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Review Article

Functional and Risky: Sprouts in Foodborne Illnesses and Their Prospects in Health

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Abstract

The paper presents cases of food poisoning after the consumption of sprouts. According to the Centers for Disease Control and Prevention definition, the cases described involved two or more people who fell ill due to the consumption of food, in this case, sprouts or food with added sprouts. The described cases have been supported by documentation from public health agencies, journal articles, media reports, etc. Between 1973 and 2025, more than 80 poisonings related to the consumption of sprouts were identified, in which over 16,000 people were harmed. Transition periods of more intense poisoning and relaxation can be found. This is due to increased inspections by public health agencies and the implementation of guidelines for sprout producers regarding the handling of plant material and production hygiene, which were strictly followed during the period of increased poisoning, which resulted in a reduction in the number of cases. With the growing demand for sprouts, related to their nutritional and bioactive ingredients, it is necessary to supervise the production process in terms of hygiene so that it does not cause further epidemics. Extensive research is performed to determine the effects of various chemical, physical, and biological methods in reducing the microbial contamination of sprouts.

Keywords: Pathogens; Food Poisoning; Epidemic; Germinated Seeds; Sprouts Contamination

Introduction

As eating habits change, new sources of threats to consumer health are discovered. This was also the case with sprouts. These young vegetables were popular in ancient times and gained importance again in the late 20th century as vegetarianism and veganism became more common. Research on health and nutritional values confirms that seed sprouts are rich in vitamins, mineral salts, and antioxidants, and may also be important in anti-cancer prophylaxis and in preventing and treating civilization diseases. Sprouts, similarly to fresh vegetables and fruits, are usually eaten raw or, less often, minimally processed, e.g. after being subjected to a short heat treatment, which entails the risk of food poisoning due to the presence of pathogens. This is confirmed by numerous cases of diseases related to the consumption of sprouts [1]. Diseases of the digestive system caused by pathogens are particularly dangerous for children, the elderly, and people with weakened immune systems. The sprouts that caused food poisoning were usually grown from alfalfa, radish, watercress, soybeans, mustard seeds, clover, and mung beans [2]. They were most often contaminated with Salmonella sp., Escherichia coli, Listeria monocytogenes, Staphylococcus aureus, Bacillus cereus, and Aeromonas hydrophila [3–5]. In the past few decades, researchers, independently and in cooperation with organizations dealing with health care, disease control, and prevention, have studied cases of various food-related epidemics and over 80 outbreaks were related to the consumption of sprouts (see Table 1, Figure 1).

Table 1. Summary of food poisoning outbreaks related to the consumption of sprouts in the years 1973-2018.

Year of poisoning	Poisoning agent	Number of cases	Place/country of poisoning	Source of pathogenic microorganisms	Reference
1	2	3	4	5	6
1973	*Bacillus cereus*	4	USA (Texas)	Soybean, watercress, and mustard sprouts The presence of *Bacillus cereus* was found on the seeds.	[29]
1982	*Yersinia entero-colitica*	16	USA	Bean sprouts The water used to produce the sprouts was probably the source of the bacteria. Girl scouts got poisoned.	[34]
1988 (March- June)	*Salmonella* Saint-paul, *Salmonella* Virchow PT34	143 (*S.* Saint-paul), 7 (*S.* Virchow)	Great Britain	Mung bean sprouts Mung bean seeds came from Australia and Thailand. After tracing the supply chain, recommendations were given to boil the sprouts for 15 s before consump-tion.	[2,38]
1989	*Salmonella* Gold-coast	31	Great Britain	Cress sprouts The sprout seeds originating from the Netherlands were the source of the pathogen. Another source of sprout in-fection could be microorganisms present on the surface of the devices in which the sprouts were produced.	[2,39]
1990	*Salmonella* Anatum	15	USA (Washington)	Alfalfa sprouts	[40]
1990	Unknown	32	USA (Washington)	Alfalfa/cucumber/lettuce sprouts Conference participants got poisoned.	[40]
1992 (autumn)	*Salmonella* 4,5,12:b:-	272	Finland	Mung bean sprouts	[41]
1994	*Salmonella* Bovis-morbificans	210 (Finland), 385 (Sweden)	Finland (southern regions), Sweden	Alfalfa sprouts	[2,42,43]
1994	*Salmonella* Newport	154	Denmark	Alfalfa sprouts	[44]
1995	*Salmonella* Stanley	114 (Finland), 128 (USA)	Finland, USA (17 states)	Alfalfa sprouts A supply chain trace showed that the seeds were contaminated during delivery by a Danish forwarder.	[42,45]
1995/1996 (autumn-winter)	*Salmonella* Newport	>133	USA (Oregon), Canada (British Columbia)	Alfalfa sprouts Attempts were made to trace the cause of poisoning associated with the Danish forwarder due to *S.* Newport poisoning in Denmark, however, it was not possible to confirm this fact.	[27]
1996 (July)	*Escherichia coli*	5 774, including 1 682 VTEC O157:H7 (3 deaths)	Japan (Sakai City, Kyoto)	White radish sprouts Sprouts were an ingredient in salads. Students in 47 elementary schools and factory workers in Kyoto got poisoned.	[1,46,47]
1996	*Salmonella* Mon-tevideo, *Salmo-nella* Meleagridis	>500	USA (California, Nevada)	Alfalfa sprouts A supply chain investigation showed that the production of sprouts was not following the sanitary requirements and recommendations. The seeds were pro-duced on a farm where chicken manure was used as a fertilizer.	[2,48,49]
1997	*Escherichia coli* O157:H7	126	Japan	Radish sprouts	[2]
1997	*Salmonella* Mele-agridis	78	Canada	Alfalfa sprouts	[2]
1997	*Salmonella* Infan-tis, *Salmonella* Anatum	109	USA (Kansas, Missouri)	Alfalfa sprouts, mung beans The presence of pathogens on the seeds was found.	[2]

1997	*Escherichia coli* O157:H7	82	USA (Michigan, Virginia)	Alfalfa sprouts A supply chain investigation identified three possible causes of pathogens: manure use, water contamination, or wildlife feces.	[50]
1997/1998	*Salmonella* Senftenberg	60	USA (California, Nevada)	Alfalfa sprouts	[2,49]
1998 (April- June)	*Salmonella* Havana	18 (1 death)	USA (California, Arizona)	Alfalfa sprouts The presence of pathogens on the seeds was found.	[48,51]
1998 (May- September)	*Salmonella* Cubana	22	USA (California, Arizona, New Mexico)	Alfalfa sprouts	[2,48,51]
1998	*Escherichia coli* O157:NM	8	USA (California, Nevada, Arizona)	Alfalfa sprouts, clovers A supply chain investigation revealed that the sprouts were sourced from the same supplier as the alfalfa sprouts in 1997 and 1998 contaminated with *S.* Senftenberg found in the United States of America.	[2,48]
1999 (January- April)	*Salmonella* Mbandaka	89	USA (Oregon, Washington, Idaho, California)	Alfalfa sprouts Poisoning was linked to sprout producers who have not followed the FDA-recommended seed preparation treatments - decontamination with sodium or calcium hypochlorite.	[22]
1999 (January-October)	Salmonella Typhimurium	112	USA (Colorado)	Clover sprouts	[52]
1999 (May)	*Salmonella* Typhimurium FT 193	<70	Finland (southern regions)	Alfalfa sprouts	[53]
1999 (May)	*Salmonella* Saintpaul	36	USA (California)	Clover sprouts	[48]
1999 (August-September)	*Salmonella* Muenchen	≥157	USA	Alfalfa sprouts	[54]
1999	*Salmonella* Paratyphi B var Java	51	Canada	Alfalfa sprouts	[55]
2000 (March)	*Salmonella* Enteritidis PT 33	75	USA (California, Nevada, Oregon, Massachusetts)	Mung bean sprouts Sprouts were an ingredient in Vietnamese and Thai dishes. Restaurants were supplied by the same producer who used a solution of 2000 ppm sodium hypochlorite to disinfect the seeds. This concentration was 10 times lower than the FDA recommendation. *S.* Enteritidis PT 33 was found in sprout irrigation water and on the surface of the production equipment. The seeds most likely came from China or Australia.	[28]
2000 (April)	*Salmonella* Enteritidis PT 11b	10	Canada (Alberta, Saskatchewan)	Mung bean sprouts The seeds came from China.	[28]
2000 (November)	*Salmonella* Enteritidis PT 4b	27	the Netherlands	Mung bean sprouts The seeds came from China. *S.* Enteritidis PT 4b was found on sprouts.	[28]
2001 (January)	*Salmonella* Enteritidis PT 1	22	USA (Hawaii)	Mung bean sprouts The seeds came from China or Australia. *S.* Enteritidis PT 1 was found in irrigation water.	[28]
2001 (February)	*Salmonella* Enteritidis PT 913	84	Canada (Alberta)	Mung bean sprouts The seeds came from China.	[28]
2001 (April)	*Salmonella* Enteritidis PT 913	33	USA (Florida)	Mung bean sprouts The seeds came from China.	[28]

2001	*Salmonella* Kottbus	32	USA (California, Colorado, Arizona, New Mexico)	Alfalfa sprouts A supply chain investigation showed that the sprouts were supplied by the same producer in four states. The seeds came from Australia. The seeds were decontaminated with a 2000 ppm sodium hypochlorite solution for 15 min, i.e. a concentration 10 times lower than recommended by the FDA. *S.* Kottbus has been found on the seeds and the floor of the production plant.	[48,56,57]
2002 (February)	*Salmonella* Enteritidis PT 913	15	USA (Maine)	Mung bean sprouts The seeds came from China. The sprouts were an ingredient of pad thai.	[28,36]
2002 (July)	*Escherichia coli* O157:H7	5	USA (California)	Alfalfa sprouts	[36]
2003 (January)	*Escherichia coli* O157:H7	20	USA	Alfalfa sprouts	[36]
2003 (February)	*Escherichia coli* O157	7	USA (Minnesota)	Alfalfa sprouts Sprouts were an ingredient of dishes in restaurants that were supplied by the same distributor. A supply chain investigation showed that the sprout seeds were sourced from the same producer.	[58]
2003 (February)	*Salmonella* Saintpaul	16	USA	Alfalfa sprouts	[36]
2003 (July)	*Escherichia coli* O157:NM (H-)	13	USA (Colorado)	Alfalfa sprouts The seeds were from the same producer as in the *E. coli* outbreak in Minnesota in February 2003.	[36,58]
2003 (October)	Noroviruses	32	USA (Colorado)	Sprouts The sprouts, which were the source of the poisoning, were an ingredient in sandwiches.	[36]
2003 (November)	*Salmonella* Chester	26 (1 death)	USA	Alfalfa sprouts	[36]
2004 (April)	*Salmonella* Bovismorbificans	35	USA	Alfalfa sprouts	[36]
2004 (April)	*Escherichia coli* O157:NM (H-)	2	USA (Georgia)	Alfalfa sprouts	[36]
2005 (December)	*Salmonella* Enteritidis	247	Canada (Ontario)	Mung bean sprouts	[59,60]
2005 (November)	*Salmonella* Braenderup	2	USA (Massachusetts)	Mung bean sprouts	[36]
2005/2006 (November- April)	*Salmonella* Oranienburg	125	Australia	Alfalfa sprouts	[61]
2006	*Salmonella* Oranienburg	15	Australia	Alfalfa sprouts	[62]
2006 (February)	*Salmonella* Braenderup	4	USA (Oregon)	Bean sprouts	[36]
2006 (September-October)	*Salmonella* Bareilly, *Salmonella* Virchow	115	Sweden (Stockholm)	Mung bean sprouts Restaurant customers were poisoned. Sprouts were an ingredient in the dishes. The sprouts were kept in lukewarm water 24 hours before consumption.	[63]
2007 (February)	*Salmonella* Montevideo	24	USA (California)	Bean sprouts	[36]
2007 (April)	*Salmonella* Mbandaka	15	USA	Alfalfa sprouts	[36]
2007 (May)	*Salmonella* Mbandaka	20	USA (California)	Bean sprouts	[36]

2007 (July-October)	*Salmonella* Weltevreden	45	Norway, Denmark, Finland	Alfalfa sprouts This pathogen has not previously been present in Scandinavia but has been present in Asia. The seeds came from a distributor in Denmark. In Norway and Finland, the seeds were chlorinated before germination. In Denmark, the seeds were not subjected to any disinfection treatments. The presence of pathogens on the seeds was found.	[64]
2007 (July- August)	*Salmonella* Stanley *Salmonella* Mbandaka	55	Sweden	Alfalfa sprouts Alfalfa sprouts were commercially available. They were also an ingredient of dishes in restaurants. Tracing the supply chain revealed that the sprouts were from the same producer and that infected seeds were the most likely cause of poisoning.	[65]
2008 (March)	*Listeria monocytogenes*	20	USA	Sprouts	[36]
2008 (July)	*Salmonella* Typhimurium	24	USA	Alfalfa sprouts	[36]
2008 (September)	*Escherichia coli* O157:NM (H-)	21	USA (Colorado)	Alfalfa sprouts, iceberg lettuce sprouts, unspecified	[36]
2008	*Staphylococcus aureus*	42	Denmark	Mung bean sprouts	[3]
2009 (February- April)	*Salmonella* Saintpaul	256	USA	Alfalfa sprouts In April 2009, the FDA issued a recommendation not to eat alfalfa sprouts without prior treatment. This recommendation also applied to sprout mixtures containing alfalfa sprouts.	[36,66]
2009 (April)	*Salmonella* Cubana	2	USA (Minnesota)	Sprouts, unspecified	[36]
2009 (June)	*Salmonella* Bovismorbificans	42	Finland	Alfalfa sprouts *S.* Bovismorbificans was found on sprouts and in water used in germination.	[67]
2009 (July)	*Salmonella* Oranienburg	25	USA	Alfalfa sprouts	[36]
2009 (August)	*Salmonella* Typhimurium	14	USA (Michigan)	Alfalfa sprouts Fast-Food restaurant customers were poisoned.	[36]
2009	*Salmonella* Cubana	12	Canada (Ontario, Alberta)	Alfalfa and onion sprouts	[68]
2010 (February)	Unidentified	4	USA (Colorado)	Sprouts	[36]
2010 (March-June)	*Salmonella* Newport	44	USA	Alfalfa sprout Seeds were the source of the pathogens.	[36,69]
2010 (August-October)	*Salmonella* Bareilly	141	Great Britain	Mung bean sprouts	[70]
2010 (December)	*Salmonella* Newport	9	USA	Clover sprouts Seeds were the source of the pathogens.	[36]
2010 (December)	*Salmonella* Cubana	3	USA	Alfalfa sprouts	[36]
2010/2011 (November-February)	*Salmonella* I 4,[5],12:i:-	140	USA	Alfalfa sprouts Tracing the supply chain revealed that the sprouts were commercially available alone or in sprout mixtures. Sprouts were also found in sandwiches at Jimmy John's restaurant.	[71]
2011 (April)	*Salmonella* Muenchen	7	USA (Michigan)	Clover sprouts	[36]

2011 (April- June)	*Salmonella* Enter-itidis	27	USA	Alfalfa sprouts, spice sprouts	[72,73]
2011 (May-June)	*Escherichia coli* O104:H4	4102 - Germany: 3976 (855 with HUS, 47 deaths)	Europe (13 countries)	Fenugreek sprouts (Germany, France), mustard and rocket sprouts (France) Fenugreek sprouts were a component of a mixture of salads and sprouts.	[3,74]
2011 (August)	*Salmonella* Agona	7	USA (Kansas)	Alfalfa sprouts	[36]
2011 (October-Novem-ber)	*Salmonella* Newport	126 (20 the Neth-erlands, 106 Germany)	Germany and the Netherlands	Mung bean sprouts	[75]molecular typing of human and food isolates and food traceback investigations. Unspecified Salmonella had been de-tected in samples of mung bean sprouts at a sprout producer (producer A
2011/2012 (December-March)	*Escherichia coli* O26 (STEC 126)	29	USA	Clover sprouts The poisoning occurred in customers of Jimmy John's restaurant.	[36]
2012 (July)	*Salmonella* Cubana	19	USA	Sprouts	[36]
2013 (December)	*Salmonella* Enter-itidis	3	USA (Utah)	Alfalfa sprouts	[36]
2014 (May)	*Escherichia coli* O121	19	USA	Clover sprouts	[36,76]
2014 (June)	*Listeria monocy-togenes*	2	USA (Virginia)	Sprouts	[36]
2014 (June – August)	*Listeria monocy-togenes*	5 (2 deaths)	USA	Mung bean sprouts	[36,77]
2014 (August)	*Escherichia coli*	24	Canada	Mung bean sprouts	[78]
2014 (September –De-cember)	*Salmonella* Enter-itidis	115	USA	Mung bean sprouts	[36,73]
2015/2016 (November-April)	*Salmonella* Muen-chen, *Salmonella* Kentucky	26 (25 *S.* Muenchen, 1 *S.* Kentucky)	USA (13 states)	Alfalfa sprouts Tracing the supply chain revealed that sprouts infected with *Salmonella* came from a single producer. Inspection of the alfalfa sprout producer showed the presence of *S.* Kentucky and *S.* Cubana in the irrigation water and on the sprouts. The FDA issued a notice not to eat alfalfa sprouts from the manufacturer, but there were more cases of poisoning. Further investigation led to the drawback of a lot of alfalfa seeds.	[79]
2016 (January- Febru-ary)	*Escherichia coli* O157	7	USA (Minnesota, Wisconsin)	Alfalfa sprouts Following an investigation, health officials advised against eating alfalfa sprouts produced by Jack & The Green Sprouts. The cause of the infection could not be identified.	[80]
2016 (May-September)	*Salmonella* Read-ing, *Salmonella* Abony	36 (30 *S.* Reading, and *S.* Abony, 5 infected with both bacteria)	USA (9 states)	Alfalfa sprouts The investigation revealed that the sprouts were obtained from a single Col-orado supplier. Sprouts were an ingredi-ent of sandwiches served in restaurants in nine states of the USA.	[81]

2018 (February)	*Salmonella* Montevideo	10	USA (Minnesota, Wisconsin, Illinois)	Sprouts The investigation revealed that the most likely cause of the poisoning were sprouts served in sandwiches at Jimmy John's restaurant.	[82]
2020 (February)	Escherichia coli O103	51	USA (10 states)	Red clover sprouts The investigation revealed that the cause of the poisoning was sprouts served at a Jimmy John's restaurant.	[83]
2022 (December)	*Salmonella* Typhimurium	63	USA (8 states)	Alfalfa sprouts (SunSprout Enterprises)	[84] [85]
2023-2025	Salmonella enterica (8 serotypes)	509	Belgium, Denmark, Estonia, Finland (94 cases), France, Germany, Netherlands, Norway (257 cases) and Sweden (110 cases)	Alfalfa sprouts from Italian seed supplier	[86] [87]

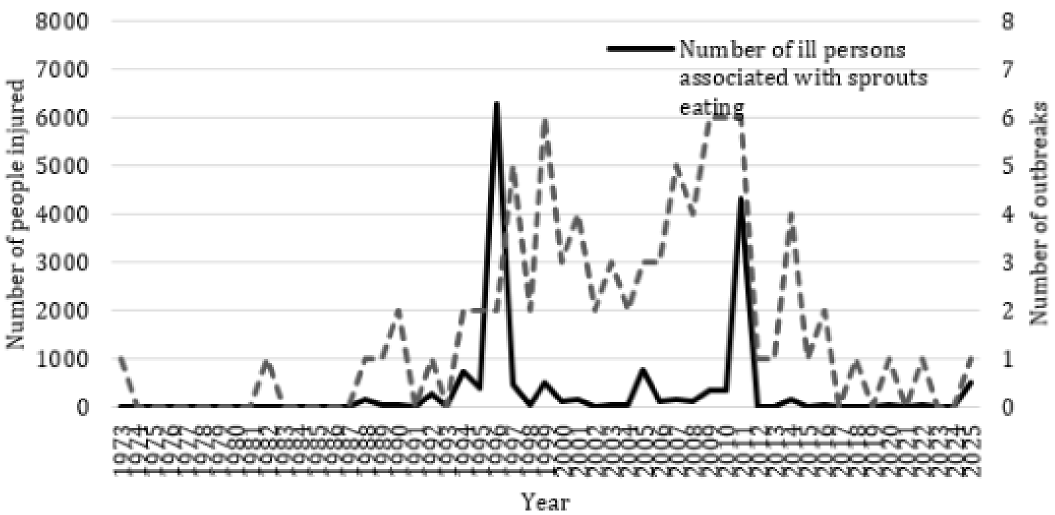

Figure 1: Number of outbreaks of sprout poisoning and number of people injured as a result of poisoning in the years 1973-2021 (based on Table 1).

Nutritional Value of Sprouts

The nutritional value of sprouts is determined by the nutritious value of the seeds and the processes that occur during the development of the young plant. During germination, seed reserve materials are released. As a result of the hydrolysis of polysaccharides, including starch, oligosaccharides, and simple sugars are produced, fats are transformed into free fatty acids, and proteins into oligopeptides and free amino acids. Due to these changes, the sprouts are rich in easily assimilated nutrients. Moreover, the share of antioxidants in sprouts; including isoflavones, polyphenols, and ascorbic acid; and the bioavailability of minerals increases [6–8]. Sprouting reduces the proportion of saturated fatty acids in favor of unsaturated fatty acids such as linoleic and α-linolenic [9–11]. The protein content of 26.1% in seeds increases to almost 30% in sprouts, and the process of their hydrolysis to oligopeptides makes sprouts a good source of proteins with better digestibility [12–14]. The concentration of minerals in sprouts is higher than in ripe vegetables, therefore their consumption is recommended by dieticians. The high nutritional value and year-round availability affect the increasing popularity of sprouts, but one should keep in mind the danger they may bring, i.e., the possibility of contamination with pathogens.

Microbiological Quality of Sprouts, Sources of Contamination with Pathogens

The microbiological quality of the sprouts is mainly influenced by the microbiological condition of the seeds, which is related to many factors to which the crop, the seeds it produces, and the sprouts from farm to fork are exposed [1,15]. One of these factors is soil contamination with pathogenic microorganisms that are introduced there as a result of fertilization with manure or composts. These fertilizers can be carriers of microorganisms of fecal origin, potentially pathogenic for humans, e.g., bacteria from the Enterobacteriaceae family and Listeria genus [16,17]. These organisms can survive in the soil for long periods depending on environmental conditions. They can develop on plants in the form of a biofilm and migrate through the root system to the other parts of plants, which makes them difficult to eradicate by washing or disinfection methods [18,19]. Under favourable conditions, pathogens can penetrate deep into the soil profile and contaminate groundwater. Using such water for watering and washing vegetables is also a significant cause of their contamination [20,21]. At the harvest stage, seeds can become infected because of poor hygiene of harvest workers or the use of treatments where seeds come into contact with the equipment contaminated with pathogens [22]. The optimal temperature and humidity during the germination process favor the growth of microorganisms, including pathogenic organisms, which are found on the surface or inside the seeds. Consequently, the total number of microorganisms can reach even more than 108 cfu·g-1 and the number of Enterobacteriaceae from 106 to 108 cfu·g-1, posing a threat to the health and life of consumers [23–26].

Outbreaks of Food Poisoning Related to the Consumption of Sprouts

Data on sprout poisoning up to the 1990s is scarce due to two main reasons. First, sprouts were not as popular in the diet at the time, and second, these young vegetables were not analyzed for the presence of intestinal pathogens, as poisonings caused by gut microbiota were not associated with this product [2]. Over half of the cases of disease after consuming sprouts were associated with alfalfa sprouts (see Figure 2). These sprouts were eaten alone or as a component of sprout mixtures. There are several reasons why alfalfa sprouts were so often a source of pathogenic microbes, causing food poisoning. Alfalfa seeds are one of the most popular seeds used in the production of sprouts due to their high nutritional value, good flavour, and short cultivation time. Simultaneously, they are a good “carrier” of Salmonella sp. since the seeds are often stored for months and years in a dry place with cooling conditions, which are optimal for these bacteria [27]. More than 25% of all outbreaks were related to the consumption of bean sprouts, a very popular ingredient in Asian cuisine [28].

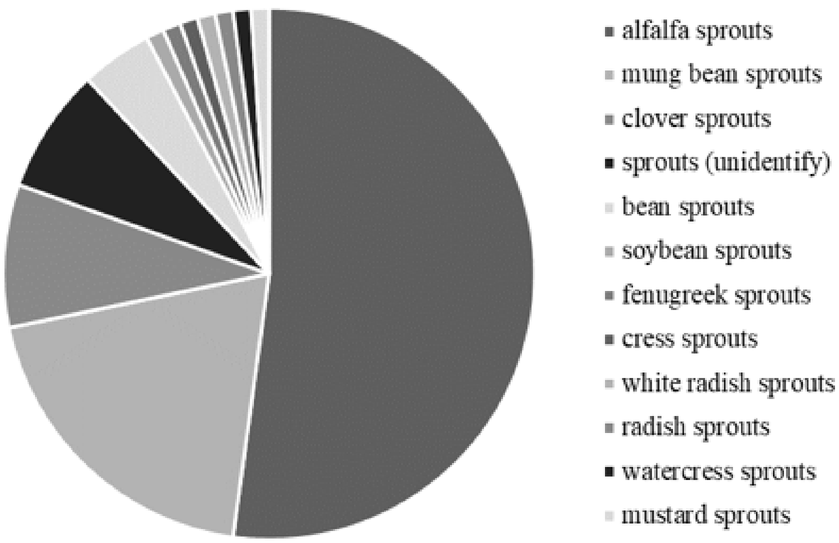

Figure 2: Sources of pathogenic microorganisms in food poisoning outbreaks related to the consumption of sprouts (based on Table 1)

The first report of poisoning related to the consumption of sprouts appeared in 1973 in the USA (see Table 1). The cause of the sicknesses of four people were soybean sprouts, cress, and mustard grown at home, infected with Bacillus cereus. The consumption of the sprouts caused nausea, vomiting, and diarrhea [29]. Clinical symptoms of poisoning are related to the type of enterotoxin produced by a given strain. The diarrheal form occurs after eating food contaminated with bacterial spores, which germinate, multiply and release toxins when they enter the small intestine. The emetic form, on the other hand, is a consequence of intoxication with the emetic toxin - cereulidin, which causes serious food poisoning, often fatal [30,31]. The optimal temperature for the synthesis of the toxin is 21oC, while the production of cereulidin at 8-10oC and above 35oC is low [32]. Thus, the storage of food products in inappropriate conditions Favors its synthesis.

Yersinia enterocolitica poisoning is not as common as other foodborne pathogens. This is a result of the relatively high infectious dose of 109 cells [33]. This bacterium is widespread and can be found in animal foods, meat, and dairy products, as well as in reservoirs and watercourses. The ability to grow in refrigerated conditions, at a temperature close to 0°C, poses a threat to unprocessed or ready-to-eat food. Y. enterocolitica is capable to develop during seed germination and in the later stage of sprout storage [1,3]. The only case of yersiniosis after consuming sprouts was reported in the USA in 1982 (Tab. 1). A number of 16 girl scouts were poisoned after eating bean sprouts. The water used to produce the sprouts was the probable source of the bacteria [34]. Similar to Bacillus cereus and Yersinia enterocolitica, one outbreak of food poisoning caused by Staphylococcus aureus has been reported so far after consuming sprouts (see Table 1). This bacterium lives on the skin and mucous membranes of warm-blooded animals, its carrier is often asymptomatic [3]. With S. aureus poisoning, symptoms are milder compared to other microorganisms and disappear rather quickly, hence staphylococcal food poisoning is not always reported and is confused with common food ailments [35]. In 2008, 42 people in Denmark suffered from vomiting, diarrhea, stomach cramps, extreme exhaustion, also with fever, after consuming mung bean sprouts. In the United States, in the years 1998 to 2015, 58 outbreaks of listeriosis were reported, while other poisonings related to the consumption of food contaminated with pathogens accounted for over 18,000. The number of deaths from the consumption of food contaminated with Listeria monocytogenes accounted for more than half of all deaths associated with food poisoning [36,37]. To date, three outbreaks of L. monocytogenes related to the consumption of sprouts have been confirmed (see Table 1). All these incidents took place in the USA in 2008 and 2014. A total of 27 people got poisoned and two died.

More than 70% of all food poisoning outbreaks related to the consumption of sprouts were caused by Salmonella Enteriditis (see Table 1). Other etiological factors were the serotypes of S. Newport, S. Cubana, S. Saintpaul, and S. Typhimurium. Most of the outbreaks caused by the genus Salmonella occurred in the USA, but salmonellosis was also often reported in the countries of Northern Europe (see Table 1). At the end of the 1980s, in Great Britain, 150 people suffered from food poisoning caused by Salmonella after consuming sprouts. S. Saintpaul and S. Vichrow PT34 serotypes were identified on mung bean seeds. As a consequence of poisoning involving so many patients, the US Department of Health and Social Security issued recommendations regarding the thermal treatment of sprouts to eliminate the possible risk. It was recommended to boil the sprouts for 15 seconds before consumption [38]. Outbreaks of food poisoning caused by Salmonella Stanley in 1995 occurred simultaneously in Finland and the USA. A supply chain investigation showed that the alfalfa seeds that were transferring the pathogen in both countries were obtained from the same Danish distributor [42,45]. A year later, another salmonellosis was detected in the USA, which affected over 500 people (see Table 1). S. Montevideo and S. Meleagridis were found on alfalfa sprouts. An investigation at the sprout producer's site revealed that the source of the contamination was seeds of plants grown in soil previously fertilized with chicken manure and in contact with horse manure stored nearby [2]. The numerous cases of poisoning caused by the consumption of sprouts in the United States resulted in the development of the Food and Drug Administration (FDA) guidelines for both the production of seeds and sprouts, as well as their storage methods. Seed growers have been required to use Good Agriculture Practice (GAP) to reduce contamination. In the guidelines for seeds, the FDA recommended treatments that reduce or eliminate pathogens, e.g. with 20,000 ppm calcium hypochlorite solution [5]. Despite the FDA announcements and the promotion of guidelines on seed preparation procedures for sprouting, numerous cases of food poisoning after sprout consumption were continuously reported in the USA (see Table 1). In 1999, 89 people got poisoned after consuming sprouts. Salmonella Mbandaka was present on alfalfa seeds used for germination, and the producers did not use sodium hypochlorite disinfection. A year later, S. Enteriditis PT 33 bacilli were identified on mung bean sprouts, which are an ingredient of dishes in restaurants in the area of four US states (see Table 1). A supply chain investigation revealed that the sprouts were sourced from a producer who sanitized the seeds with a 2,000 ppm sodium hypochlorite solution, i.e. 10 times lower than the FDA recommendation. From 2000 to 2002, the S. Entiriditis serotype was the cause of several poisonings in North America. In most cases, the source of the poisoning was mung bean sprouts, the seeds of which were sourced from China [28]. In total, almost 5,000 people suffered from food poisoning as a result of consuming sprouts in which Salmonella sp. was present.

The consumption of sprouts contaminated with Escherichia coli caused the poisoning of over 10,000 people (see Table 1). Between 1973 and 2015, 16 E. coli outbreaks were recorded, including two epidemics. Escherichia coli is part of the naturally occurring microflora of the large intestine of humans and warm-blooded animals. Usually, E. coli is not dangerous, but some pathotypes may cause infections, especially in immunocompromised people and newborns. E. coli is ubiquitous in feces and through poor sewage management, it can get into soil and water and, consequently, to food products, posing a risk to consumers [88]. The first case of food poisoning due to the presence of Escherichia coli O157: H7 on white radish sprouts was reported in Japan. At that time, over 5,700 people got poisoned and three people died. Sprouts were an ingredient in dishes served in the canteens of primary schools in Sakai City and a factory located 50 km away from the city [46,47]. In 1997, alfalfa sprouts were the source of E. coli in the USA (see Table 1). A supply chain investigation revealed that the source of the pathogens on the sprouts were seeds contaminated with soil-borne microorganisms. The presence of wild animals was reported near the crops and their faces could be the cause of infection. Another possible source of E. coli could have been manure used for the fertilization of soil or contaminated water used for irrigation [50]. In May 2011, in Germany, an epidemic of haemolytic uremic syndrome and hemorrhagic diarrhea related to Shiga-toxic Escherichia coli infections belonging to the serotype O104: H4 took place [3]. In the period from May 1 to August 16, 2011, there were 855 cases of the haemolytic uremic syndrome and approximately 3,000 cases of food poisoning caused by E. coli in Germany [89,90]. Even though the peak incidence occurred on May 21 and 22, until June 28, 2011, cases of poisoning in other European countries were confirmed in people who were in northern Germany in May. Initially, these cases were not associated with contaminated food. Only another post-peak investigation revealed that vegetables such as tomatoes, cucumbers, or lettuce, which were eaten raw could have caused the E. coli outbreaks [91]. The interviews with patients showed that only 25% of them ate sprouts, therefore, they were not considered a source of pathogenic microorganisms at that time. However, when the distribution of sprouts in Germany was suspended in the first days of June, no new outbreaks appeared. In June 2011, France also reported numerous cases of hemorrhagic diarrhea and haemolytic uremic syndrome. A supply chain investigation across Germany and France revealed that the source of E. coli O104: H4 were fenugreek seeds from a single batch from an Egyptian producer. The seeds were grown organically in Egypt and, most likely, have been infected during production or harvesting by contact with manure [3].

Guidelines for Producers of Seeds and Sprouts

Sprouts were and still are the cause of food poisoning. Organizations related to public health and food safety prepared information campaigns and participated in the work on regulations aimed at reducing the occurrence of poisoning. In 1995, the US Food and Drug Administration commissioned the National Advisory Committee on Microbiological Criteria of Food to analyze food poisoning associated with the consumption of unprocessed food. Based on this report, in 1999 guidelines for sprout producers were developed, which recommend the application of Good Agricultural Practices (GAP) and Good Manufacturing Practices (GMP). Producers were also advised to disinfect seeds for sprout production with a 20,000-ppm sodium hypochlorite solution [5,92]. Simultaneously, the Food and Drug Administration announced more intensive inspections, the scope of which was extended to the sampling of seeds, sprouts, and water, as well as staff controls. In 1999, when new recommendations for sprout producers were introduced, numerous inspections were performed and in almost half of the companies inspected at that time, flaws affecting the health and safety of consumers were found. The re-inspection of sprout producers by the FDA in 2000 showed fewer failures compared to the first inspection [92]. In 2000, in the United States, an agreement was made between public health organizations that developed an educational and information campaign dedicated to sprout producers. In the years 2005-2007, the Food and Drug Administration did not record any outbreaks of poisoning caused by the consumption of sprouts, hence it can be concluded that the introduction of guidelines for sprout producers, information campaigns, and controls achieved the intended effect. When, at the end of 2008, sprouts were again the cause of food poisoning in the US citizens, the FDA recommended complying with the guidelines developed in 1999 [92].

Not only public health authorities in the United States have developed recommendations for sprout producers and distributors. International guidelines for the hygiene of sprout production can be found in Codex Alimentarius, Annex 2 of the Code of Hygienic Practice for unprocessed fruit and vegetables. Similar to the FDA recommendations, Codex Alimentarius also emphasized that the manufacturer should follow the Good Practices at every stage of the production. This document also mentions the use of seed disinfection before sprouting as a preventive method against food poisoning [93]. In 2007, the Canadian Food Inspection Agency (CFIA) prepared guidelines for Canadian sprout producers. The Code of Hygienic Production of Sprouted Seeds includes guidelines from the Good Agricultural Practice, application of organic fertilizers, and hygiene requirements for staff. Besides the guidelines specific to primary production, the CFIA recommended sprout producers to use hazard monitoring based on the principles of Hazard Analysis and Critical Control Point (HACCP) [94]. A year later, the World Health Organization (WHO) food poisoning outbreak research and control guide was published. The guide included, among others, questionnaires to be conducted in the event of suspicion of an outbreak caused by the consumption of sprouts [95]. 2009, due to the increased incidence of food poisoning outbreaks related to the consumption of sprouts in Australia in 2005-2006, work began on establishing guidelines and standards for sprout production. Consequently, a report was prepared by the Food Standards Commission in Australia and New Zealand (FSANZ), referring to guidelines and recommendations for producers and distributors of seeds and sprouts [62]. In the European Union countries, standards and guidelines for sprouts were included in the regulations on unprocessed food. However, the 2011 epidemic in EU countries caused by Escherichia coli O104: H4 found on fenugreek sprouts initiated work on regulations concerning the import of seeds for sprouts. The 2013 EU Regulations contained requirements for the traceability of seeds and produced sprouts, microbiological criteria and sampling guidelines, certificates for seeds or sprouts imported from third countries into EU countries, and requirements that must be met when approving companies producing sprouts [96–99].

Requirements for the Microbiological Quality of Seeds and Sprouts

According to the Commission Regulation (EC) No 2073/2005 as amended by Commission Regulation (EU) No 209/2013, sprout producers must pre-check a representative sample of each batch of seeds for the presence of verotoxic E. coli (STEC) O157, O26, O111, O103, O145, and O104: H4 and Salmonella spp. Only those batches of seeds that have passed the test may be approved for use. Assessment of the above-mentioned microbiological quality should be performed not earlier than 48 hours before the germination process begins, at least once a month. No STEC or Salmonella spp. can be detected in any of the seed samples. If the laboratory has proven that the product is free from microbial contamination, sprouts produced from the batch analyzed may be introduced on the market. Producers are also required to test sprouts against food safety criteria when products are placed on the market during their shelf-life. Thus, Salmonella spp. and STEC must not be present in 25 g of the product, and the upper limit for Listeria monocytogenes is 100 cfu·g-1 [97]. If sprouts are contaminated with L. monocytogenes, they may be further processed, but a treatment eliminating the threat should be applied. Such action may also be taken for STEC or Salmonella spp., provided that the treatment eliminates the danger and has been approved by the competent authority.

Methods of Sprout Decontamination

The delicate structure of the sprouts and the need to maintain their growth potential are the two main factors that limit the choice of disinfection methods. Nonetheless, multidirectional research is undertaken to reduce the number of microorganisms in both seeds and sprouts. Various physical, chemical, and biological factors are used for this purpose, either individually or in combination (i.e., hurdle technology). The use of combined methods is most efficient and, at the same time, preserves the nutritional value of the sprouts [100–102]. As shown by Kruk and Trząskowska [103], they are also effective in reducing the bacterial biofilm present on seeds, which may cause the contamination of sprouts.

Physical Methods

Physical treatments used in seed disinfection are based on the use of high temperature, high pressure, ultrasounds, UV and gamma irradiation, and plasma-activated water (PAW). Thermal methods include the use of hot water, steam, and hot dry air. Depending on the type of seed, water with a temperature ranging from 50 to 85°C is used for a few seconds to an hour [3]. Weiss and Hammes [104] disinfected mung bean seeds in water at 80°C for 2 minutes, thus reducing the number of Salmonella spp. by six orders of magnitude. Dry air with a temperature of 40-80°C can also be applied for several hours to even several days for the thermal disinfection of seeds [3]. Bari et al. [105] heated radish and mung bean seeds in the air at 50°C for 24 hours, which decreased the E. coli population by 105 and 103 cfu·g-1, respectively. To improve the efficiency of the thermal inactivation of the seed microorganisms, additional high pressure can be used. Neetoo, Pizzolato, and Chen [106] treated alfalfa seeds with air at 40 and 45°C at a pressure of 550 MPa. The combination of those methods resulted in the elimination of E. coli bacilli on the seed surface within just 2 minutes. There are also trials to decontaminate seeds with electromagnetic radiation. Thayer et al. [107] used ionizing radiation to decontaminate alfalfa seeds for sprouts and achieved a 90% reduction of the E. coli and Salmonella sp. populations at a dose of approximately 1 kGy. Gamma radiation was also used to disinfect ripe ad ready-to-eat mung bean and radish sprouts. Bari et al. [108] decreased the number of E. coli and Salmonella bacteria below the detection threshold with a dose in the range of 1.5-2.0 kGy, and in the organoleptic evaluation, the irradiated sprouts were still acknowledged by the consumers. Chiu [109] showed that ultrasonication is one of the most effective decontamination methods of seeds used for the production of sprouts. It enables both the total number of aerobic microorganisms and total coliforms to be reduced to less than 3 logs cfu·g-1 on alfalfa, mung bean pea, and radish sprouts. Another, less conventional, decontamination method is a pulsating magnetic field. They were used by Lipiec et al. [110] with 5-day oat sprouts, who reported a significant reduction in microbial contamination of the product, dependent on the field strength and frequency. With five impulses of 5T at 250 µs intervals, the number of bacteria was halved, and the number of molds and yeasts was tenfold lower. The potential of nonthermal plasma-activated water (PAW) was also verified in the decontamination of mung bean sprouts. It was found that within 30 minutes the populations of total aerobic bacteria and fungi were decreased by 2.32-2.84 log cfu·g-1 [111].

Chemical Methods

Chemical methods consist in treating seeds or sprouts with bacteriostatic compounds. The most commonly used chemicals are chlorine compounds (chlorine, sodium or calcium hypochlorite, chlorine dioxide), organic acids (acetic acid, peracetic acid, lactic acid), electrolyzed water, hydrogen peroxide, ethanol, ammonia, and ozone [3,105,106,112,113]. The Food and Drug Administration recommends decontaminating the seeds for sprout production with a 20,000 ppm sodium hypochlorite solution [5], however, calcium hypochlorite is also effective in disinfecting seeds for sprouts and the sprouts themselves. Fett and Cooke [114] reported a decrease in the bacteria number on alfalfa seeds by more than 3 orders of magnitude by using an active chlorine concentration of 16,000 ppm for 10 minutes. Extending the disinfection duration in mung bean seeds with the same compound to 15 minutes reduced the E. coli and Salmonella populations by 3.9 and 5.0 logs, respectively [115]. Hypochloric acid is the most powerful antimicrobial component of acid electrolyzed water (AcEW). Its application with alfalfa seeds (redox potential of around 1 mV, the concentration of hypochlorite ion: 50-84 ppm, time: 10-64 minutes) reduced the number of microorganisms present on the seed surface by 1.5-2 logs [3,113]. On the other hand, Sharma et al. [116] treated alfalfa seeds and sprouts with 21 ppm ozonized water for 64 minutes. This led to a reduction of the E. coli population by 2.2 orders of magnitude. Wade et al. [117] conducted a similar experiment in which, after a 20-minute treatment of alfalfa seeds with ozone water at a concentration of 21.8 ppm ozone, a 50% reduction in the L. monocytogenes population was reported. Organic acids are also effective and safe compounds that can be used to control the bacterial flora on the seeds and sprouts. They have the status of generally recognized as safe (GRAS), and their acceptable daily intake (ADI) does not require limitation [118]. For the decontamination of alfalfa and radish seeds, Nei et al. [119] used an 8.7% (v/v) acetic acid solution at 55°C for 3 hours, which resulted in a 5 log reduction in the number of E. coli cells. When the time of treatment with the disinfecting agent was extended to 24 hours, full elimination of microorganisms from the seed surface was achieved. On the other hand, Lang, B.H. Ingham, and S.C. Ingham [120] treated alfalfa seeds with lactic acid. After soaking the seeds for 10 minutes in a 5% solution at 42°C, the authors reported a 3 log reduction in the number of E. coli cells without affecting the viability of the seeds. The combined action of various chemical compounds is also studied, e.g., for the disinfection of alfalfa seeds, an aqueous mixture of 15% caprylic and decanoic acids (3:2), 15% lactic acid, and 7.5% monolaurin was used. The seeds were soaked for 3 minutes in a disinfecting mixture, which resulted in a reduction of pathogens present on the seed surface by 3.9-6.2 logs while maintaining seed viability above 90% [121].

Biological Methods

The use of antagonistic bacteria against pathogens, essential oils, or bacteriophages are the main biological methods used in the decontamination of seeds and sprouts [122–124]. These treatments are based on the inoculation of seeds with microorganisms that produce substances with antimicrobial activity, such as bacteriocins, organic acids, and enzymes. Matos and Garland [125] inoculated seeds with the Pseudomonas fluorescens 2-79 strain, which had previously been used to protect plant roots against soil pathogens. The authors reported a reduction in the number of Salmonella spp. cells by more than 4 logs already on the first day of germination. On the other hand, Fett [126] suspended P. fluorescens in the water used to soak the seeds before sprouting, which reduced the S. enterica population from 10 to 5 logs after 6 days of germination. Lactic acid bacteria are also used to protect the sprouts. They can grow during germination, producing lantibiotics or hydrogen peroxide, which inhibit the development of pathogens [127,128]. The Lactobacillus plantarum 299v strain used for seed decontamination in combination with H2O at 60°C and a disinfecting mixture consisting of H2O, H2O2, and CH3COOH was used to eradicate the biofilm formed by Escherichia coli and Salmonella [103]. Bacteriocins, especially those produced by lactic acid bacteria, also have great potential in reducing seed and sprout contamination. Among numerous substances of this type, only two - nisin and pediocin PA-1 / AcH have been approved for use as food additives by the FDA and, although they are not approved for contact with vegetables, the results of several studies indicate that they would be good natural antimicrobials and alternatives to chemical food preservatives. The effects of nisin and pediocin on the survival of five Listeria monocytogenes strains on cabbage, broccoli, and mung bean sprouts were tested [129]. Bacteriocins were used alone or in combination with chemicals, and it was found that the growth of Listeria spp. was most effectively inhibited by the mixture of nisin, pediocin, and phytic acid, leading to a 1.2-log cfu·g-1 decline in bacteria number.

Bacteriophages also have great antagonistic potential against many pathogens, such as Salmonella spp., Shigella spp., and E. coli, which may be present in food and its production environment. Liao et al. [130] evaluated the biocontrol potential of Phage Sa45lw against various strains of bacteria that can contaminate the sprouts. It was found that the phage had a broad host range with lytic activity against generic E. coli (ATCC 13706), E. coli O45:H16, E. coli O45:H-, E. coli O157:H7 (RM18959, ATCC 35150, and ATCC 43888), Salmonella Montevideo, S. Thompson, and S. Anatum. Phage Sa45lw was particularly effective in reducing E. coli O45:H16 on the contaminated mung bean seeds for 15 min by 2 logs at 25°C. It was also found that the method of phage application to sprouts affects the efficiency of contamination reduction. Gientka et al. [131] studied the effect of 18 phages targeting bacteria dominant in sprouts by using two application methods - spraying and an absorption pad. The first method was significantly more efficient, and the maximum reduction effect after 48 h was 1.5 log cfu·g-1. Plant extracts and essential oils also have bacteriostatic properties that can be used to eliminate pathogens from seeds. Natural substances that inhibit the development of microflora include extracts of spices and plants - cinnamon, thyme, grapefruit, horseradish, tea, and others [132,133]. Singh, N., Singh K., and Bhunia [134] used thyme oil to treat the seeds. Soaking alfalfa seeds for 3 to 10 minutes in a solution containing 0.5% thyme extract resulted in a reduction of the E. coli population by over 2 logs. Even higher efficiency was achieved by using a combination of three substances, i.e., chlorine dioxide, ozone, and thyme oil. There was a reduction in the number of pathogens from 6.12 to 2.80 logs.

Despite the efforts made by scientists, global organizations, and EU institutions, so far, no effective method of sprout decontamination has been developed that would guarantee a product that would be safe for the consumer. There are still cases of food poisoning caused by the consumption of this product all over the world, therefore there is a need for further research and implementation of new solutions to prevent fatal incidents. However, it seems that seed disinfection alone cannot eliminate microbial contamination in sprout production. To minimize microbial hazards associated with sprouts, some systemic solutions should also be implemented [135].

Conclusions

Sprouts, while recognized for their exceptional nutritional and health-promoting properties, remain one of the most problematic food products in terms of microbiological safety. Analysis of over 80 documented outbreaks of foodborne illnesses between 1973 and 2025 reveals a persistent pattern of contamination primarily with Salmonella spp. and Escherichia coli, leading to serious public health consequences, including large-scale epidemics and fatalities. Despite the introduction of hygiene guidelines, disinfection protocols, and international regulations, outbreaks continue to occur worldwide, indicating that current preventive measures are not universally effective or consistently applied. Particularly alarming is the high vulnerability of raw sprouts to contamination due to favourable conditions for pathogen growth during germination, the difficulty in eliminating microorganisms through post-harvest treatments, and gaps in traceability and monitoring, especially for imported seeds. The collected data clearly highlight the urgent need for a comprehensive and multi-level strategy to ensure the microbiological safety of sprouts. A key component of this strategy involves the strict enforcement of Good Agricultural Practices (GAP) and Good Manufacturing Practices (GMP), covering every stage of the production process—from seed cultivation to packaging of the final product. Equally important is the mandatory decontamination of seeds prior to sprouting, using methods that have been scientifically validated for their effectiveness. Regular and standardized microbiological testing of both seeds and sprouts is also essential. This enables the early detection of potential contamination and helps prevent unsafe products from reaching consumers. Moreover, public awareness campaigns are needed to educate consumers about the health risks associated with eating raw sprouts. Increased knowledge in this area can lead to more informed dietary choices and encourage adherence to safety recommendations for handling, preparing, and storing sprouts.

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