing foods like soups and stews have been implicated in *C. perfringens* outbreaks. It has been associated with corned beef, chicken curry, and salmon.[99] Outbreaks of foodborne botulism totaling 197 were recorded by Fleck-Derderian *et al*.[101] with over a hundred fatalities. *C. butyricum* was the causative agent of botulism in 34 Indian schoolchildren that led to three fatalities.[102]

Staphylococcus aureus
This is a Gram-positive coccoid bacterium frequently isolated from the surface of tomatoes as a spoilage organism. It produces enterotoxins and thrives at a_w greater than 0.83.[103] It may be transferred to tomatoes during harvesting and packaging. Ingested tomatoes such as contaminated fresh tomato slices in sandwiches may lead to disease. Proper sanitary measures, if followed by food handlers, particularly in restaurants, may help prevent an outbreak.[104] It causes Staphylococcal food poisoning. The samples isolated by Carmo *et al*.[20] showed enterotoxins A, B, and D. The screened food handlers were the likely source of contamination. Common symptoms are nausea, vomiting, stomach cramps and diarrhea. Infection usually lasts a day.[103] Infection poses more danger to infants, elders and HIV patients as they may have severe dehydration. Rehydration is the best course of treatment. Denison *et al*.[105] detailed an outbreak of *S. aureus* food poisoning in a high school from contaminated cream puffs produced in a highly unsanitary environment. About 31 people in a restaurant at Brazil became infected 30 minutes after a meal containing tomato sauce.[20] *S. aureus* causes over 200,000 food-related illnesses in the US annually.[104] *S. aureus* was the second highest prevalent organism on tomato in the investigation of Wu *et al*.[106] and was reported to be implicated in contamination of chicken, rice cereal, infant formula, cheese, and leafy vegetables.

Pantoea (Enterobacter) aglomerans
This is a yellow Gram-negative rod, commensal and opportunistic human pathogen.[107] It is found in water, soil, sewage, vegetables, seeds, feces and foodstuffs. Telias *et al.*[108] found *Enterobacter* to be abundant on the surface of tomatoes. They were also shown on peppers by Harding *et al*.[23] Pantoea is found in association with Gastroesophageal Reflux Disease (GERD) when infected vegetables are consumed and there is absence or imbalance of stomach acidity.[109] It causes severe infections in young children and previously ill individuals such as diabetics and hepatitis patients. Its symptoms are gastrointestinal problems, anaemia, hypotension, shock, vomiting, fever, dehydration and bloody diarrhea and is treated with Ceftriaxone, Ceftazidime and Levofloxacin. Electrolyte replacement drinks, broths, or breast milk (for babies) should be administered to minimize dehydration. The infection may not require antibiotics to treat. Cruz *et al*.[110] identified *Pantoea* as the culprit in 53 pediatric cases and a nosocomial outbreak in Brazil found children infected with *Pantoea* isolated from the transference tube.[111] Mardaneh & Dallal[112] found it to contaminate infant formula milk. Dutkiewicz *et al*.[113] reviewed cases of *Pantoea* infections linked to trauma from plant material. The case of an infected diabetic male was presented by Kaur *et al*.[107]

Current Challenges
Literature reveals that the presence of the aforementioned organisms in fresh, processed and cooked tomatoes and bell peppers and their products poses challenges to public health and the food industry in the following ways.

High incidence
There have been at least 3,231 reported cases of infections from tomatoes between 1980 and 2016[13] which gives a cause to worry as there is a growing demand for fruits and vegetables in people's diet. This poses the challenge of keeping the infection rate to the barest minimum from the farm and through food handlers and consumers.

Self-limiting infections
Many of the infections run their course and some infected individuals may not be able to trace the source of infection. The short time of infection also prevents people from seeking professional assistance as the disease may have resolved before they visit the hospital. This impedes the efforts to get an accurate disease burden as many cases thus go unreported.

Limited healthcare resources
Many communities and settlements, including cities may lack sufficient resources to carry out research, diagnosis and treatment.

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Some health centers may be understaffed, over-burdened, have managerial challenges or outdated/non-existent equipment. This prevents health workers from delivering their full potential to patients, leaving many cases unattended or unrecorded.

Wrong diagnosis

In the advent of enough resources to run tests, many health workers implicate frequently encountered organisms like *Staphylococcus aureus*, *Candida* spp. and *Escherichia coli*. This is probably due to similar diagnostic methods and results with subtle differences in organisms which may go unnoticed by a non-vigilant health worker. Such patients are then misdiagnosed, wrongly treated, and the wrong organism is implicated. A case was presented by Rennie *et al*.[100] where *Klebsiella pneumoniae* gastroenteritis was initially attributed to *Clostridium perfringens*.

Delayed diagnosis

Traditional diagnostic methods are time-consuming. It is possible for symptoms of patients to have evolved, even leading to irreversible or fatal conditions before the pathogen is isolated and identified and a treatment course is started. In some cases, sampling and retesting has to be done repeatedly at the expense of the patient. This leads to infections progressing at undesirable rates and an increase in potential fatalities.

Conclusion and Recommendations

This review has highlighted some infections that could occur as a result of consumption of tomatoes and bell peppers that have been infected with spoilage and human pathogenic bacteria and/or fungi. Microorganisms are regular spoilage agents and contaminants of tomatoes, bell peppers, as well as their various products and derivatives. Many gastrointestinal diseases have been linked to the consumption of contaminated tomatoes more commonly than peppers. Thus, adequate food preparation and storage methods are required to reduce the incidence of these microorganisms especially on minimally processed foods.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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