Nutritional Significance and Parasitic Contamination of Vegetables: A Comprehensive Review

Abstract

Vegetables are plants consumed whole or in parts. Furthermore, they have long been recognized as a significant source of sustenance. The current study reviews vegetables' nutritional attributes and health benefits. This paper also outlines the main parasites that cause vegetable contamination. Moreover, vegetable components, such as leaves, stems, roots, bulbs, seeds, and fruits, can be used to feed humans. In addition, they have relatively few calories to consume regularly. It also contains a lot of water and fiber. The World Health Organization advises consuming 400 grams of non-starchy veggies daily to enhance general health. Vegetables have an essential role in disease prevention and therapy. Their consumption lowers the risk of many cancers, regulates blood pressure and heart disease, avoids blocked arteries, fights obesity, improves cardiovascular health, improves skin health, and promotes digestive health. Nonetheless, vegetables are a major cause of foodborne diseases in both people and animals. It can, for example, constitute a route for the transmission of numerous parasites infections. For instance, they may be a route of transmission for various parasitic pathogens. Several investigations and study projects have documented the contamination of numerous kinds of vegetables with parasites that are liable for transmitting diseases, including *Entamoeba histolytica*, *Giardia lamblia*, *Cryptosporidium* spp., *Strongyloides* spp., *Ascaris lumbricoides*, *Enterobius vermicularis*, *Trichuris trichiura*, *Toxocara* spp., *Toxoplasma gondii*, and plenty of others. Numerous hypotheses have been proposed to explain vegetable contamination with these parasites. Some of these include the use of contaminated water for irrigation, contamination from the soil, exposure to environmental factors like rain and wind, transmission by animals and insects acting as vectors for parasites, contamination during harvesting, processing, and storage, as well as during transportation of vegetables to markets. To mitigate these risks, it is crucial to enhance hygiene practices, promote education and awareness, and foster a clean culture. Additionally, using clean water and proper tools is recommended. Washing vegetables thoroughly before consumption reduces parasite-related infections.

Key words: vegetables, nutritional value, parasites, contamination, foodborne diseases.

1- Introduction

The origins of the word "vegetables" are disputed among sources. One suggestion is that during the Middle Ages, the word originated from a Latin term which conveyed the idea of plants growing and thriving. Over time, it evolved from a late Latin word that meant stimulating and speeding up. Eventually, the term "vegetables" refers to plants cultivated for food consumption [1]. An additional definition of vegetables aligns with the previous one, referring to plants cultivated for consumption. This definition encompasses plants whose edible parts or components are consumed, and also includes vegetables and fruits [2]. Furthermore, the Asian Centre for Research and Development of Vegetables agreed on vegetable explanations. They defined vegetables as edible plants that are typically juicy or have parts that are consumed alongside primary foods as a main dish. In addition, they can serve meals as a supplement. Vegetables can be consumed either cooked or raw. Despite over 10,000 plant species consumed globally as vegetables, only around 50 are commercially significant. It is worth noting that while mushrooms are classified as fungi, they can also be considered vegetables [3, 4]. Obviously, a broad understanding of the term 'vegetable' is an important aspect of the diversity of vegetable crops. As a result of this ambiguity, we can refer to vegetables as any vegetable component that is taken as food and does not fit under the category of mature fruits or seeds. Petioles (celery, *Apium gravel*), whole leaves (lettuce, *Lactuca sativa*), and early fruits (cucumber, *Cucumis sativus*), roots (carrot, *Daucus carota*), and specialized structures such as bulbs (onion, *Allium cepa* group) and tubers (white potato, *Solanum tuberosum*) [5].Vegetables, as mentioned before, are edible plant portions that nourish people and animals. This vegetable is thought to have originated in hunting communities, which defined the practice of harvesting wild plants and grew in popularity between 10,000 and 7,000 BC. Furthermore, it is grown in several areas. Nowadays, climatic circumstances have a significant impact on vegetable production, and crop farming is both useful and influenced by the environment. Vegetables, on the other hand, are low in fat and carbs while high in nutrients such as vitamins, minerals, and fiber. Nutritionists suggest consuming five or more servings of fruits and vegetables daily. Vegetables are a remarkable source of nutrients, antioxidants, and fiber [6].It is fascinating to observe the vast variety of vegetables cultivated worldwide. According to a global vegetable survey, there are roughly 402 different vegetable crops grown across the globe. Among these crops, we can find an impressive variety, with 69 different families and 230 distinct genera. This remarkable diversity highlights the extensive range of vegetables grown around the world[7]. Vegetables are horticultural crops that can be either annual or perennial, and this needs to be emphasized. Additionally, consumers have the choice of eating vegetables whole or in pieces because they come in a variety of parts, such as roots, stems, flowers, fruits, and leaves. Moreover, play a crucial role in healthy diets like the Mediterranean diet, whether they are cooked or raw. This diet is advised because it includes a variety of plant-based foods like fruits, vegetables, legumes, nuts, and grains, as well as healthy oils like olive oil. Along with encouraging the use of spices and flavorings to enhance food flavor, it also encourages reducing red meat consumption and including fish and poultry at least twice a week. Beyond reducing the risk of chronic diseases, the Mediterranean diet has many positive health effects. It has also been linked to lowering mortality rates overall and fostering healthy aging [8, 9]. Fruits and vegetables, unlike meat and processed meals, are acceptable for raw eating or undergo minor processing processes such as washing, sorting, peeling, and slicing. Surprisingly, neither freshness nor nutrients are compromised by these methods. As a result, vegetables maintain a considerable amount of their natural physical and chemical nutritious qualities even after minimal processing. This distinguishes vegetables as one of the most significant dietary categories capable of retaining their inherent features and nutritious content despite basic cooking techniques[10, 11].

2- Classification of Vegetables

There are many ways to categorize vegetables; however, the most significant classification depends on the part of the plant used and its nutritional value. Among these are leafy vegetables, which have edible leaves that are frequently consumed by both humans and animals. It is worth mentioning that many vegetables fall into this category, including spinach, lettuce, cabbage, parsley, etc. The leafy vegetables, also known as greens or leafy greens, are enormously popular and widely consumed worldwide, especially in Asia. In addition, they are fast-growing crops that can be harvested four up to six weeks after planting. These vegetables are predominantly cultivated in semi-urban areas. It is crucial to highlight that leafy vegetables serve as an abundant source of proteins and vitamins, especially vitamin A and C, along with essential minerals like iron, phosphorus, and calcium, making them a significant component of a well-balanced diet [16,17]. Second, edible stem vegetables. This category includes a range of plants whose edible stems are the main part consumed. These vegetables are well-known for their satisfying crunchiness and delicious taste, which explains their popularity in various cuisines worldwide. Examples of edible stem vegetables include asparagus, celery, cauliflower, and rhubarb. In addition to their enjoyable flavor, these vegetables offer essential nutrients like fiber, vitamins, minerals, and other nutrient components that are crucial for a well-rounded diet[17, 18, 20].Third, edible flowering vegetables, commonly known as edible flowers, contain a variety of plants that can be consumed as food in our diets. Besides being a delightful addition to dishes, they serve as a substantial source of nutrients. These visually appealing vegetables not only add to the meal with vibrant colors and delicate flavors but also offer a wide range of nutritional benefits. These include essential vitamins, minerals and antioxidants. These flowering vegetables include broccoli, cauliflower, globe artichoke ... etc. [16, 19].Lastly, root vegetables are an unusual agricultural category distinguished by edible roots. These vegetables are quite significant on the commercial market. This group includes well-known members such as radishes, carrots, potatoes, turnips, and beets. They thrive in cold climates and grow underground. Furthermore, root vegetables are well-known for their high nutritional value as sources of vitamins, minerals, and fiber. Therefore, they are a crucial component of a healthy diet. These veggies provide health benefits in addition to nutritional ones. These benefits include a lower incidence of chronic diseases such as heart disease, malignancies, and obesity. Their distinct health-enhancing qualities increase their significance in improving overall well-being [20, 21]. The information pertaining to the classification of vegetables based on the edible part is summarized in Table No. 1 below.

Table 1: the categorization of vegetables according to their edible components[16].

Category	(Examples) Vegetables
1- Leafy vegetables	Spinach, Cabbage, Lettuce, Mustard greens, Beet, Watercress,Dill ...etc.
2- Stem vegetables	Asparagus, Celery, Broccoli, Cauliflower, Brussels sprouts, Kohlrabi, Fennel and etc.
3- Fruit and flower vegetables	Tomatoes, peppers, eggplants, artichokes, broccoli, cauliflower, zucchini, cucumber and etc.
4- Root vegetables	Carrots, Radishes, Turnips, Beets, Ginger, Onions, Garlic, Parsnips, Sweet potatoes, Potatoes, fennel and etc.

3- Chemical Composition of Vegetables

Vegetables and horticultural crops play a crucial role in maintaining a healthy body through nutrition. They provide essential nutrients like water, carbohydrates, fats, proteins, fibers, minerals, organic acids, dyes, vitamins, antioxidants, and other significant substances essential for human well-being. Moreover, vegetables, in particular, are highly beneficial due to their plentiful amounts of fiber, minerals, vitamins, and antioxidants. These nutrients substantially contribute to human health. Furthermore, vegetables offer a wide variety throughout the year. They are not only delicious in taste but also possess favorable attributes in terms of texture, color, flavor, and convenience. They can be consumed fresh, cooked, hot, cold, canned, frozen, or even dried[12].In addition, vegetable composition is influenced by various factors, including climatic conditions, cultural practices, storage conditions, and plant maturity. These factors significantly impact the nutritional content of vegetables. One interesting aspect is the moisture content, given that vegetables with over 80% are considered succulent and contain less energy than grains. Carbohydrates make up between 3 and 20% of vegetables. particularly starch in the form of polysaccharides, serve as fuel for the body. Whereas vegetable consistency is contributed by cellulose, hemicellulose, and pectin. Protein content in vegetables typically ranges from 0.5–3.5%, except for legumes like peas, beans, and lentils, which have a higher protein percentage. In addition, they have a low-fat content, characteristically 0.1–3% [13, 14]. In general, vegetables are abundant in diverse types of phenolic compounds, encompassing phytochemical acids and flavonoids like flavones, flavonols, flavanonols, flavanols, catechins, anthocyanins and chalcones. In addition, vegetables are abundant in amino phenolic compounds. These phenolic compounds are renowned for their antioxidant properties and are associated with various health advantages. For example, lowering the risk of chronic ailments like heart disease and cancer. In addition, vegetables offer vital vitamins, minerals, and dietary fiber, promoting overall health and well-being [15].

4- Health Benefits of Vegetables

Vegetables are cultivated globally and form a significant part of people's diets in numerous regions. They hold a crucial role in human nutrition, serving as animportant source of essential vitamins such as C, A, B1, B6, B9, and E, along with minerals, fibers, and various beneficial compounds. These vegetables are closely linked to promoting digestive health, enhancing vision, and reducing the risk of ailments like heart diseases, cerebrovascular diseases, diabetes, and certain types of cancer [22, 23, 24].Furthermore, the consumption of vegetables significantly contributes to curtailing the advancement of cancer. Findings presented by both the Global Fund for Cancer Research and the American Institute for Cancer Research highlight that incorporating non-starchy vegetables like lettuce, leafy greens, broccoli, Chinese cabbage, garlic, onions, and cabbage, along with certain fruits, can protect against various types of cancers. These include cancers affecting the mouth, throat, esophagus, stomach, and even lung cancer[29]. It is significant to highlight that a diet abundant in vegetables and fruits has a substantial impact on reducing blood pressure. Moreover, it lowers the likelihood of heart disease and strokes. Additionally, it plays a vital role in preventing certain types of cancer and reducing the risk of other health issues, like eye problems and digestive disorders, as mentioned earlier. Also, it aids in weight loss, contributing to a healthier diet overall[25]. An intriguing observation emerged from one study, affirming that a diet abundant in fruits and vegetables can lower heart disease and stroke risks. Notably, this particular study involved an extensive participant pool of over 469,000 individuals. It concluded that a higher intake of fruits and vegetables correlates directly with a reduced risk of cardiovascular disease mortality. On average, each extra daily serving of fresh fruits and vegetables was associated with a 4% decrease in cardiovascular-related death risk[26]. It is essential to highlight that, despite the significant importance of vegetables in a healthy diet, it is astonishing that a vast majority of people fail to consume an adequate amount of fruits and vegetables. In order to obtain their health and nutritional benefits, the World Health Organization recommends consuming a minimum of 400 grams of vegetables per day. Regrettably, in 2017, approximately 3.9 million deaths worldwide were attributed to insufficient fruits and vegetables intake. Estimates suggest that a lack of fruits and vegetables may contribute to around 14% of deaths from gastrointestinal tract cancer. This is in addition to 11% of deaths due to ischemic heart disease, and 9% of deaths from strokes. This underscores the critical role these food items play in preventing various diseases and maintaining overall well-being[27, 28]. Table No. 2 provides information on the chemical composition and medicinal benefits of some selected vegetables.

Table No 2: Phytochemicals and Medical significance of selected vegetables.

Name of Vegetable	Phytochemicals	Medicinal significance
Asparagus *Asparagus officinalis*	Vitamins A, C, E, K, and B6, folate, iron, potassium, copper, calcium, protein. antioxidants[30].	Weight Loss, ease constipation, lower cholesterol [31], Reduce gas, Improve digestion [32].Antibiotic, antispasmodic, demulcent, diaphoretic, diuretic, laxative [5].
Broccoli *Brassica oleracea var. italica*	Sulphoraphane, indoles, -carotene, lutein, and quercetins [5]. Calcium, Magnesium, Selenium [33].	Antioxidants [34], anti-inflammatory [35], anticancer, reduce LDL oxidation [5].
Cabbage *Brassica oleracea var. capitata*	Protein, Fiber, Vitamin K, Vitamin C, Folate, Manganese,Vitamin B6, Calcium, Potassium,Magnesium[36].Sulphoraphane and indoles [5].	Antioxidants[37],improve heartHealth [38], Anticancer and vison loss protection [39, 40].

Carrots *Daucus carota subsp. sativus*	Beta carotene, fiber, vitamin K1, potassium, and antioxidants[41], fiber [42], lutein, zeaxanthin and vitamin A [43].	Effective in diabetes mellitus, lowers cholesterol, reduces colon cancer, improves skin tone [5], improve immunity [44], vision loss prevention [45].
Watercress *Nasturtium officinale*	Carbs, Protein, Fat, Fiber, Vitamin A, Vitamin C, Vitamin K, Calcium, Manganese[46], vitamin E, thiamine, riboflavin, vitamin B6, folate, pantothenic acid, magnesium, phosphorus, potassium, sodium and copper [47].	Antioxidant [47], cancer, diabetes and heart disease prevention [48. 49], Lowering blood pressure [50].
Garlic *Allium sativum*	Sulfur-containing compounds [5], manganese, vitamin B6, vitamin C, selenium and fiber [51], proteins, free amino-acids, minerals, vitamin K, and B-complex vitamins [52].	Antioxidant, anti-inflammatory, immunomodulatory, regulating lipid metabolism[53], Antiviral (54), reducinghigh blood pressure, anti-cancers, common cold treatment [55].
Peas *Pisum sativum*	Proteins and fiber [5], Carbohydrates,Sugars, Fat, vitamin A, vitamin B6, folate, magnesium, vitamin C, vitamin K, thiamin, and manganese [56].	Anti-diabetic [57, 59], Enhances gut health [58], anti-cancer, improves serum lipid levels, cardiovascular disease prevention, maintain blood pressure [59].
Radish *Raphanus sativus*	Glycoproteins, Glucosinolates, Oil Seed Components, Organic Acids, Phenolic Compounds, Pigments, Polysaccharides, Proteoglycan, Sulfur Compounds, β-Carotene, Vitamin C, β-sitosterol [60].	Antimicrobial, Antioxidative, Antitumor, Antiviral, Hypotensive, Immunological Properties, Phytoalexins[60], Reduces weight, respiratory problems, diabetes mellitus [5].
Spinach *Spinacia oleracea*	Vitamin A, Vitamin C, Vitamin K1, Folic acid, Iron, Calcium, other vitamins and minerals, including potassium, magnesium, and vitamins B6, B9, and E [61], β-Carotene, lutein, zeaxanthin [5].	Antioxidant [62], eye and skin health improvement [63], anti-cancer, blindness and memory loss prevention [5].

5- Foodborne diseases and vegetables

Given the crucial role of vegetables in human diets, it is vital to recognize the potential risk of foodborne diseases, particularly parasitic infections, that they may pose if consumed in their raw or undercooked form, despite their high nutritional value. These diseases could be caused by viruses, bacteria, or parasites, and contaminated food, including vegetables, could serve as a vehicle for the transmission of such diseases[64; 65; 66]. In addition, there has been a noticeable surge in the number of outbreaks of human diseases linked to the consumption of raw fruits and vegetables in the past decade. Several factors have contributed to this increase, including changes in agricultural and processing practices, as well as a higher per capita consumption of raw fruits and vegetables [67]. It is conceivable that parasites could contaminate vegetables through several avenues. Nonetheless, the most plausible explanation for contamination is that it occurs before harvesting, when the plants are still in the fields. Furthermore, contamination may occur through infected fertilizer or irrigation water or through contact with wild, stray, or domestic animals including insects during harvesting, transportation, processing, distribution, marketing, and even at home [68; 69]. It is well-established that a moist environment is favorable to the growth of various types of vegetables; however, this moisture also provides an ideal setting for the spread of parasites that can contaminate these vegetables. Numerous studies have documented parasite contamination in vegetables worldwide. The extent of this contamination varies significantly from one geographical region to another, showing considerable differences. For instance, vegetable contamination ranges from 15.1% in the United Arab Emirates to 100% in Yemen. The wide variation in contamination levels between different geographical areas can be attributed to factors such as climate conditions, region, location, environmental variations, the types of vegetables being examined, sample sizes, and the specific techniques used for parasite detection [70].

6- Parasitic contamination of vegetables

Numerous investigations regarding parasite contamination of vegetables have been conducted across the world. Table 3 below provides an overview of the types of vegetables and the parasites detected.

Table 3: Several vegetable varieties and parasites detected.

Vegetable type	Detected Parasites	References
Tomato	*Entamoeba histolytica/ E. dispar, Giardia lamblia, Cryptosporidium spp, Strongyloides spp, Ascaris lumbricoides, Enterobius vermicularis, Trichuris trichiura, Toxocara spp.*	[72, 74, 76, 79]
Green Pepper	*Entamoeba histolytica/ E. dispar, Giardia lamblia, Cryptosporidium spp, Strongyloides spp, Toxocara spp,*	[72, 74]

	Hymenolepis nana, H. diminuta, Cystoisospora belli	
Cabbage	*Entamoeba histolytica/ E. dispar, Giardia lamblia, Cryptosporidium spp, Strongyloides spp, Ascaris lumbricoides, Fasciola hepatica, Hookworms, Toxocara spp, Hymenolepis nana, H. diminuta, Cystoisospora belli, Toxoplasma gondii*	[72, 74,77]
Spinach	*Entamoeba histolytica/ E. dispar, Giardia lamblia, Cryptosporidium spp, Strongyloides spp, Fasciola hepatica, Hookworms, Toxoplasma gondii, Vermamoeba vermiformis*	[72, 77, 78]
Lettuce	*Entamoeba histolytica/ E. dispar, Giardia lamblia, Cryptosporidium spp, Strongyloides spp, Fasciola hepatica, Hookworms, Toxocara spp. Hymenolepis nana, H. diminuta, Cystoisospora belli, Cyclospora spp, Toxoplasma gondii, Vermamoeba vermifor,Blastocystis spp, Ascaris lumbricoides, Enterobius vermicularis, Trichuris trichiura, Taenia spp*	[69, 72, 74, 76, 77, 78, 79, 80, 81]
Carrot	*Entamoeba histolytica/ E. dispar, Giardia lamblia, Cryptosporidium spp, Strongyloides spp, Ascaris lumbricoides, Hookworms, Toxocara spp.Hymenolepis nana, H. diminuta, Cystoisospora belli*	[72, 74]
Parsley	*Entamoeba histolytica/ E. dispar, Giardia lamblia, Cryptosporidium spp, Strongyloides spp, Ascaris lumbricoides, Enterobius vermicularis, Trichuris trichiura, Cyclospora spp,*	[69, 76, 78, 79, 80]
Dill	*Entamoeba histolytica, Blastocystis spp, Toxoplasma gondii, Toxocara spp*	[76, 78, 80, 81]
Watercress	*Entamoeba histolytica, Ascaris lumbricoides, Giardia intestinalis, Enterobius vermicularis, Strongyloides stercoralis, Trichuris trichiura*	[76, 79, 80]
Mint	*Toxoplasma gondii, Entamoeba histolytica/dispar cyst, Giardia. lamblia cyst, Cryptosporidium oocyst, Blastocystis hominis cyst.*	[80,82]

The following part of this research will focus on offering a simple approach to reviewing the most prevalent instances of parasite contamination of vegetables.

6.1 *Entamoeba histolytica*

It is a parasitic organism responsible for causing amoebic dysentery in both humans and various other animals. Although its primary effect is amoebic dysentery, it can also lead to other manifestations beyond the intestinal region. This parasite transmits through contaminated food and drinks containing its cysts. According to numerous statistics, approximately 50 million people worldwide display symptoms of this parasite. This results in around 100,000 annual deaths attributed to infection, though 90% of cases show no symptoms. Moreover, amoebic infection is more prevalent in countries with lower socio-economic circumstances and contaminated water sources. As this parasite contaminates vegetables, consumption of contaminated vegetables can lead to a parasitic infection that is pathogenic for both humans and animals alike [71]. Numerous global studies have been conducted to investigate amoebic contamination of vegetables, yielding interesting findings. *Entamoeba histolytica* has been detected on various vegetables such as lettuce, spinach, cabbage, tomatoes, and others. Contamination prevalence varies depending on location, environmental conditions, growth circumstances, personal hygiene, and cultural and traditional practices. Developing countries tend to have higher contamination rates. The main routes of vegetable contamination involve the use of contaminated water during irrigation and contact with soil or hands that may carry the parasite. Implementing appropriate sanitation and hygiene practices is crucial to reducing contamination risk. Furthermore, effective measures include using clean water for irrigation, thorough vegetable washing before consumption, and maintaining proper hand hygiene. Furthermore, cooking vegetables at high temperatures can eliminate parasites [72, 73, 74, 75].

6.2 *Giardia lamblia*

Giardia lamblia, also known as *Giardia intestinalis* or *Giardia duodenalis,* is a protozoan parasite that infects humans and other animals. This parasite belongs to the Diplomonads family and is well known as one of the primary causes of parasitic diarrhea worldwide[83]. It can contaminate water sources, while consuming its cysts can lead to giardiasis, a self-limiting type of acute gastroenteritis. Furthermore, infected individuals may exhibit symptoms such as acute diarrhea accompanied by malaise, bloating, and cramping. In addition, it may exhibit chronic diarrhea with malabsorption or asymptomatic infection. This variant is the only species within its genus related to human infection. Besides, this pathogen presents a significant challenge to the water industry since it is impervious to purification by chlorine treatment. It can pass through more advanced membrane filters with efficiency rates of up to 30%. Shockingly, the incidence of *G. lamblia*in the developing world is roughly between 20% and 30%. This is with up to 100% of children contracting the infection before three years old in some regions[84]. It is noteworthy to emphasize that *G. lamblia*can contaminate vegetables. Numerous research studies have detected this protozoan parasite in a variety of vegetables, such as Napa cabbage, lettuce, tomatoes, radishes, broccoli, parsley, mint, carrots, cabbage, green pepper and cucumbers[72, 82, 85, 86].

Out of these vegetables, broccoli, radish, spring onions, mint, and chard exhibited the highest contamination levels [85]. Vegetables can become contaminated with *G. lamblia*in various ways, including the use of organic fertilizers or the use of contaminated irrigation water during cultivation in fields. Furthermore, contamination can also occur during the harvesting, processing, distribution, and sale of vegetables [68, 69]. To minimize *G. lamblia* contamination in vegetables, several preventative measures are highly recommended. One essential step is thoroughly washing vegetables before consumption. Additionally, it is crucial to refrain from eating raw vegetables, especially while travelling to countries with potentially unsafe and heavily contaminated food supplies. Moreover, focusing on proper hygiene practices, such as frequent handwashing with soap and water, particularly during critical times when foodborne contamination risk is elevated, can significantly help prevent this protozoan and other foodborne pathogens [87].

6.3 *Strongyloides spp*

Strongyloides is a group of parasitic roundworms (or nematodes) that infect a variety of vertebrate hosts, including humans. The most significant *Strongyloides* species that impacts human health is *Strongyloides stercoralis*[88]. This species causes strongyloidiasis, a neglected tropical disease that affects millions across the globe. This disease affects people more frequently in areas with poor hygiene and inadequate sanitation practices. What makes *Strongyloides stercoralis* unique from other parasitic worms is that it includes both a parasitic and a free-living stage during its lifecycle[89]. The main mode of infection is through exposure to soil contaminated with free-living larvae. After penetrating the skin, the larvae move to the lungs and subsequently to the intestines, where they develop into adult worms. These worms reproduce inside the host, causing an auto-infection circle that can continue for years if not treated. Strongyloidiasis symptoms vary in intensity, ranging from mild to severe, and may include abdominal discomfort, diarrhea, weight loss, and a skin rash. In some cases, the impact may be more significant and include malnutrition, anemia, and pneumonia. Severe cases of the disease can be life-threatening if the infection spreads to other organs of the body. Therefore, early detection and timely intervention are crucial to prevent further complications and minimize long-term damage[88, 89].

Additionally, numerous research studies have identified the presence of *Strongyloides spp*. in different types of vegetables, such as lettuce, cabbage, celery, spinach, carrot, broccoli, radish, parsley, mint, and Thai basil [72, 79, 90, 118]. From the many researches' findings, it appears that the main origins of *Strongyloides spp*. contamination in vegetables are: soil that is tainted with free-living larvae, the use of organic fertilizers, irrigation water that is contaminated during the growing process in fields and contamination during harvesting, processing, and distribution stages[91, 92].*Strongyloides* spp. is transmitted to humans from sources based in the soil through direct contact between the skin and the soil. Nonetheless, another way of acquiring soil-based infections includes the intentional ingestion of soil, a custom known as geophagy. Geophagy is culturally accepted and widespread behavior, especially in sub-Saharan Africa. Pregnant women often actively participate in this behavior, and as a result, cases of *S. stercoralis* infections, as well as other soil-transmitted helminth infections, have been observed in these women. Geophagy is occasionally used as a dietary supplement in low-income regions. It is critical to note that such areas are more likely to have soil contaminated with helminths, which significantly increases the risk of infection[92].

6.4 *Toxoplasma gondii*

Toxoplasma gondii, a protozoan parasite responsible for toxoplasmosis, can infect a wide range of warm-blooded creatures, including humans. However, felines are the definitive hosts, as the parasite can reproduce sexually within them. Infection can occur through several routes, such as consuming undercooked meat containing tissue cysts, in addition to ingesting contaminated food or water with cat feces, exposure to contaminated environmental samples, receiving infected blood transfusions or organ transplants, and vertical transmission from mother to fetus. Moreover, toxoplasmosis is a widespread infection that affects a significant portion of the global population, with an estimated 1 in 3 individuals being infected by the *T. gondii* parasite. Many people who contract the infection do not experience any symptoms. However, severe infection can occur in children born with the infection or individuals with a weakened immune system, including those with AIDS. Toxoplasmosis symptoms may manifest as fever, headaches, muscle aches, and swollen lymph nodes. Pregnant women who become infected with *T. gondii* can transmit the infection to their unborn child, which can result in serious complication [80, 93].

Furthermore, numerous studies have reported *Toxoplasma gondii*'s occurrence in vegetables. This contamination has been observed in different types of vegetables globally, such as lettuce, endive, watercress, parsley, spinach, mint, and other leafy greens. Vegetable contamination with *T. gondii* can be attributed to various factors, including the use of contaminated irrigation water during cultivation in fields. This is also true during harvesting, processing, distribution, and sale[77, 80, 94, 95].Cockroaches, earthworms, and flies play a significant role in the scattering of *T. gondii* oocysts from areas where cats defecate to the soil in vegetable-growing areas, leading to the subsequent contamination of vegetables. This contamination can also be facilitated by the use of contaminated equipment and transportation by animals, which attract insects that serve as mechanical vectors for parasites, in addition to several environmental factors such as rain and winds [80]. Properly boiling vegetables can deactivate *T. gondii* and reduce infection risk. However, complete eradication of *T. gondii* contamination through cooking may not be guaranteed, particularly if the vegetables were heavily contaminated before cooking. To minimize the risk of *T. gondii* infection, it is recommended to thoroughly wash vegetables before cooking and ensure they are prepared at the appropriate temperature. Additionally, when traveling to countries with uncertain food safety standards, it is advisable to refrain from raw vegetables[96].

6.5 *Ascaris lumbricoides*

With an estimated 1.2 billion people infected, these worms are among the most common intestinal parasites infecting humans worldwide. The elevated incidence is related to female worms' ability to generate vast quantities of eggs that tolerate extreme environmental conditions during fertilization. Furthermore, when eggs containing larvae are ingested in contaminated foods and drinks, these worms are easily spread between individuals. Unfortunately, there is no vaccine available to protect against this species. Because worms block the intestines, acute Ascaris infection is deadly, killing over 60,000 people each year, mostly children. It is more widespread in countries with low socio-economic status [97]. Ascaris eggs are transmitted through accidental contact with soil or contaminated fruits, vegetables, and greens. In regions where, human feces are used as fertilizer for vegetable production, the soil and surfaces can become contaminated with Ascaris eggs. This underscores the significance of practicing proper hygiene and implementing sanitation measures to prevent Ascaris infection spread through contaminated food [97, 98]. Numerous studies have reported the existence of Ascaris eggs in vegetables, including lettuce, watercress, parsley, leeks, green onions, tomatoes, green peppers, and others[72, 98, 99, 100]. Astonishingly, Ascaris egg contamination was found to be the most prevalent parasite among fresh vegetables in some studies[98, 99]. The sources of contamination are not far from what was previously mentioned. These sources can result from the use of organic fertilizers, irrigation water contamination, or various stages such as harvesting, transportation, processing, or distribution of vegetables [80, 98]. To mitigate the likelihood of consuming Ascaris egg-contaminated vegetables, it is recommended to take certain precautions. Thoroughly wash vegetables using safe water, ensure proper cooking, peel or remove outer layers when possible, avoid using human feces as fertilizer, and maintain proper hygiene practices. By adhering to these guidelines, you can lower the risk of ingesting Ascaris egg-contaminated vegetables and promote overall food safety[100, 101].

6.6 ***Cryptosporidium spp***

Cryptosporidium is a parasitic intracellular and extracytoplasmic protozoan that causes cryptosporidiosis. It belongs to the Apicomplexa phylum and has distinct properties such as the ability to generate self-infections, an unusual position within the host cell, and intrinsic disinfectant resistance. The pathogens that cause the vast majority of human infections (about 90%) are *C. hominis* and *C. parvum*. Dehydration, stomach pain, and diarrhoea are common symptoms of cryptosporidiosis. The disease is transmitted via contaminated water sources such as swimming pools and drinking water. To avoid cryptosporidiosis, it is critical to practice appropriate hygiene and have access to safe drinking water[102]. On the other hand, several studies have revealed *Cryptosporidium* spp. oocysts in raw vegetables (72, 74, 103, 104). For instance, in Iraq, the average prevalence rate of *Cryptosporidium* in vegetables was 6.5%. Likewise, a study conducted in Korea detected *Cryptosporidium* spp.in various raw vegetables, including lettuce, perilla leaves, and watercress[103, 104]. The main source of contamination for these vegetables is often the use of contaminated irrigation water during their cultivation in fields. This highlights the significance of implementing proper water management and hygiene practices in agricultural settings to prevent *Cryptosporidium* spp. dissemination. To minimize infection risk, consumers must thoroughly wash and cook vegetables before consumption. Furthermore, practicing proper hygiene, such as washing hands with soap and water, particularly during critical times when oocysts are likely to spread, can contribute to preventing the transmission of *Cryptosporidium* spp[105].

6.7 *Enterobius vermicularis*

The pinworm, *Enterobius vermicularis*, is a tiny parasitic nematode (roundworm) that infects the human gastrointestinal tract, notably the colon and rectum. It is one of the most prevalent intestinal parasites, affecting both children and adults worldwide. Enterobiasis or oxyuriasis is the medical term for this type of disease [106]. Furthermore, this parasite is transmitted by swallowing parasite's eggs. Infected people, particularly children, can spread the eggs by not washing their hands after using the toilet. They can also scratch the anal region and then contacting things or surfaces. Female adult worms migrate at night to the perianal region of the large intestine to lay their eggs. In addition, migration and egg-laying facilitate infection dissemination, which leads to itching, discomfort, abdominal pain, nausea, and diarrhea. Preventive measures encompass adopting proper hygiene practices, such as frequent handwashing, maintaining short fingernails, and regularly laundering clothing and bedding [106, 107]. Currently, there are scarce data concerning the presence of *Enterobius vermicularis* (pinworm) in vegetables. Nonetheless, one study revealed the potential contact between *Enterobius vermicularis* eggs and vegetables like lettuce, parsley, and cress, along with other fruits and vegetables. Additionally, another study conducted in Benha, Egypt, assessed the level of parasitic contamination in vegetables and detected the presence of this parasite's eggs in some samples [98, 108].

6.8 *Toxocara spp*

Toxocara spp., the zoonotic roundworms, namely *Toxocara canis* and *T. cati*, are prevalent globally in their definitive hosts. They are also mayinfect a variety of animal species, including humans. These roundworms are commonly present in dogs and cats' intestines, where the female *Toxocara s*pp. can lay up to 200,000 eggs. These eggs have the potential to be excreted in infected animals' feces, leading to soil, water, and food contamination. As a result, there is a risk of infection for humans who come into contact with these contaminated sources[109, 110]. Indeed, it is crucial to understand that geophagia (eating soil) and poor personal hygiene are not the sole factors that elevate the risk of infection with *Toxocara* spp. Other practices, such as drinking contaminated water or eating inadequately cooked food, can also pose a significant threat. In addition to these factors, handling and preparing raw garden vegetables should be accompanied by stringent sanitation and hygiene practices to minimize infection risk. Being aware of these potential sources of contamination and adopting appropriate precautions can play a pivotal role in preventing *Toxocara* spp. infections in humans[111]. Toxocariasis ranks among the most frequently reported zoonotic helminth infections globally. Moreover, seroprevalence surveys conducted in Western countries have revealed that approximately 2 to 5% of apparently healthy adults residing in urban areas tested positive for *Toxocara* spp. antibodies, while a significantly higher percentage, ranging from 14.2 to 37%, showed positive results in rural areas. This indicates a higher prevalence of Toxocariasis in rural regions compared to urban settings[112]. Currently, investigations have demonstrated that *Toxocara* spp. eggs can contaminate a wide range of vegetables, such as lettuce, tomatoes, green peppers, cabbage, carrots, dill, and various others. These eggs exhibit resistance to environmental conditions, enabling them to survive in soil for extended periods. Consequently, it becomes imperative to adopt proper measures, including thorough washing and cooking of these vegetables, to effectively eliminate the risk of *Toxocara* spp. infection. By adhering to these precautions, individuals can significantly reduce the likelihood of contracting the parasite and maintain their health [74, 113, 114].

6.9 *Trichuris trichiura*

Trichuris trichiura, also known as human whipworm, is a roundworm responsible for trichuriasis in humans. This parasitic infection is prevalent in areas with inadequate sanitation and hygiene practices. Transmission occurs when individuals consume whipworm eggs, which then hatch in the intestines, developing into adult worms that attach to the intestinal wall. The name "whipworm," stems from its appearance, suggesting a whip with wide handles at the posterior end. The worms measure around 3 to 5 cm in length, with females larger than males and able to lay between 2,000 and 10,000 eggs daily. Generally, these eggs are deposited in the soil through the feces of infected organisms[115, 116].Within 14 to 21 days, the eggs develop into an infectious stage. Upon ingestion by humans, the eggs hatch in the small intestine, harnessing intestinal microflora and nutrients to reproduce and grow. The maturity of larvae migrates to the cecum, where they access the mucosa and reach adulthood. In cases with a high worm burden, the infection impacts the distal parts of the large intestine. Besides, larvae migration within the intestines can cause inflammation and damage to the intestinal lining. This results in symptoms such as abdominal pain, diarrhea, and bloody stools [115]. This disease is one of the most widespread parasitic infections globally, impacting alarming numbers. Reports indicate that over a billion individuals worldwide are affected by this disease. This includes approximately 114 million preschool-aged children and more than 230 million school-age children. What's concerning is that in certain regions, the prevalence of this parasitic infection reaches 95% among children[117]. Numerous global studies investigating vegetable contamination with parasites have recorded the occurrence of this specific parasite in various vegetables. As an illustration, research conducted in Thailand found that *Trichuris trichiura* was present in 2.6% of the 265 vegetable samples examined, Culantro and Chinese cabbage were among these vegetables [118]. Moreover, there have been studies that document the occurrence of this parasite in various types of vegetables and fruits, including tomatoes, lettuce, parsley, and other varieties [72]. In another study, *Trichuris trichiura* was detected in 18 % of vegetables analyzed in Pakistan, illuminating the wide yield contamination with this parasitic worm. This finding raises awareness about implicit health hazards associated with consuming contaminated vegetables. It emphasizes the need for improved sanitation and hygiene practices in agrarian settings [119]. To prevent *Trichuris trichiura* contamination in vegetables, the following measures are essential: Firstly, thoroughly wash vegetables with clean water before consumption. This helps to eliminate any potential eggs or larvae on the vegetable surfaces. Secondly, implementing proper sanitation practices on farms and maintaining hygienic conditions during harvesting, handling, and packaging of vegetables can significantly lower the risk of *Trichuris trichiura* contamination. Lastly, it is highly recommended to avoid fecal contamination of food and refrain from eating soil-contaminated vegetables[116, 120, 121].

6.10 *Hymenolepisnana*

It is important to mention that this type of nematode is very common in humans, especially young children. Because of its tiny size (approximately one millimeter wide and two to four centimeters long), it is known as the dwarf tapeworm. This widely distributed species may be found all over the world, but is more common in temperate zones. Its human dominance stems from its proclivity to develop anywhere there is a human population and rodents. The nematode has been found in a number of regions, nevertheless it is most typically seen in children and persons with compromised immunity who live in overcrowded and unclean conditions [122, 123]. *H. nana* inhabits the intestines and obtains nutrition from the intestinal lumen. This tapeworm characteristically causes more discomfort than serious health risks for adults, and it can be dangerous for small children. The larval stage of tapeworm is highly hazardous for children. Furthermore, infection with *H. nana*normally causes no symptoms, leading to misinterpretation as pinworm infection. Severe disease is uncommon and in fact occurs only when the parasite is heavily infested. It is significant to note that no deaths have been reported due to this parasitic infection[124, 125]. Without a doubt, this parasite contaminated vegetables. Numerous research investigations in this field have proved the parasite's existence in vegetables. As an instance, a research conducted in Benha, Egypt, detected *H. nana*eggs in roughly 2.8% of the vegetable samples analyzed. Watercress had the greatest contamination rate among these samples, with around 6% of them testing positive for parasite eggs [98]. Certainly, another research conducted in the United

Arab Emirates also supported the detection of *H. nana*eggs in vegetable samples. The study indicated that approximately 3.0% of the analyzed samples were contaminated with this parasite. Among the infected vegetables, lettuce stood out as the most prevalent source of parasitic worms[85]. Lastly, in a study conducted in Alexandria, Egypt, *H. nana* eggs were detected in commonly consumed raw vegetables. Out of the total 300 vegetable samples tested, approximately 2.6% were contaminated with *H. nana* eggs. This study highlights the importance of ensuring food safety measures and proper hygiene practices during the production and consumption of raw vegetables. This is to minimize parasitic infections risk[126].

6.11 Other parasites

The outcomes of parasitic contamination investigations extend beyond the aforementioned findings. It is intriguing to note that numerous other parasites, though in lesser proportions, have been identified as contaminants in vegetables. This has led to various parasitic diseases and substantial economic losses. For instance, parasites like *Hymenolepis diminuta*, *Cystoisospora belli*, *Fasciola hepatica*, Hookworms, *Vermamoeba vermiformis*, and others have been documented as contaminants in vegetables [72, 74, 78, 79]. Table 4 presented below provides a depiction of the predominant parasites accountable for contaminating vegetables in addition to the regions of the conducted studies.

Table 4: The most common parasites accountable for contaminating vegetables.

Parasite	**Region of the study**	**References**
Entamoeba histolytica	Ethiopia Iran Bangladesh Jordan Libya	[72, 74] [73] [70] [90] [127]
Giardia lamblia	Ethiopia Egypt. United Arab Emirates India	[74] [82, 98] [85] [86]

Strongyloides spp	Ethiopia Southwest Ethiopia Malaysia Thailand	[72] [78] [90] [118]
Toxocara spp	Ethiopia Southwest Ethiopia UK Mexico	[74] [78] [113] [114]
Hymenolepis nana	Egypt United Arab Emirates Egypt	[98] [85] [126]
Trichuris trichiura	Ethiopia Thailand Pakistan	[72] [118] [119]
Enterobius vermicularis	Egypt Turkey	[98] [108]
Cryptosporidium	Ethiopia Iraq Korea.	[72, 74] [103] [104]
Ascaris lumbricoides	Ethiopia Egypt Pakistan Libya	[72, 74] [98] [99] [127]
Toxoplasma gondii	Spain Palestine Portugal and Spain China	[77] [80] [94] [95]

Conclusion

After thoroughly reviewing numerous published studies and research, the current investigation concluded that vegetables hold significant importance as a crucial food source for humans. Apart from being rich in essential nutrients, they also possess remarkable medicinal value, aiding in disease prevention. Nonetheless, vegetables remain regarded as a possible source of foodborne diseases all over the world, particularly parasitic infections such as protozoa and worms. The study also revealed that the global prevalence of foodborne parasite infections remains extremely substantial. This is particularly evident in impoverished countries facing inadequate infrastructure and personal hygiene. The current study also concluded that consuming vegetables should include some preventive measures, such as washing them thoroughly, using clean water to irrigate agricultural crops, as well as improving culture and awareness and raising the standards for social education so that we can eat vegetables, reap their benefits, and avoid parasitic infections from being transmitted as a result.

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