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Safety of Water Used in Food Production

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INTRODUCTION

Water is an indispensable resource for the food industry, which has many applications. In general, water is often taken lightly in most food preparation and processing operations. Water has a wide variety of uses in food production, for cleaning, sanitation, and

manufacturing purposes. In addition to being an ingredient in many foods, it may be used for various other operations, such as for growing, unloading, fluming, washing, brining, ice manufacture, and in sanitation and in hygiene programs. Water quality has great detrimental impact on products and operations in food production systems. The fundamental importance of water quality in food production is often underestimated. This underestimation generally becomes the underlying cause for several problems, such as mismanagement of water, equipment operation, and maintenance issues; loss of revenue; food safety; and product quality.

Food safety and food security are interrelated concepts that have a profound impact on the quality of human life. There are many external forces that affect both of these areas. Food safety is a very broad term. It covers many aspects of handling, preparation, and storage of food. Water is an inherent component in food production. In-depth understanding is required to know the impact of these factors on food safety. Every care in detail is essential to prevent illness and injury from the viewpoint of food production. Food production also covers chemical, microbiological, and microphysical aspects of water and food safety. Therefore, for adequate control of food chemical quality, control of allergens that can be life threatening to people who are highly sensitive to such allergens gets top priority in ensuring food safety. Any pathogenic bacteria, viruses, and microorganisms may produce toxins, which act as possible contaminants of water used in food production and that therefore affect food safety. At times, microphysical particles such as glass and metal, when present in water, can be hazardous and cause serious harm to consumers.

RESOURCES OF WATER

It is estimated that the world has about 1386 million km³ of water. Out of this water, 35 million km³ (2.5%) is freshwater. The significant amounts of freshwater (24.4 million km³) are present in ice caps, glaciers, and deep in the ground, which is 10.5 million km³ that is not accessible for use. Water which can be used comes essentially from rainfall over land, generated through repeated evaporation and periodic precipitation, the so-called hydrological cycle. Water is continuously recycled as a result of evaporation driven by solar energy. Therefore, the hydrological cycle consumes more energy each day than that used by humankind over its entire history.

Globally, the average annual rainfall over land is around 119,000 km³. Out of this amount 74,000 km³ evaporates back into the atmosphere. The remaining 45,000 km³ flows into lakes, reservoirs, and streams or infiltrates into the ground to replenish the aquifers. Not all of the 45,000 km³ is accessible for use, as part of the water flows into remote rivers and flows down during seasonal floods. An estimated 9000–14,000 km³ is economically available for human use. This is equivalent to a teaspoon in a full bathtub, when compared to the total amount of water on earth (FAO, 2002).

When we talk about freshwater, in general, it refers to the water present in rivers, lakes, underground water, and glaciers. All this water is collectively termed as “*blue water*.” Only part of the total rainfall accounts for this freshwater supply. The majority of rainfall that comes down on the Earth’s surface either evaporates directly as ‘nonbeneficial evaporation’

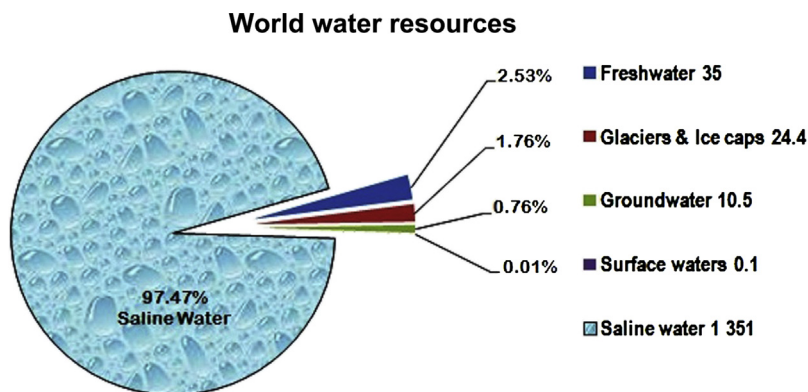


FIGURE 9.1 Distribution of water in world (figures in the legend are volume of water in millions km³, while in the chart it is in percentage of total water).

or, after being used by plants, as 'productive transpiration'. This second type of rain water is called *green water*. The proportion of green water, out of the total available freshwater supply, varies between 55% and 80%, depending on the local wood density as well as on the region of the world. Storing of more green water in soil and plants, as well as storage as blue water, is the biggest opportunity and challenge for future water management.

Out of the total freshwater, over 60% of rain water is green water, which evaporates above savannah grazing land, forests, and agricultural land. About 40% of rain water (43,000 km³) present in rivers, lakes, groundwater, and glaciers constitutes blue water, which then ultimately flows back into the oceans. Blue water withdrawals by humans are about 9% (or 3900 km³) of total blue water resources. Of these, 70% is being used for irrigation (2700 km³) and the remaining 1200 km³ is used for industry and households, while only a very small part of this water cycle serves as drinking water (Aquastat, 2014).

The water used in food production is potable water (i.e., drinking water). It may come from a variety of possible sources including surface water such as streams, rivers, lakes, groundwater (e.g., underground natural springs, wells), rainwater, and seawater (after desalination). The quality of water is essentially dependant on the source of water. Adequate treatment of the water is necessary to ensure that it meets a drinking water standard which is safe to be used in food production (i.e., safe for human consumption). The food industry is supplied drinking water primarily in two ways. Firstly, it is by public distribution by local government authorities, and secondly through private supply by the food business itself. In European countries, the majority of drinking water supplied to the food industry comes from public distribution system by government authorities.

WATER IN FOOD PRODUCTION

In a very broad sense, there are four major uses of water in food production: (1) primary production, (2) cleaning and sanitation, (3) processing operations, and (4) as food ingredient.

Water in Primary Production

Food and agriculture sectors are the largest consumers of water. The largest use of water is in primary food production. In agriculture, water is predominantly used for crop irrigation purposes. In livestock farming, large volumes of water are used for livestock watering along with maintenance of general hygiene of the animals and equipment.

The demand of water for agriculture is one hundred times more than it is used for personal needs. Global distribution of water is shown in Fig. 9.1. The largest percentage (69%) of the global freshwater withdrawals is committed to agriculture. The industrial sector uses 19%, while a small fraction of only 12% of the water withdrawals are destined for households and municipal use. Currently, around 3763 km³ of freshwater is withdrawn each year for human use (Aquastat, 2014). Of this, grossly half is actually consumed as a result of evaporation, incorporation into crops, and transpiration from crops. The other half recharges groundwater and surface flows or is lost in unproductive evaporation. The majority, up to 90% of the water withdrawn for domestic use, is returned to rivers and aquifers as wastewater. Industries consume only about 5% of the freshwater they withdraw.

The global nutrition has significantly improved since the 1960s, providing more food per capita at progressively lower prices. This was possible due to developments in high-yielding seeds, irrigation, and plant nutrition. The main source of food for human population in the world is agriculture, and this term also includes livestock husbandry and forestry. Food production from the livestock sector has diversity such as meat (beef, pork, poultry, and others), dairy products, and fishes, aquatic or sea food. As the population keeps increasing, more food and livestock feed has to be produced in the future, and obviously more water is required for this purpose. Thus, agriculture has to claim larger quantities of water to produce the food required to feed the world.

The pattern of global agricultural water withdrawal is uneven (Fig. 9.2). It is least in European (25%) and American (48%) countries while maximum in Asian and African countries (81%) around 2010. There is reverse trend in water withdrawal for industrial use. It is higher in Europe (54%) and America (37%), while it is least in Asia (10%) and Africa (4%) (around 2010). Asian countries use the highest total volume of water for agriculture in the world (2556 km³/year), and the least is in the Oceania countries (25 km³/year), which include Australia, New Zealand, and other Pacific Islands (Aquastat, 2014).

The concept of “water footprint” provides an appropriate framework for analysis to find the link between the consumption of animal products and the use of the global water resources. The water footprint is defined as “the total volume of freshwater that is used to produce the goods and services consumed by an individual or community.” It is baffling but true that the water footprint of any animal product is larger than the water footprint of a wisely chosen crop product with equivalent nutritional value. The most logical reason lies in the fact that animals are secondary consumers in the food chain; therefore, in the calculation of water footprint of animals always adds up inherent increments of primary consumers. Twenty-nine percent of the total water footprint of the agricultural products in the world is related to the generation of animal products. One third of the

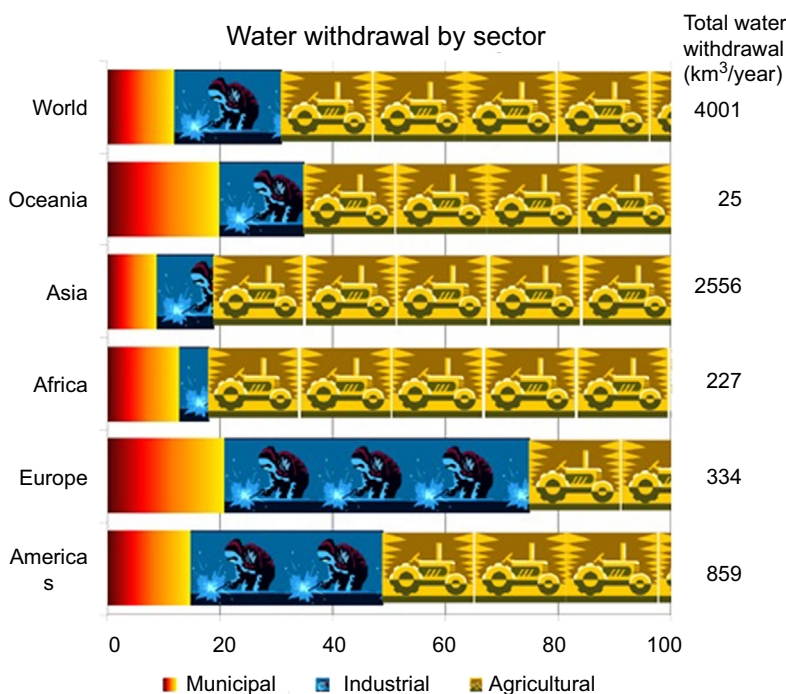


FIGURE 9.2 Comparison of sectorial water withdrawal in the world (percentages of the total water withdrawal per year. The values are the volume of water in km³/year, around 2010).

global water footprint of animal production is related to beef cattle (Mekonnen and Hoekstra, 2010).

It is very much insidious that global meat production has almost doubled in the period from 1980 to 2004, and this trend is likely to continue in future, given the projected doubling of meat production in the period from 2000 to 2050 (Steinfeld et al., 2006). The on-going shift from traditional extensive and mixed farming to industrial farming systems is likely to continue to meet this rising demand for animal products. This intensification of animal production systems will result in increasing blue and gray water footprints per unit of animal product due to the larger dependence on concentrate feed in industrial systems. The pressure on the global freshwater resources will therefore increase both because of the increasing meat consumption and the increasing blue and gray water footprint per unit of meat consumed (Mekonnen and Hoekstra, 2010).

Plants require water in adequate quantities and at the right time for vegetative growth and development. Crops have very specific water requirements, and these vary depending on local climate conditions. The production of meat requires between 6 and 20 times more water than for cereals. An overview of the water consumption in food and agriculture is given in Table 9.1, which shows examples of water required per unit of major food products, including livestock that consume the most water per unit. Cereals, oil crops, and pulses, roots, and tubers consume far less water (FAO, 2003).

Virtual water concept emerged in the 1990s to draw increasing focus of people concerned with water management, and in particular with water related to food production.

TABLE 9.1 Water Consumption in Food and Agriculture

	Products	Unit	Water Required in m ³ Per Unit
1	Cereals	kg	1.5
2	Pulses	kg	1.0
3	Citrus, fruits	kg	1.0
4	Palm oil	kg	1.0
5	Fresh poultry	kg	6.0
6	Fresh lamb	kg	10.0
7	Fresh beef	kg	15.0
8	Sheep and goat	Head	500.0
9	Cattle	Head	4000.0

Source: Adapted from FAO, 2003. *Agriculture, Food and Water. Food and Agriculture Organization of the United Nations, Rome, Italy*, <http://www.fao.org/docrep/006/Y4683E/y4683e07.htm#P0_0> (accessed 8.11.18.).

Virtual water is defined as the water embedded in a product, that is, the water consumed during its process of production. The value is generally expressed in terms of volume (m³), which results from multiplying the quantity of product (kg) by the unit value. On an average, it takes 2–4 L/day to satisfy the biological needs of drinking water of a human being. This may be around 1000 times as much water as required to produce the food for normal person. Therefore, the concept of virtual water is so important when discussing food production and consumption. In other words, when a country imports 1 million tons of wheat, it is also enlarging its water resource by 1 billion m³ of water.

Specific values for the water equivalent of a selection of food products are variable, and it is highest for animal food. For instance: Cattle 4000 m³/unit; Sheep and Goat 500 m³/unit; as compared to plant food like palm oil 2 m³/unit; fruits, pulses, and vegetables 1 m³/unit of consumption. At a global level, the importance of virtual water is likely to dramatically increase as projections show that food trade will increase rapidly. It may be doubling for cereals and tripling for meat between 1993 and 2020. Hence, the transfer of virtual water embedded in the food which is traded is becoming an important component of water management on a global as well as regional level, especially in the water scarce regions (Renault, 2002).

Water in Sanitization

Water is a universal solvent. Cleaning is a very broad term. When used in the context of food handling, it implies the complete removal of food soil and associated nonfood visible components using water and detergent chemicals by appropriate methods or processes, under recommended conditions. The most important first step is flushing with water to remove visible soil. Cleaning also refers to washing of the equipment,

instruments, containers, plants, associated machinery, and even the personnel who handle raw or processed food. In all practical purposes, the quality of water used for cleaning and washing should be similar to potable water.

Sanitization refers to the reduction of microorganisms to the level that is considered safe from a public health viewpoint. It is essential to differentiate and define certain terminologies in the context of food safety. *Sterilization* is the statistical destruction and removal of all living organisms, whereas *disinfection* refers to inanimate objects and the destruction of all vegetative cells (not spores). The official definition of sanitizing for food product contact surfaces as given by the Association of Official Analytical Chemists is a process that reduces the contamination level by 99.999% (5 logs) in 30 seconds (Schmidt, 1997).

Water is used in sanitization. It can be used alone or it can be used along with some chemical agent for effective sanitization. The *chemical sanitization* involves the use of chemical sanitizer at a specified concentration and contact time. In chemical sanitization, water is used as medium or vehicle for more effective and efficient cleaning and sanitization. It is imperative to understand basic water chemistry and microbiology before selecting a cleaning compound. The chemistry of waters may differ significantly from different sources. Water chemistry can also affect sanitizer performance. Water used for cleaning must be of good microbiological quality. The recommended microbiological guidelines for water destined for final cleaned water must have total plate count $<500 \text{ mL}^{-1}$, coliform $<1 \text{ mL}^{-1}$, and psychotrophs $<10 \text{ mL}^{-1}$ (ILSI, 2008).

Water is involved in approximately 95–99% of cleaning and sanitizing operations of food productions. Water functions as a vehicle to carry the detergent or the sanitizer to the surface as well as removes soil or contaminations from the food surface. The effectiveness of a detergent or a sanitizer is drastically altered by impurities in water. Water hardness is the most important chemical property that has a direct effect on cleaning and sanitizing efficiency. Hardness of water is measured in parts per million (ppm) or grains per gallon (gpg). Water having 0–60 ppm (0–3.5 gpg) hardness is soft water, 60–120 ppm (3.5–7 gpg) is moderately hard, and 120–180 ppm (7–10.5 gpg) is hard water, whereas $>10 \text{ ppm}$ (>10.5) is considered as very hard water.

The chemistry of the water, the hardness in particular, greatly affects the performance of cleaning chemicals. Water hardness increases detergent consumption. It can cause formation of film, scale, or precipitates on equipment surfaces. Ignorance in proper understanding of water chemistry can cost money and economic losses to the processors. It may be in the form of increased use of cleaning agents or increased cleaning time.

Water pH ranges generally from 5 to 8.5. This range is of no serious consequence to most detergents and sanitizers. However, additional buffering agents may be required for highly alkaline or highly acidic water. Chlorine is more effective at lower pH. At the lower pH, more hypochlorous ions are formed, and this increases the antimicrobial activity. When the pH of water is 8.5, the efficacy of chlorination is significantly reduced. If the water used is very hard, it is necessary to treat the water adequately before use. Generally, water softening becomes essential for both processing and cleaning applications.

Water can also contain a significant number of microorganisms. Water used for cleaning and sanitizing must be potable and pathogen-free. Prior to use in cleaning regimes, standard treatments and sanitization of water may be required. Some water impurities that effect cleaning functions are presented in [Table 9.2](#).

TABLE 9.2 Some Common Water Impurities and Their Associated Problems

Impurities	Problem Caused
<i>COMMON IMPURITIES</i>	
1 Oxygen	Corrosion
2 Carbon dioxide	Corrosion
3 Bicarbonates (sodium, calcium or magnesium)	Scale formation
4 Chlorides or sulfates (sodium, calcium, or magnesium)	Scale and corrosion
5 Silica	Scale formation
6 Suspended solids	Corrosion and deposition
7 Unusually high pH (above 8.5)	Mediate corrosion and deposition; alter detergent efficiency
8 Unusually low pH (below 5)	Mediate corrosion and deposition; alter detergent efficiency
<i>LESS COMMON IMPURITIES</i>	
9 Iron	Filming and staining
10 Copper	Filming and staining
11 Manganese	Corrosion

Thermal Sanitization

When sanitization involves the use of hot water or steam for a specified temperature and contact time, it is called thermal sanitization. It is generally adequate for most purposes. As with any heat treatment, the effectiveness of thermal sanitization is dependent upon a number of factors, such as initial contamination load, humidity, pH, temperature, and time.

STEAM

The use of steam as a sanitizing process has limited application. It has several disadvantages. It is generally expensive as compared to alternatives. Temperature is difficult to regulate and also it is practically inconvenient to monitor the contact temperature and time. Further, the by-products of steam condensation can complicate cleaning operations.

HOT WATER

In general, hot water sanitization process is commonly used. It involves immersion (of small parts, knives, etc.), spray (such as dishwashers), or circulating systems. The time required for sanitization is determined by the temperature of the water. The standards of hot water use in dishwashing and utensil sanitizing applications are specified by regulatory authorities in various countries. It is recommended that hot water immersion should be at 77°C (170°F) for at least 30 seconds for manual operations. For single tank, single temperature machines, a final rinse at temperature of 74°C (165°F) is required, and for other machines it is 82°C (180°F) (Schmidt, 1997). Many state regulations require a utensil

surface temperature of 71°C (160°F) as measured by an irreversibly registering temperature indicator in ware-washing machines. Recommendations and requirements for hot-water sanitizing in food processing may vary. The Grade-A Pasteurized Milk Ordinance specifies a minimum of 77°C (170°F) for 5 minutes. Other recommendations for processing operations are 85°C (185°F) for 15 minutes or 80°C (176°F) for 20 minutes (Schmidt, 1997).

There are several advantages of hot-water sanitization. These include relatively inexpensive method, readily available, easy to apply, effective over a broad range of microorganisms, penetrates into cracks and crevices, and is relatively noncorrosive. The disadvantage of hot-water sanitization could be a slow process that requires gradual warm-up and cool-down time. In addition, it can have high energy costs and has certain safety concerns for employees. The process also has the disadvantages of film formations and subsequent shortening of the life of certain equipment or machinery parts of plants.

Water Conditioners

When mineral content of water increases, particularly calcium and magnesium, the hardness of water also increases, rendering the water unfit for cleaning. In such situations, minerals are deposited in the form of film or scales on the hard surfaces which are in contact with such water for a long time. To prevent the buildup of various such mineral deposits, water conditioners are used. These conditioners are chemicals that usually act as sequestering agents or chelating agents. These sequestering agents work by forming soluble complexes with calcium and magnesium. Examples of some common water softeners are sodium tri-polyphosphate, tetra-potassium pyrophosphate, organo-phosphates, and polyelectrolytes. Some chelating agents include sodium gluconate and ethylene diamine tetra-acetic acid (EDTA).

Water in Processing Operations

In food processing, there are broad range of possibilities with regard to water management, including increased promotion with increased efficiency of water reuse. This water reuse efficiency can be enhanced by tailoring the water quality requirements for a specific process. The major demand for water arises during diverse food processing operations such as transport of products, dissolving ingredients, treatment of products (e.g., alteration, separation), maintenance of appropriate water content in the final product, cooling processes, steam generation, and abnormal incidents (e.g., fire protection).

In general, there are two main types of water reuse that can be identified. This is relating to whether water comes into direct contact with food product(s) or not. Typical reuse applications, where water usually has no such contact, include its use in cooling and for the generation of steam. The other category is where water that does have contact with food could be at the raw product stage (e.g., washing or transport), at intermediate stages (e.g., cleaning of equipment), or in the final product itself, which is residual water (ILSI, 2008).

The reuse of water by recycling has become an increasingly vital component of food processing operations. It is a very essential way to conserve water, reduce costs, and provide security of water supplies. Under current legislation in several countries, recycled water can be used in food processing operations or as an ingredient of food, provided that it should be of the same standards as drinking water. Even though clean seawater is

nonpotable, it is commonly used in processing operations such as washing whole fishery products and shellfish.

In some circumstances, nonpotable water is used by the food industry for operations such as for fire control, steam generation, and others. In such applications, the water must be clearly identified as nonpotable water and it should not be connected or mixed with the drinking water supply or used directly in food production.

Water as an Ingredient or Component of Food

Water is also used as a component of food or an ingredient of the component of food. It is a very important safety concern when one considers water as part of the food. It acts as a medium through which food can be preserved, stored and consumed by humans. Fruit juices, jams, jellies, pickles, soups, and many more such consumed forms of food products have water as an ingredient.

It is fundamental that when water is used as a component of food or as an ingredient of the food component, it must be free from undesirable color, odor, taste, and impurities that are harmful to consumers and result in low-quality products. Ordinary tap water that meets the criteria of the safe drinking water standard may not necessarily achieve these qualifications. Undesirable odor and taste can be removed, usually by using an activated carbon filter. Activated carbon particles have a massive surface area that adsorbs substances like yeast, chlorine, and those that affect odor and taste, and nonpolar materials such as mineral oil and polyaromatic hydrocarbons. The activated carbon filter helps to remove unwanted material, which might interfere in subsequent treatment steps, like ion exchange and reverse osmosis.

WATER IN FOOD STORAGE AND PRESERVATION

The role of water in food storage and preservation is an important consideration from the point of food safety and stability. In general, it is the *water activity* of food, abbreviated as a_w , and not the water content, which determines the lower limit of water for microbial growth (Sandulachi, 2012). In several food industry operations, monitoring a_w is a critical control point. The importance of a_w in food systems cannot be exaggerated in food safety. It is well known that, throughout history, several methods of food preservation like drying and the addition of sugar or salt were prevalent, and they are commonly used even today. These methods have one common principle, which is to keep low water activity. These methods prevent growth of food-spoiling microorganisms and maintain food quality.

Water activity is defined as “the ratio of the partial vapor pressure of water in equilibrium with a food to the partial saturation vapor pressure of water vapor in air at the same temperature” (Fontana, 2000). This is equivalent to the relative humidity of the air that is in equilibrium with the food. The value of a_w ranges from 0 to 1. The a_w of a food denotes the energy state of water in the food, and therefore it delineates the potential of this water to act as a solvent and participate in chemical/biochemical reactions and growth of microorganisms. It is an important property that is used to predict the stability and safety of food with respect to microbial growth, rates of deteriorative reactions, and chemical/physical properties. Water activity values are used by food designers to use water activity to

formulate shelf-stable food. Mold growth is inhibited if a product is kept below a certain water activity. This results in a longer shelf-life (Sandulachi and Tataro, 2012).

In food products made with different ingredients, the water activity values can also help to limit moisture migration within a food product. For instance, if raisins of a higher a_w are packaged with bran flakes of a lower a_w , the water from the raisins migrates to the bran flakes over time, making the raisins hard and the bran flakes soggy. Food formulators generally use the water activity principle to predict how much moisture migration affects their product.

Colligative effects of dissolved species such as salt or sugar interact with water through dipole–dipole, ionic, and hydrogen bonds. Surface interactions in which water interacts directly with chemical groups on undissolved ingredients like starches and proteins are, through dipole–dipole forces, ionic bonds (H_2O or OH^-), Van der Waals forces, hydrophobic bonds, and hydrogen bonds. The permutations and combinations of these interactions, in addition to the factors in a food product, lower the energy of the water and consequently decrease the relative humidity as compared to pure water (Fontana, 2001).

The lowest a_w at which the vast majority of food spoiling bacteria will grow is about 0.9. The growth of *Staphylococcus aureus* is inhibited at an a_w of 0.91 under anaerobic conditions; however, similar inhibition occurs at a lower a_w level 0.86 under aerobic condition. The a_w for mold and yeast growth inhibition is about 0.61, whereas the lower limit for growth of mycotoxigenic molds is at 0.78 (Fig. 9.3). A list of the water activity limits for growth of microorganisms significant to public health and examples of foods in those ranges are given in Table 9.3 (Fontana, 2001).

The browning reactions in food generally increase with a_w from 0.25, it reaches the peak around a_w 0.6, and then falls down sharply until a_w 0.75. In this range, only covalent interactions of water with food component are predominant (Fig. 9.3). The lipid peroxidation reactions start increasing from a_w 0.4 and continue until the maximum value of water activity. At the higher values beyond a_w 0.8, the solute and capillary action become predominant, which promote growth of microorganisms, yeast, and molds.

The effect of temperature on the a_w of a food is product specific. In some products, a_w increase with increasing temperature, while in others a_w decrease with increasing temperature, and high-moisture foods have negligible change with temperature. Therefore, it is

TABLE 9.3 Common Food Spoiling Organisms and Their Water Activity (a_w) Limits for Growth

Microbial Group	Species	a_w	Food Products That are Affected
Normal bacteria	<i>Salmonella</i> spp. <i>Staphylococcus aureus</i> , <i>Clostridium botulinum</i>	0.91	Fresh milk, meat
Normal yeast	<i>Torulopsis</i> spp.	0.88	Fruit juice concentrate
Normal molds	<i>Aspergillus flavus</i>	0.80	Jams, jellies
Mycotoxigenic mold	<i>Aspergillus</i> , <i>Fusarium</i> and <i>Penicillium</i> spp.	0.78	Cereals, vegetable products, meat, grapes juice and wine
Halophilic bacteria	<i>Walleimia sebi</i>	0.75	Honey
Xerophilic molds	<i>Aspergillus echinulatus</i>	0.65	Flour
Osmophilic yeast	<i>Saccharomyces bisporus</i>	0.60	Dried fruits

rather difficult to predict even the direction of the change of a_w with temperature, as it depends on how temperature affects the factors that control a_w in the food.

There is no ideal device that can directly measure the a_w of a food. It is measured by an indirect method. Practically, a food sample is placed in a small air-tight chamber, and the water in the air is measured after it equilibrates with the sample. Elaborate methods for a_w determinations are described elsewhere (Fontana, 2000). Reliable laboratory instrumentation is required to guarantee the safety of food products and enforce government regulations. Recently, newer instrument technologies have been developed that have vastly improved speed, accuracy, and reliability of a_w measurements. Broadly, two types of instruments are commercially available for a_w measurement. One category of instrument uses chilled mirror dew-point technology, while the other category measures relative humidity with sensors that change electrical resistance or capacitance. Each type of instrument has certain pros and cons. The methods also vary in accuracy, repeatability, speed of measurement, stability in calibration, linearity, and convenience of use (Fontana, 2000).

The concept of water activity is very useful in predicting food safety and stability with respect to microbial growth, chemical/biochemical reaction rates, and physical properties. By measuring and controlling the a_w of foodstuffs, it is possible to predict which microorganisms will be potential sources of spoilage and infection. It also becomes easy to explain logically how to maintain the chemical stability of foods by lowering a_w , minimize nonenzymatic browning reactions, arrest spontaneous autocatalytic lipid oxidation reactions, and prolong the activity of enzymes and vitamins in food. In addition, it becomes easy to optimize the physical properties of foods, such as texture and shelf-life. A global stability map (Fig. 9.3) of foods shows these factors as a function of water activity (Fontana, 2000).

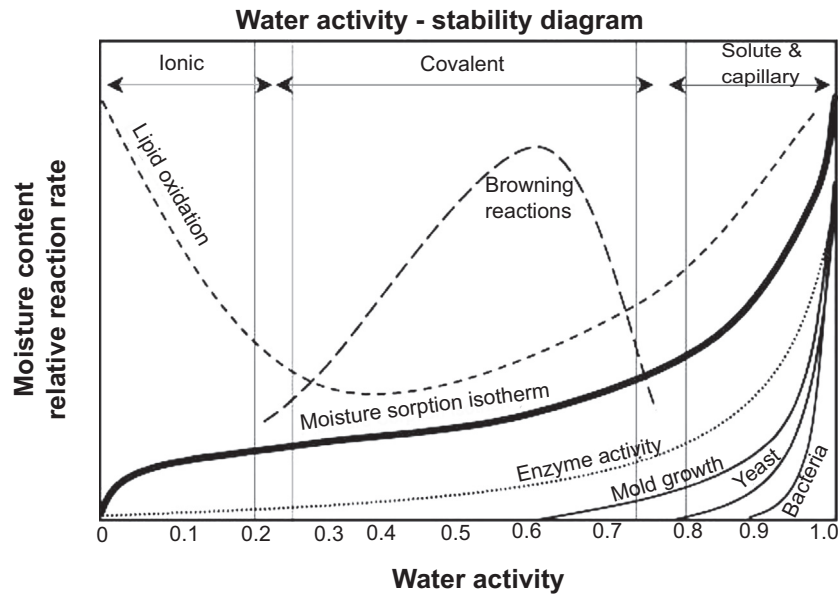


FIGURE 9.3 Global water activity-stability diagram or moisture-sorption isotherm (water activity is along the horizontal axis, while moisture content or reaction rate is plotted along the vertical axis).

The growing recognition of the a_w principle is evident from the fact that it is incorporated into U.S. Food and Drug Administration (FDA) and U.S. Department of Agriculture regulations, and most recently in NSF International Draft Standard 75 (Fontana, 2001). The major purpose of these regulations is to provide explicit requirements, critical control points, and practices to be followed by food industries and to implement and enforce these specific requirements, critical control points, and practices by industries so that products are pure, wholesome, and produced under sanitary conditions and are safe for human consumption. Recently, the instrument technologies have greatly improved speed, accuracy, and reliability of water activity measurements and are definitely an indispensable tool for food quality and safety.

WATER QUALITY

Safe and readily available water, whether it is used for drinking, domestic use, food production, or recreational purposes, is essential for public health. Improved water supply and sanitation, and better management of water resources, can boost economic growth of a country and also can contribute greatly to reduce poverty. Since the 1990s, water pollution has increased in almost all rivers in Africa, Asia, and Latin America (UNEP, 2016). The deterioration of water quality is expected to escalate over the following decades, and this will jeopardize human health, the environment, and sustainable development (Veolia/IFPRI, 2015). An estimated 80% of all industrial and municipal wastewater is released in the environment without any pretreatment. This results in an increasing deterioration of overall water quality, which has detrimental impacts on human health and ecosystems. Worldwide agricultural intensification has already resulted in increased use of chemicals to approximately 2 million tons per year (De et al., 2014). The gross impacts of this trend are largely unquantified and there are serious data gaps (WWDR, 2018).

In Europe, around 15% of groundwater monitoring stations recorded that the level of nitrates, as established by the WHO, were exceeded in drinking water. Further, the monitoring stations recorded that approximately 30% of rivers and 40% of lakes were eutrophic or hypertrophic during the period from 2008 to 2011 (WHO, 2015). The low- and lower-middle-income countries have the greatest increases in exposure to pollutants, primarily due to higher population growth and poor economic conditions in these countries, especially those in Africa (UNEP, 2016), and the lack of wastewater management systems (WWDR, 2017).

The quality of water used in food production and processing decides the food quality and its security. It is essential that to have healthy and hygienic food, the water used must be of very high quality. It is very essential that analysis of water with stringent quality control criteria must be followed at every point of food processing, packaging, and storage. In Europe, it is mandatory for the food industry to have an adequate supply of drinking water for use in food production to ensure that foods are not contaminated. Drinking water means that it is fit for human consumption, not only for drinking, but also suitable for cooking as well as for food preparation. In principle, this must be devoid of microorganisms and other contaminants that may jeopardize public health (WHO, 2017a).

Water safety can never be taken lightly. Unsafe water, which results due to direct contamination or improper or inadequate water treatment processes, generally results in a contaminated food product. Even though all types of foods are at risk, the highest among them are ready-to-eat products.

Impurities of water that are identified and measured fall into three basic categories: qualitative, general quantitative, and specific (Osmonics, 1997). Qualitative identification includes physical parameters such as turbidity, taste, color, and odor. These generally describe obvious conditions of water. Most of the qualitative parameters do not describe the concentration of the contaminants and therefore do not identify the source. However, it should be noted that taste, color, and odor evaluations should be very accurate qualitative measurements that can be instantly completed. The human nose, for instance, is sensitive to detect odors in concentrations down to the parts-per-billion level. A comprehensive quantitative water analysis, obviously, has higher precision compared to qualitative analysis (Osmonics, 1997).

WATER-BORNE FOOD CONTAMINANTS

In production of safe and ultimately secure food, safety of water assumes fundamental importance. The safety of water can be discussed by considering the possible hazards to human health. The presence of infectious agents, toxic chemicals, and radiological hazards can compromise water quality. These hazards may arise due to poor quality of water used directly or indirectly in the food production. Therefore, great attention is necessary to learn various health hazards of water such as biological, chemical, or physical pollutants that jeopardize human health.

Physical Contaminants

Physical contaminants are derived from incoming water that is not usually controlled by filtration, and it can be monitored by turbidity measurements. Microphysical particles like glass and metal microparticles are hazardous and cause serious injury to consumers. Chemical hazards include organic compounds, inorganic elements (e.g., heavy metals), and complex chemicals (e.g., pesticides), which are mentioned in detail in the EU drinking water directive and the WHO guidelines (WHO, 2017a). Chemical contaminants occur due to a variety of ways, such as environmental contamination or from a chemical spill, or due to incorrect use of pesticides or because of cross-contamination of the water supply with sewage and/or industrial waste.

Biological Contaminants

Biological contaminants not only include the organisms of concern but also the consequences of their presence (e.g., toxin formation). Water-borne microorganisms potentially causing illness include bacteria, viruses, protozoa, and helminths

TABLE 9.4 Typical Biological Contaminants of Water

Sr. No.	Biological Contaminant	Types (Examples)	Diseases Produced or Health Hazards
1	Bacterial pathogens	<i>Salmonella</i> , <i>Shigella</i> , <i>Campylobacter</i> and various pathogenic strains of <i>Escherichia coli</i>	Cholera, salmonellosis, shigellosis, leptospirosis
2	Viral pathogens	Norwalk virus, hepatitis virus, and other human enteric viruses	Hepatitis A, dengue fever, SARS CoV, legionellosis
3	Protozoan parasites	<i>Entamoeba histolytica</i> , <i>Giardia lamblia</i> , <i>Cryptosporidium parvum</i> , <i>Cyclospora</i> , <i>Plasmodium</i>	Diarrhea, malaria
4	Helminthes	<i>Schistosomes</i> , <i>Tinia solium</i> , <i>Liver fluke</i> , <i>Clonorchis sinensis</i>	Schistosomiasis, clonorchiasis
5	Fungal species	Molds, yeast, and others	Toxins
6	Algae	Spirogyra and others	Toxins

List is illustrative only and not exclusive/exhaustive.

(Table 9.4). The resistance/susceptibility of these organisms to commonly used water treatments and the way of transmission need to be considered to ensure water quality. Most of the pathogens do not grow in water. These pathogens are introduced into the water by animal and/or human sewage. However, some are environmental pathogens that can normally grow in water. Legionella is one example, which is transmitted by inhalation/aerosols, leading to an infection of the respiratory tract (Washington, 1996). The risks related to Legionella have to be considered with respect to personnel safety (showers/washrooms), and as well to the wider environment of the plant, such as cooling towers that are used from where water can spread into the wider surrounding (Castilla et al., 2008). Water temperatures below 20°C and above 60°C would prevent multiplication in the system due to the growth characteristics of these bacteria. The European guidelines also provide information with respect to effective treatments/disinfection of water systems (EU-OSHA, 2005).

Food industries must have a system in place to ensure that they are continuously using safe/potable water in food production and processing. The Canadian Food Inspection Agency (CFIA) periodically reminds industries to follow water safety requirements for food production, processing, and handling, and maintain an action plan in the event of a major accident/water safety alert (CFIA, 2017). It is very essential that food industries have to be very vigilant and establish a communication system with the appropriate municipal, provincial, or territorial water authorities for the timely exchange of information in the event of accidents.

The food industry is ultimately responsible for safe food. Water contamination is a serious threat to human life. The food industry should be fully aware of the various possible contaminants and their potential risk to human health and must take appropriate safety precautions. Some common biological contaminants of water encountered in food industries are shown in Table 9.4.

HEALTH HAZARDS IN WATER AND FOOD CONTAMINATION

A majority of water-borne diseases are spread by pathogenic microorganisms that are transmitted through contaminated fresh water. These diseases can be transmitted while bathing, washing, or drinking water or by eating food exposed to infected water. Infection commonly results during drinking contaminated water or use of such water in the preparation of food, or the consumption of food contaminated with these pathogens. Various forms of water-borne diarrheal diseases are the most prominent examples and affect mainly children in developing countries. According to the World Health Organization, such diseases account for an estimated 4.1% of the total Disability Adjusted Life Years (DALYs) global burden of disease and cause about 1.8 million human deaths annually (Hatami, 2013). The World Health Organization estimates that 58% of that burden, or 842,000 deaths per year, are attributable to a lack of safe drinking water supply, sanitation, and hygiene (WHO, 2017b).

In terms of popularity and based on the incidence, the top most water-borne disease is the travelers' diarrhea, caused by *Escherichia coli* along with a variety of viral and parasitic enteric pathogens. Each year, between 20% and 50% of international travelers, and an estimated 10 million persons develop diarrhea. Giardiasis and cryptosporidiosis are the second largest cause of water-borne disease, due to transmission of microscopic parasites or cysts of *Giardia* and *Cryptosporidium*. *Giardia* is found worldwide and is within every region of Canada and the United States. The third top most water-borne disease is dysentery caused either by *Entamoeba histolytica* amebic dysentery and/or by salmonella and shigella bacillary dysentery. Dysentery kills around 700,000 people worldwide every year. *Salmonella bongori* and *Samonella enteric* are gram negative rod bacteria with >2500 serotypes or serovars known to cause the water-borne salmonellosis. Each year, almost 1 in 10 people fall sick and that results in loss of 33 million of healthy life years. It is one of the four key global causes of diarrheal diseases. Followed by this is typhoid fever due to *Salmonella typhi* bacterium at fifth place. An estimated 11–20 million people get sick from typhoid and between 128,000 and 161,000 people die per year. Next popular is cholera due to *Vibrio cholera* bacterium with 1.3–4.0 million cases per year, and 21,000–143,000 deaths worldwide are due to cholera. Viral hepatitis caused by the A virus is largely an endemic disease with transmission through water. Epidemics of A virus can be explosive and cause substantial economic loss. Similarly, the viral hepatitis caused by the E virus (HEV) can result in epidemics if common community water sources get polluted. It is estimated that there are 20 million HEV infections worldwide each year, leading to an estimated 3.3 million symptomatic cases of hepatitis-E. Worldwide, 1 in 10 people fall ill due to infection by *Campylobacter*, a spiral-shaped, S-shaped, or curved, rod-shaped bacteria. *C. jejuni* (subspecies *jejuni*) and *C. coli*. *C. lari*, and *C. upsaliensis* (less freq). A total of 33 million of healthy life years are lost and 550 million people fall ill yearly (including 220 million children under the age of 5 years).

The entire picture of water-associated diseases is complex due to various reasons. As a consequence of the emergence of newer water-borne infection diseases and the reemergence of older known diseases, the picture of water-related human health issues has become more and more comprehensive over a period of decades. Scanty data are available for some water-, hygiene-, or sanitation-related diseases like cholera,

salmonellosis, or shigellosis. The analysis is yet to be performed for other water-related disease like schistosomiasis, malaria, or more modern infections such as SARS CoV or legionellosis. The burden of a variety of disease groups may only partly be attributed to water determinants. It becomes difficult to pinpoint the relative importance of water components of the local ecosystem, even where water has an essential role in the ecology of diseases.

In developing countries, four fifths of all illnesses are water-borne diseases. In this list, diarrhea is the leading cause of death among children. For approximately 1.1 billion people around the world, who still lack access to improved drinking water sources, the global picture of health and water has a strong local dimension. There is strong evidence that sanitation and water- and hygiene-related diseases account for around 2,223,000 deaths each year, as well as an annual loss of 82,196,000 disability-adjusted life years (DALY) (WHO, 2013).

Around 246.7 million people over the world are assumed to be infected by schistosomiasis. Of this, 20 million people experience the full-blown infection, while another 120 million people experience only milder symptoms. An estimated 80% of transmissions occur in Africa and south of the Sahara. In Bangladesh, around 35 million people are daily exposed to arsenic. As the water they drink has elevated levels of arsenic, this will endanger their health and eventually shorten their life expectancy.

In the United States, 9.4 million people fall sick, and 1350 deaths occur each year, due to 31 major pathogens that contaminate food (Scallan et al., 2011). As relatively higher numbers of illnesses that occur relating to food are due to microorganisms, microbiological quality thus becomes the most important aspect of food safety. Therefore, food safety primarily focuses on the control of food contamination by pathogens.

In the United States, Norovirus, *Salmonella*, *Clostridium*, *Listeria*, *E. coli* O157:H7, and *Campylobacter* are the most common and leading pathogenic microorganisms in food-borne illness (Scallan et al., 2011). Among these, *Listeria* and *E. coli* O157:H7 are primarily the causative pathogen in a majority of food-borne deaths. In 1999, the CDC launched Food-Net, a useful data monitoring system, in an effort to monitor food-borne illnesses in the United States (Mead et al., 1999). In 2007, WHO initiated a system to estimate the worldwide burden of food-borne diseases (Kuchenmuller et al., 2009). These two data monitoring systems have greatly facilitated efforts to identify and subsequently decrease incidences of food-borne illness.

During the production process, foods can become contaminated at any point along the production line. Thus, programs such as Hazard Analysis and Critical Control Points (HACCP) have been designed to control food contamination (Codex, 2003). HACCP is a management system that addresses food safety through the analysis and control of biological, chemical, and physical dangers and threats from raw material production, procurement, handling, manufacturing, distribution, and even up to the consumption of the finished product. It is executed in the industry to decrease food safety risks. As the number of illnesses due to microorganisms is relatively greater than foreign objects or allergens, HACCP typically focuses on pathogen reduction and prevention (Gorham and Zurek, 2006). Some material is considered unavoidable, and the tolerance levels of such material have been set in HACCP. However, due to the high risk and potential severity of disease, certain hazards are not tolerated at all, including contamination of products by *E. coli* O157:H7 or *Listeria monocytogenes*, in the stringent criteria of HACCP.

WATER TREATMENT

The choice of the most suitable water treatment technique depends on the water source and the intended application of the water. It also depends on the design aspects of storage and distribution in a food manufacturing facility. Variable solids and chemical and microbial contents occur in water due to various factors like rainfall events, seasonal weather patterns, distribution system issues, and other factors.

The hygienic design of the water distribution and storage systems are the effective microbiological controls. The general principles, as adopted for food manufacturing equipment, should be followed in food production such that dead ends and stagnant areas are avoided, and prevention of biofilms and scaling is ensured. It is also ensured that the entire system can be cleaned and disinfected as and when needed on a regular basis. All material used for fittings, pipes, and tanks should be compatible with the conditions in the system, which includes the resistance of the material used against cleaning and disinfection agents.

Great care should be taken to prevent any backflow by providing a break at the entry point of the facility. Storage tanks should be enclosed to prevent any contamination by pests or extraneous matter. All vents should preferably be equipped with an air filter to achieve air filter class F7. At minimum, an insect screen should be installed. The tank design should favor full drainability when emptying. The entire system should be designed such that the maximum stay time of the water does not exceed 24 hours.

The water storage and distribution system design should allow for easy cleaning and disinfection. However, in reality, this is quite often an issue and cleaning is hardly possible. So typically, the water is treated at the entry point into food manufacturing units and the quality is maintained and monitored within the factory. The microbiological quality of water is monitored at various points in the plant, including last points of pipes, and appropriate treatments are applied. In a majority of cases, a combination of techniques will be necessary to meet the demands.

Ideally, water treatment processes should remove pathogens and impurities that may otherwise be harmful to human health or esthetically unpleasant. Water treatment processes may vary depending on the source water. Typically, an adsorbent material is added to the water to bind dirt and form heavy particles, which settle down after sometime to the bottom of a water storage tank for easy separation. The water is then filtered to remove even smaller particles. Finally, a small amount of disinfectant (e.g., chlorine), at a level safe for human consumption, may be added to kill any remaining viable microorganisms (WHO, 2017b).

It should be noted that the treatment of water used by the food industry is the obligatory responsibility of the concerned food business using a private water supply. Typically, private water supplies require treatment and ongoing monitoring of water quality verification following treatment. This can be carried out by laboratory testing to ensure they are fit for human consumption and can be used in food production (Kirby et al., 2003). A summary of the most common water treatment techniques in relation to the hazards that need to be controlled is given in Table 9.5.

Hardness is generally due to calcium and magnesium ions in water that may deposit in pipes, valves, and process equipment surfaces. Some food products may not dissolve well in hard water. In addition, hardness may affect flavor, aroma, and palatability of foods.

TABLE 9.5 Most Common Treatment Techniques in Relation to the Hazards That Need to be Controlled (✓Indicate Most Preferred Technique)

Treatment Method	Hazards/Dangers/Threats/In Water									
	Solids	Odors/ Flavors	Algae	Protozoa	Bacteria	pH	Organic Chemical Residues	Salts, (Hardness)	Viruses	
Settling	✓									
Deaeration		✓					✓			
Activated carbon	✓	✓	✓ ^a				✓	✓		
Neutralization						✓				
Membrane filtration (RO)	✓		✓	✓	✓		✓	✓		✓
Chlorination/ozonization				✓ ^b	✓					✓ ^c
Ion exchange							✓	✓		
UV radiation				✓ ^b	✓					✓
Electrochemically activated water			✓	✓	✓					✓

^aIf contamination is detected; RO = Reverse osmosis.

^bCryptosporidium.

^cDepending on virus species.

A water softener should be used to decrease hardness. It is a specific type of ion exchanger that is used to remove hardness. If bacteria are suspected, then a disinfection step such as ozone, chlorine, or ultraviolet treatment becomes necessary in the water treatment protocol. Filtration is recommended in all cases for all potable water use.

Filtration

Depending upon the contamination risk, the incoming water might be required to pass through a filter that retains solids (e.g., for well-water). The filtration methods vary from porous filters for larger particles to membrane filtration to retain smaller suspended particles and even microorganisms (reverse osmosis). The risk of microbiological growth needs to be considered when filters do not constantly receive water. Therefore, a continuous recirculation of the water is recommended, if no water is consumed.

Chlorination

The most common chemical oxidizing method used for disinfection of water systems is chlorination. It is used as hypochlorite solution (liquid bleach) and chloride dioxide. The major advantage of this method is that chlorine is relatively inexpensive and that

automated systems and generator do not require a large capital investment. For an effective disinfection, a residual concentration of minimum 0.5 mg/L free chlorine for at least 30 minutes (pH < 8) should be maintained.

Hypochlorite reacts with the nitrogenous component of organic substances. This means it will be used up during this reaction. Automated systems for continuous water chlorination are available. The main disadvantages of hypochlorite are that it is highly corrosive in its undiluted form, may form unwanted by-products (chloramines, chlorophenol), and will be used up easily by organic matters.

Chloride-dioxide is a very unstable gas and must be generated at the point of use. It has some advantages over hypochlorite such as being less corrosive. The effectiveness to tackle biofilms is higher compared to hypochlorite and thus this is the preferred method for chlorination.

Electrochemically Activated Water

Treatment with electrochemically activated water has recently become increasingly popular. An electrochemical cell generates a highly oxidized fluid (anode) and a reduced fluid (cathode) using just water and salt. The cell may be separated by a diaphragm. The oxidized water has higher oxidation-reduction-potential (ORP) of up to +1300 mV, whereas, chlorine-based solutions have up to +800 mV. The solution is meta-stable for up to a couple of weeks and like chlorine-dioxide generated onsite. The disinfectant contains mainly hypochlorous acid, smaller amounts of chlorine-dioxide, and ozone. Small quantities of these will be dosed into the water system. Several manufacturers claim that this is a chemical-free method for water treatment. However, it is not true, even though concentration of chemicals is extremely low and the working principle of this method is based on the ORP rather than on the chemicals.

Ozone Treatment

Like chlorine-dioxide, it is not stable and must be generated onsite. It has a very high ORP above +2 volts and thus a high capability for disinfection with a broad spectrum of activity, including viruses. Due to its good water solubility, it is very suitable for the disinfection of water systems maintaining a concentration of 0.4 mg/L for 5 minutes (in the presence of spores 2 mg/L). The major disadvantages of this method are firstly that ozone will be used up easily by organic matter and secondly that the energy costs to produce ozone are fairly high. It should be noted that ozone should not be used in evaporative cooling systems due to its high volatility.

Ultraviolet Radiation (UV)

Microorganisms are inactivated by shortwave UV light (UV-C, 100–280 nanometer wavelengths). The nucleic acid, DNA of the microorganisms' cells is damaged during the treatment. The UV light source is usually enclosed in a transparent protective sleeve and installed in a way that water can pass through a flow chamber.

Suspended particles may protect microorganisms (shadow effect), so the effectiveness of the treatment very much depends on turbidity, adsorption, and concentration of particles and/or organic material. UV treatment could ensure up to a 4 log reduction; however, it will never lead to obtain sterile water. As the treatment is only done at the UV light source, but not throughout the system, removal of biofilms will not be possible. This treatment method is chemical free and it has a broad spectrum of activity. These are the advantages of the method.

In general, water quality controls should start at the source and also include the review of incoming and/or used municipal water supplies. The history of drinking water supplies should also be taken into account, such as known outbreaks related to the water supply or boiling water notices, when applying treatment options to ensure water quality. More detailed information on the effectiveness of treatments commonly used in the food industry can be found elsewhere (Koopmans and Duizer, 2004; Dawson, 2005; ILSI, 2008).

SOIL AND WATER QUALITY

Soils have significant influence on human health due to the amazing ability to remove contaminants from water. This power of water purification of soil is due to the removal of contaminants by physical capture as the water moves through micropore spaces in soil particles. Further removal is by chemical adsorption to solid surfaces, and by means of the biodegradation carried out by microorganisms living in the soil (Helmke and Losco, 2013). Soils that have desirable properties such as well-developed structure and sufficient organic matter act as efficient filters and purify the surface water as it percolates to lower strata. Soil degradation, which includes soil erosion and loss of soil structure and nutrient content, has negative impact on crop production and threatens food security (Brevik, 2013b; Mishra et al., 2016). In recent times, environmental pollution and food safety are two of the most important emerging issues. Soil and water pollution have historically impacted on food safety, and have serious important threats to human health. Heavy metals in soil, which is toxic to humans, usually pass on to humans through crop uptake and thus compromise food safety. The increasing negative effects on food safety from water and soil pollution have put more people at risk of carcinogenic diseases (Lu et al., 2015). In this context, soil can have great influence on human health. When the soil degradation occurs, it generally has negative health effects on human health. It may directly affect health through drinking water or indirectly through food that accumulate the pollutants such as heavy metals, organic chemicals, or soil pathogens.

Heavy Metals

The heavy metals of greatest concern relating to human health are arsenic, lead, cadmium, chromium, copper, mercury, nickel, and zinc. Heavy metals occur in soil naturally due to the weathering of rocks. In addition, they are also introduced into the soil through human activities. Heavy metals are mostly the by-products of mining ores. They

are present not only in the soils of mines and in the immediate surroundings of metal processing plants but also in far-off urban areas (Horváth et al., 2015). Heavy metals also leach into soils from landfills that contain industrial and household wastes and from sewage sludge that comes from wastewater treatment plants. In recent times, E-wastes, or wastes associated with electronic appliances, are assuming larger source of metals like lead, strontium, mercury, cadmium, and nickel in the soil (Robinson, 2009). Urban soils are susceptible to significant accumulations of heavy metals from activities like coal burning, automobile exhaust, erosion of metal structures, and refuse incineration (Horváth et al., 2015). In the agricultural sector, the use of fertilizers, manures, and pesticides have all contributed to the accumulation of heavy metals in soils (Mishra et al., 2016). Arsenic has been used in pesticides, and the buildup of arsenic in orchard soils has become a major problem as it is known to persist for decades (Walsh et al., 1977).

Organic Chemicals

Organic chemicals are deposited into the soil, both naturally as well as anthropogenically. A wide and diverse type of organic chemicals that are released into the air and water consequently end up in the soil. Soil pollution with organic chemicals is a serious problem in all nations (Lu et al., 2015). The largest source of these organic chemicals is from agricultural sector. Pesticides have been playing an important role in the success of modern food production since the 1950s. The excessive and indiscriminate uses of herbicides, insecticides, and nematicides result in soil and water pollution. It is true and widely accepted that the use fertilizers and pesticides has greatly improved grain production. However, on the other hand, inefficient, incorrect, and excessive uses of pesticides have also posed considerable risks to human health. Inadequate management of pesticide application in food production constitutes a potential occupational hazard for farmers and environmental risks for agricultural ecosystems.

Soil pollution with organic chemicals is not only limited to farming areas, as soils in urban areas are, in fact, still more polluted with organic chemicals as a result of industrial activities, coal burning, motor vehicle emissions, waste incineration, sewage, and solid waste dumping (Mishra et al., 2016). Soil contamination of both agricultural and urban areas includes a complex mixture of organic chemicals, metals, microorganisms, and the growth caused by municipal and domestic septic system waste, farm animal waste, and other biowastes. In addition, more recently pharmaceutical waste derived from antibiotics, hormones, and antiparasitic drugs manufacturing factories are becoming rising sources of pollution (Albihn, 2001).

Polyhalogenated biphenyls, aromatic hydrocarbons, insecticides, herbicides, fossil fuels, and the by-products of fossil fuel combustion are some of the most common types of organic chemicals found in soil (Burgess, 2013). These organic chemicals are present in highly diluted form in the upper strata of soil. They form complex chemical mixtures by reactions due to microorganisms. Very scanty toxicological information is available regarding the health effects of these chemical mixtures (Brevik and Burgess, 2014). As they have very long half-lives, many such organic chemicals are referred to as “persistent

organic pollutants.” Several such organic chemicals resist decomposition in the environment and get concentrated in higher consumers by bioaccumulation as they move up the food chain.

Soil Pathogens

In general, soil is host of innumerable organisms. There is great biodiversity of soil organisms. The majority of these are useful and are not always harmful to humans. However, soil also serves as a home for many pathogenic organisms. More than 400 genera of bacteria have been identified together with as many as 10,000 species. These bacteria, with the exception of viruses, in most cases, are more abundant than any other organism in soils (Nieder et al., 2018). Around 300 soil fungi species, out of the vast numbers of more than 100,000 fungi species that occur in soils, are known to cause disease in humans (Bultman et al., 2005; Nieder et al., 2018). For instance, the soil fungus *Exserohilium rostratum* caused a fungal meningitis outbreak in the United States in 2012 (Brevik and Burgess, 2013). Most of the protozoans that are found in soil feed on organic matter, including bacteria and algae; however, a few of these cause human parasitic diseases like diarrhea and amebic dysentery (Brevik et al., 2018). Soil serves as a common reservoir for helminthes. Helminths are parasites that may inhabit the human intestines, lymph system, or other tissues. Helminthic diseases require a nonanimal intermediate host like humans for transmission. Billions of people are infected by helminths worldwide each year, with an estimated 130,000 deaths annually (Abdeltawabi et al., 2017). Helminth infections generally occur via ingestion of contaminated water and food, and in most cases it involves intestinal infection (Nieder et al., 2018). Soil is not a natural reservoir for viruses; however, viruses are known to survive and stay in a dormant state for years together in soil. Pathogenic viruses are generally introduced into soil via human septic or sewage waste. Viruses that cause communicable diseases like conjunctivitis, gastroenteritis, hepatitis, polio, aseptic meningitis, or smallpox have all been detected in soil (Bultman et al., 2005; Hamilton et al., 2007; Nieder et al., 2018).

Globally, inadequate and improper sewage sanitation is a common problem in approximately 40% of the world’s population (WHO, 2017b). As a consequence, millions of people die each year from water-borne diseases (Massoud et al., 2009). We must take the advantage of nature and the amazing purifying powers of soil to address wastewater issues. However, to get the necessary benefits, the soil must be of good quality and have good structure. Well-designed, properly maintained, and functioning onsite sewage treatment systems become highly effective in reducing the risk of water-borne diseases, especially in areas with low population densities (Massoud et al., 2009). Efficient use of soils to deal with and solve several groundwater contamination issues is not a recent idea. It has been rediscovered with the ongoing research and developments in soil sciences. In many countries, food safety policies are not integrated with soil and water pollution management policies (Lu et al., 2015). Therefore, it is very essential that a comprehensive map of both soil and water pollution threats to food safety should be prepared together with implementation of integrated policies addressing soil and water pollution. This should be an ideal holistic approach in achieving food safety.

WATER AND GENETICALLY MODIFIED FOOD

Worldwide corporate companies in developed countries produce genetically engineered foods, often called “genetically modified organism” (GMO), by using biotechnology techniques. Instead of using the natural breeding methods that farmers have used for centuries to select for desirable traits, GMO crops and GMO animals are actually radically altered genetically to repel pests, withstand droughts, and grow faster. These changes are patented and help corporations to increase their control over the seed supply. However, they rarely have any interests of people or the environment in mind. The relevance of genetic manipulations in the food production may not be overlooked. In view of the present scenario of water use and availability for primary food production, in majorities of the countries in the world, it becomes a necessity to develop more water efficient crops and livestock.

Genetically modified crops have become increasingly popular since the last decade. Although it is a highly controversial topic, it may be viewed and if ethically used, it is an emerging highly promising technology. This genetic technology, if carefully regulated and tested, should have much-desired beneficial effects in terms of water conservation. The most logical approach in the genetic modification, for example, should be the selection of the traits to increase the rate of photosynthesis, depth of root structure, as well as a decrease the transpiration rate at which water is lost. This strategy should increase the nutrients yield of the crop and at the same time decrease the water requirement of the staple cereal crops. These changes have the great positive potential to lower pressures on the amount of global water resources required in food production. The enormous potential and the promising possibilities of genetic engineering and biotechnology research and development have the better future solutions to the current problems of water conservation, specifically in primary food production. Therefore, more precise and highly controlled and targeted genetic modifications should be very helpful in wheat, rice, and maize to increase their water efficiency and drought resistance. This approach will work more effectively by implementing genetically altered crops into the advanced and water efficient agricultural system.

Rice is well known as a very water-intensive food crop. The gene *Arabidopsis* HARDY is identified to have increased water efficiency of rice by increasing the rate of photosynthesis and decreasing the amount of water loss through transpiration (Karaba et al., 2007). Modification of this gene has also been demonstrated to increase the strength and amount of root structure. Plants with the HARDY gene have shown a 55% greater photosynthesis rate under normal conditions (Karaba et al., 2007).

Genetic modifications of the staple foods like the wheat plant are very much needed for water deficient countries. Wheat can be genetically modified to have deeper root structure by extending the vegetative growth period of the plant for later-flowering genotypes. Deeper root systems facilitate more water uptake, which means the plants require less irrigation and perform better under drought conditions. One example of drought tolerant wheat is Serim82, also known as “stay-green wheat.” This new variety has deeper root systems that lead to greater water uptake. It has been shown that this increased water uptake during drought periods gives 14.5% increase in yield compared to the traditional variety (Manschadi et al., 2006).

Although the FDA contends that there is no scientific evidence to demonstrate that consumption of GMO foods can cause chronic harm, in this context, the process of the FDA for evaluating the safety of these controversial GMO foods appears to be completely inadequate and unreliable. Recently, several media reports appeared supporting the safety of GMO foods. They all ignore growing concerns of the scientific community that say that GMO foods are far from safe. The scientific community criticizes the weak regulatory bodies that grant approval to GMO crops without safety concerns of humankind. The underlying truth of all the controversies is that there is no consensus on the safety of GMO foods. In fact, the evidence shows a serious potential for harm, particularly to our environment.

The GMO controversy does not end with GMO crops. GMO animals are now entering in the field. Recently, genetically engineered salmon has been approved by the FDA. It is feared that this GMO fish could present serious risks to consumer health, animal welfare, wild fish populations, fishing economies, and the environment.

Despite the approval of many genetically engineered foods by the FDA, questions persist about the safety of eating them. Safety concerns should be raised by strong public resistance and halting all sales of genetically engineered foods until the safety questions are scientifically addressed. Therefore, consumers should have a guarded approach in the consumption of GMO foods. When GMO food is used, it is mandatory that one should review the basic principles of food safety at every step of its production from raw material up until final consumption of the finished product.

CONCLUSION

Water plays a major and fundamental role in the safety of food production. Water is a critical resource for the food industry. In food production processes, water quality and its impact on products and operations are generally underestimated. Such underestimation often leads to mismanagement of water, equipment operation and maintenance issues, loss of income, food product quality, and safety. The agricultural sector is the largest consumer of water, compared to any other sector. The water footprint of any animal food product is larger than the water footprint of a plant product with equivalent nutritional value. In the world, 29% of the total water footprint of the agricultural sector is related to the production of animal products. The production of meat requires between 6 and 20 times more water as compared to cereals, vegetables, or fruits. The global meat production has almost doubled since 1980, and this trend is likely to continue given the projected doubling of meat production up to 2050. The shift from traditional extensive and mixed farming to industrial farming systems is likely to continue to meet this rising demand for animal products. Due to the larger dependence on concentrate feed in industrial systems, intensification of animal production systems will result in increasing blue and gray water footprints per unit of animal product. The pressure on the global freshwater resources will therefore increase both due to the increasing meat consumption together with the increasing blue and gray water footprint per unit of meat consumed. Therefore, the biggest opportunity and challenge for future water management for us is to store more green water in soil and plants, as well as to increase the storage as blue water.

The “water activity” is a key parameter in food storage and preservation. This important property is used to predict the stability and safety of food in relation to microbial growth, rates of deteriorative reactions, and chemical/physical changes in the food products. Food designers ingeniously use water activity values to formulate shelf-stable food. If a product is kept below a certain value of water activity, mold growth is inhibited. This results in a longer shelf-life.

The quality of water is the fundamental consideration in any food production process. The quality depends on the source of water and the actual application in food production. The pollution of water occurs at any stage in various ways. Physical, chemical, or biological agents cause significant health hazards in safe production of food. Contaminations of water by several pathological microorganisms create major challenges in food safety and jeopardize human and animal health. Water must be free from undesirable taste, odor, color, and impurities including pathogenic organisms that could be harmful to consumers and product quality, when water is used as an ingredient in food. The quality of water must adhere to the safe drinking water standard.

The quality of the water is greatly dependant of the source. It is the source of water that generally determines quality. The chemistry of waters from different sources may differ significantly. The pH and various impurities in water can drastically alter the effectiveness of water used in several processes in food production. Water hardness is the most important chemical property, which has profound direct effect on cleaning and sanitizing efficiency. Adequate treatment of the water is required to ensure that it meets drinking water standards and is safe to be used in food production, which is safe for human consumption. Various techniques and methods of water treatments should be used to purify water as per the guidelines of government authorities to improve food safety.

Water quality can be compromised by the presence of infectious agents, toxic chemicals, and radiological hazards. These hazards may arise due to poor quality of water used directly or indirectly in the food production. The majority of water-borne diseases by pathogenic microorganisms are transmitted through contaminated freshwater. Various forms of water-borne diarrheal diseases are the most prominent examples and affect mainly children in developing countries. An estimated 4.1% of the total DALYs global disease burden is due to such diseases. This also results in about 1.8 million human deaths annually. Therefore, great attention is necessary to learn various health hazards such as biological, chemical, or physical pollutants in water that jeopardize human health. Foods can become contaminated at any point along the production line. Control programs such as Hazard Analysis and Critical Control Points help in maintenance of food safety through the analysis and control of biological, chemical, and physical hazards from raw material production until the finished product. It is implemented in food industries to reduce food safety risks.

Soil has multiple roles in deciding water quality. Good quality of soil has better ability to remove all types of contaminants of water, whereas deteriorated soil becomes a source of heavy metals, organic chemicals, and soil pathogens in water contamination. Water quality controls should start at the source and should also include the review of incoming/used municipal water supplies. It is very essential to build a comprehensive map of both soil and water pollution threats to food safety together with implementation of integrated policies addressing soil and water pollution, which should be an ideal holistic approach in achieving food safety.

Use of genetically modified food is gaining much popularity recently. Even though a controversial topic, great care must be taken when GMO food is used. It is very essential that one should review the basic principles of food safety. Thus, there are several challenges in using water for the production of safe and secure food. One must keep a wide vision and rigid policies for use of proper water in food production for safety of human life.

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