Chapter

Understanding of Cultivability of *Escherichia coli* in Aquatic Microcosm in the Presence of Some Plant Extracts for Possible Treatment of Bacterio-Contaminated Water

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Abstract

Escherichia coli (*E. coli*) is a bacterial indicator of sanitary and hygienic importance widely used in the evaluation of the quality of drinking water, mainly because they are easy to detect and enumerate in water. Its presence in water reflects a deterioration in water quality. The *E. coli* species is heterogenous in its biotypes, serotypes and lysotypes as in its ecology and its association with pathologies. Studies have reported several cases of infections, sometimes even fatal, caused by contact or consumption of water contaminated by pathogenic strains of *E. coli*. The detection of *E. coli* in surface water was shown in field studies to have significant information about the microbial quality of water contaminated with enteric pathogens. Studies using the properties of plant extracts for the inhibition of this bacterium have been widely carried out. Some studies show the potential exploitation of *Artemisia annua*, *Eucalyptus microcorys* and *Moringa Oleifera* extracts treatment of bacterio-contaminated water. The effect of some aqueous extracts on planktonic cells of *E. coli* in the planktonic and adhered state are summarized in this chapter.

Keywords: *Escherichia coli*, bacterial indicator, water quality, extracts plant, treatment of bacterio-contaminated water

1. Introduction

Water has a vital role in the world. In general, humans use it for their daily needs, for economic activities and recreation [1]. However, the different uses of water can become sources of pollution. The alteration of the physico-chemical and microbiological quality of water is sometimes the result of poor management by humans of waste and wastewater of domestic, agricultural and industrial origin [2]. The use of polluted water exposes populations to health risks. The medium- and long-term risks are linked to the poor chemical quality of the water, while the short-term risks are biological in origin. The poor biological quality of water is partly due to the presence of protozoa, viruses or bacteria [3]. Several microbial communities

live in aquatic and soil environments, with physiologies that are sometimes similar in both types of biotope despite a significant difference in nutrient sources [4].

Bacteria are generally the most abundant microorganisms in nature and their unwanted presence in an environment can represent a health risk of varying degrees for humans. Indeed, the pathogenicity of normally harmless bacteria can occur as a result of the immunosuppression of a host. Bacteria are known to be responsible for water contamination in a community generally belong to the genera *Salmonella*, *Shigella*, *Escherichia*, *Yersinia*, *Vibrio* and *Campylobacter* [5, 6]. These bacteria can cause diarrhea, gastroenteritis and genitourinary infections in humans [7]. Their morphology and physiology in an aquatic environment vary with the general environmental conditions. The *E. coli* species belongs to the group of fecal coliforms or thermotolerant coliforms. The presence of these coliforms in water is generally a sign of the deterioration of its bacteriological quality, due to its contamination by other microorganisms that are strict pathogens or opportunistic pathogens [8–10]. For nearly a decade, numerous outbreaks attributed to pathogenic *E. coli* strains have been regularly reported worldwide [11–14]. In Ngoïla in the eastern region of Cameroon, from December 1997 to April 1998, 298 people came into contact with an epidemic of gastroenteritis caused by *E. coli* O157:H7 [15]. Contamination was by the oral route through ingestion of contaminated water or food.

In recent years, water disinfection methods using plant extracts have been proposed as a new alternative for household water treatment [16–18]. The use of plants for therapeutic purposes has been common practice for thousands of years [19]. However, little is known about the sensitivity of bacteria to these water extracts in the aquatic environment. There is still little information on the synergistic effect of the aqueous extract of *Eucalyptus microcorys* (*E. microcorys*) and light on planktonic cells of *E. coli* in the aquatic environment. Little information about the plant extracts of *Eucalyptus microcorys*, *Artemesia annua* and *Moringa oleifera* on *E. coli* bacterial cells is available. The present chapter summarizes the known effects of aqueous extract of the medicinal plants *Eucalyptus microcorys*, *Artemesia annua* and *Moringa oleifera* on the cultivability of *E. coli* in aquatic microcosm.

2. *Eucalyptus microcorys* extracts

2.1 Bioactive *Eucalyptus* compounds

Phytochemical screening showed that alkaloids, anthraquinones, flavonoïds and saponins are the major components of the aqueous extract of *E. microcorys*. Whereas anthocyanines, gallic tannins, polyphenols and triterpenes are found in negligible quantity [18].

2.2 Effect of *Eucalyptus microcorys* leaves extracts on planktonic *Escherichia coli*

A variation in the abundances of planktonic cells of *E. coli* was generally observed in the presence of the extract of *Eucalyptus microcorys* [18]. This variation is dependent not only on the concentration of the plant extract, but also on associated factors such as incubation temperature and lighting conditions. Thus, the incubation temperature affects the cultivability of *E. coli* cells with inhibition percentages varying from 3 to 100% for enteropathogenic *E. coli*, from 5 to 100% for commensal *E. coli*. *Eucalyptus microcorys* has a bactericidal property whose scope varies relatively according to the type of cell and the environmental conditions. Cultivable cells of *E. coli* happen to be relatively less abundant at temperatures 23°C and 37°C than 7°C, when grown in presence of *Eucalyptus microcorys* extract.

Planktonic cells of enteropathogenic *E. coli* have proven to be more resistant to bactericide properties of the *Eucalyptus microcorys* extract in psychrophilic conditions.

A gradual decrease in the abundance of cultivable enteropathogenic *E. coli* cells were observed during the period of exposure to light in the presence of the extract of *Eucalyptus microcorys* [20]. There is a progressive increase in the rate of cell inhibition in the cells tested in the presence of extract after exposure to light. Under dark conditions, the percentage of metabolically non-culturable enteropathogenic *E. coli* cells ranged from 17 to 99%. These inhibition rates increase under light conditions after each incubation period. Under an intensity of 1000 lx, the inhibition percentages fluctuated from 16 to 100% when considering all concentrations of *Eucalyptus microcorys* extract.

At 2000 lx, these inhibition rates fluctuated between 38 and 100%. At 3000 lx, peak inhibition rates of 100% were obtained after 12 hours of incubation at an extract concentration of 0.05%. Overall, the 3000 lx light intensity appears to result in the maximum inhibition of enteropathogenic *E. coli*.

The hourly inhibition rate of *E. coli* is very low in dark conditions and increases with increasing light intensity. In dark, cell inhibition rates are generally between 0.102 h^{-1} and 0.146 h^{-1}. These inhibition rates increase considerably in the presence of light, with values sometimes reaching 0.662 h^{-1} at 3000 lx. The more the light intensity increases, the more the percentage of cell inhibition increases, whatever the concentration of the plant extract. For a light intensity of 3000 lx, the percentages of inhibition of *E. coli* cells are greater than 80%. The combined effect of light and herbal extract *E. microcorys* influence considerably the evolution of the percentage of cellular inhibition about each concentration of extract and each light condition.

The observation of commensal *E. coli* and enteropathogenic *E. coli* abundances is different when considering all the extract concentrations and incubation temperatures. Studies showed that the number of the colony forming units (CFU) of each of the cell strains in the presence of *Eucalyptus* extract, decreased in most cases for the increase of the concentration of aqueous extract and the incubation temperature. The cell inhibition percentage varied from one strain to another and with respect to the extract concentration and temperature incubation. The enteropathogenic *E. coli* strains seem to resist the effects of the extract concentrations 1% and 1.5% at 7°C, 23°C and 37°C, in contrary to the commensal strains with which the relatively higher percentages were observed in the same conditions.

Natural or acquired resistance to antibiotics would explain the observed resistance of enteropathogenic *E. coli* strains. Indeed, it is well known that bacteria can develop protective mechanisms such as changes in cell wall permeability and structure, production of inhibitory enzymes and alteration of antibacterial molecules [21]. This could explain the difference observed between CAIRs (Cell Apparent Inhibition Rates) of both bacteria strains. Indeed, whether we consider the enteropathogenic *E. coli* strain or the commensal strain, the rate of cell inhibition per hour for each incubation temperature increases as the concentration of the extract of *Eucalyptus microcorys* increases (**Figure 1**). Extracts of crushed and dried leaves of *Eucalyptus cloeziana*, *Eucalyptus microcorys*, *Eucalyptus saligna* and *Eucalyptus grandis* exhibit inhibitory activity against *E. coli* cells. Molecules present in *Eucalyptus* leaves that provide disinfectant properties are the monoterpenes, such as 1,8-cineole, alpha and beta-terpinene, 4-terpineol and tannins. 1,8-cineole has germicidal potential against *E. coli* cells.

2.3 Effect of *Eucalyptus microcorys* leaves extracts on adhered *Escherichia coli*

The different percentages of adhered and detached enteropathogenic *E. coli* cells after contact with the *Eucalyptus microcorys* extract solution at the different

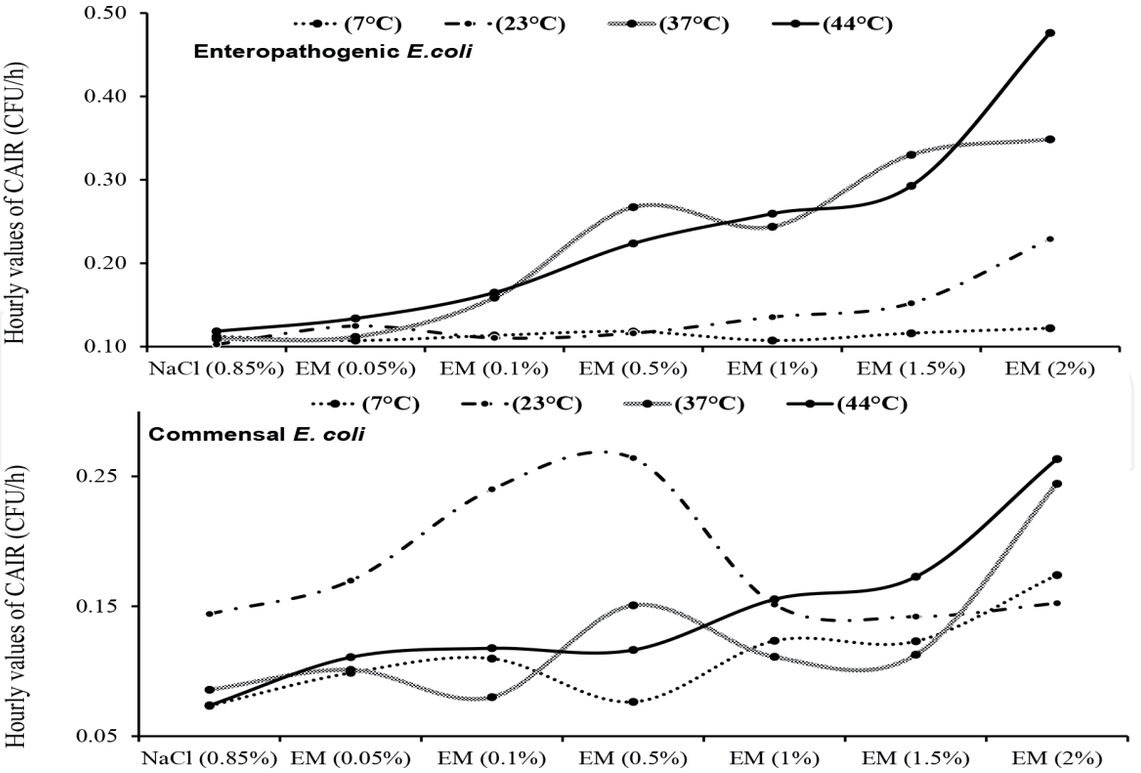

Figure 1.
Hourly inhibitory rate of Enteropathogenic and commensal E. coli *cells (determined as hourly values of cell apparent inhibition rates, CAIR) for each concentration of the* Eucalyptus microcorys *leaves extract (EM) at different incubation temperatures.*

concentrations chosen, were evaluated for the cells from each growth phase. They are presented in **Table 1**.

When the cells were from the lag phase, the percentages of cells remaining adhered after a stay in the extract solution fluctuated between 1.2 and 15%, 0.3 and 12.2%, and 0.2 and 6.4% after 1, 2 and 3 hours respectively when the concentration of the *Eucalyptus microcorys* extract was 1%. These percentages varied between 0.5 and 5.4%, between 0.3% and 3.1%, and between 0.2% and 4.7% after 1 h, 2 h and 3 h respectively in the 1.5% extract solution. In the 2% extract solution, these percentages fluctuated between 1% and 8.4%, between 0.1% and 4.9%, and between 0.9% and 4.4% after 1 h, 2 h and 3 h of residence respectively. At the same time, the percentages of detached cells varied from 1.7 to 11.0%, 0.5 to 9.2% and 2.0 to 4.5% respectively at extract concentrations of 1, 1.5 and 2% respectively (**Table 1**).

For cells from the exponential growth phase, the percentages of cells remaining adhered fluctuated between 0.4 and 10.2%, between 0.2 and 5.8%, and between 0.3 and 4.9% after 1 hour, 2 hours and 3 hours of contact with the 1% extract solution. They varied between 1.2 and 6.8%, between 0.6 and 5.4%, and between 1.0 and 5.2% after 1 hour, 2 hours and 3 hours of contact with the 1.5% extract solution. At the 2% extract concentration, these percentages fluctuated between 1.2 and 5.6%, between 0.3 and 6.5%, and between 1.0 and 1.8% after 1 hour, 2 hours and 3 hours of contact respectively. Under similar experimental conditions, the percentages of detached cells ranged from 1.6 to 11.4%, 0.9 to 68.8% and 1.0 to 12.7% at 1, 1.5 and 2% extract concentrations respectively (**Table 1**).

Solutions of *Eucalyptus microcorys* extract lead to detachment of the bacterial cells initially adhered to the polyethylene fragment. The importance of this cell detachment varies not only as a function of the concentration of the extract but also as a function of the residence time of the adhered cells in the extract solution. The bacterial adhesion to substrates involves two main steps: reversible adhesion and

Cell growth phase and preincubation time	Percentage of detached (%D) and adhered (%A) cells of enteropathogenic Escherichia coli, after 1, 2 or 3 hours of contact with the plant extract solution at concentrations of 1%, 1.5% and 2%																	
Growth phase	**Duration of preincubation for cell adhesion[a]**	**1%**						**1.5%**						**2%**					
		%A			**%D**			**%A**			**%D**			**%A**			**%D**		
		1 h	**2 h**	**3 h**	**1 h**	**2 h**	**3 h**	**1 h**	**2 h**	**3 h**	**1 h**	**2 h**	**3 h**	**1 h**	**2 h**	**3 h**	**1 h**	**2 h**	**3 h**
Lag	3 hours	15.0	12.2	6.4	1.7	2.8	2.0	1.2	1.3	0.2	3.9	3.5	0.4	8.4	1.7	4.4	4.4	4.5	4.0
	6 hours	1.3	0.3	0.2	2.9	0.5	2.9	0.5	0.3	0.2	0.4	3.4	2.8	1.0	0.1	0.9	1.8	0.9	4.9
	9 hours	1.2	2.2	1.3	11.0	9.2	4.5	5.4	3.1	4.7	11.1	9.9	11.2	3.6	4.9	2.7	9.3	5.7	1.5
Exponential	3 hours	10.2	5.8	3.0	10.5	3.6	9.4	6.8	5.4	2.4	13.3	9.3	62.8	5.6	6.5	1.8	12.7	1.0	7.3
	6 hours	0.4	5.3	4.9	11.4	8.8	8.6	4.5	4.9	5.2	14.6	5.2	68.8	4.4	2.9	1.0	8.1	1.4	1.3
	9 hours	0.8	0.2	0.3	5.7	1.9	1.6	1.2	0.6	1.0	4.2	0.9	12.9	1.2	0.3	1.3	8.3	1.9	2.6
Stationary	3 hours	11.3	14.0	17.1	33.3	12.4	37.6	16.1	17.2	7.0	4.6	3.7	48.5	5.6	6.8	4.8	3.7	2.8	2.9
	6 hours	4.3	9.6	7.7	16.0	24.0	33.6	3.0	5.4	10.5	3.1	2.5	33.5	1.6	8.5	7.7	2.2	1.7	1.9
	9 hours	8.8	8.8	3.3	34.0	33.4	25.6	13.5	11.1	5.4	3.0	1.9	25.1	7.6	5.9	1.3	2.9	1.3	1.8
Decline	3 hours	33.0	15.3	17.2	55.6	44.9	48.3	14.6	15.3	8.8	3.3	0.7	9.7	14.0	13.0	9.7	1.9	2.5	4.5
	6 hours	4.6	17.7	12.4	21.3	14.7	12.6	6.8	8.9	8.6	1.8	2.3	30.2	17.2	14.4	5.8	0.9	1.8	1.1
	9 hours	7.9	11.3	25.4	14.5	14.4	13.8	8.0	5.2	13.5	1.2	1.2	16.0	9.7	5.4	5.0	1.5	1.8	4.8

[a]*Incubation duration for cell adhesion process on polythene fragment in NaCl solution (0.85%) prior exposure to the Eucalyptus leaves extracts.*

Table 1.
Effect of 1%, 1.5% and 2% Eucalyptus *leaves extracts on adhered EPEC cells from different growth phases and preincubation periods in 0.85% NaCl solution.*

irreversible adhesion [22]. The reversible adhesion is governed by physico-chemical interactions of type Van der Waals and Lewis acid–base [23]. The irreversible adhesion is slower than the previous one, the irreversibility of the membership using the bacterial metabolism step.

The detachment of enteropathogenic *E. coli* cells, initially fixed on the fragments of polyethylene, would be caused by the secondary metabolites present in the plant extract, which would cause the breakdown of the hydrogen bonds within the exopolysaccharide secreted by the enteropathogenic *E. coli* cells such as a protective matrix. In bacteria, the permeabilization of membranes by these compounds is associated with a loss of ions and degradation of the ATP potential, the aromatic molecules having the highest antibacterial activity being the phenols.

The polyphenols present in the extract of *Eucalyptus microcorys* would constitute stress factors and probably deprive the bacteria of their protective glycocalyx, thus causing a disorganization of the biofilm and the dislodgement of the bacteria from the surface of the polyethylene slides. However, studies showed that the rates of detached cells remain below 15%. This low rate would be linked to the exopolymer covering the bacteria which creates a concentration gradient so that the permeabilization of the protective layer is not complete. Thus, only bacterial cells from a certain distance from the support are affected and dislodged. Some bacteria carry specific genes in their plasmids, genes that code for virulence factors (type IV fimbriae, adhesins, toxins) and which play an important role in the cell adhesion process. They allow the interconnection of bacteria in micro-colonies, promoting their stabilization, which can lead to resistance to the effect of the detachment of the extract.

The change of strains from the adhered state to the planktonic state further exposes the bacterial cells to the antibacterial effect of the flavonoids and alkaloids contained in the plant extract. Alkaloids are hydrophobic cations with antibacterial properties and targeting cellular DNA. This inhibitory effect is modulated by the adherent cell-extract contact time, the long contact times acting on targets not reached by relatively short contact times. The percentages of inhibition of enteropathogenic *E. coli*, for all the four phases of cell growth, vary between 73.56% and 99.49%, the concentration of *E. microcorys* 2% being that which results in high levels of cell inhibition.

The presence of bacterial strains still living in the planktonic state in the extract could be explained by the phenomenon of resistance such as the phenomenon of microbial resistance to antibiotics. Bacteria can synthesize enzymes capable of destroying or modifying antibacterial molecules, the enzymatic reactions leading to this destruction or this modification, although varying with the bacterial strain. The resistance mechanism observed appears to be multifactorial. Indeed two mechanisms are generally advanced to explain the resistance of biofilms to antibacterials. It can be due either to a limitation of the diffusion of the antibacterial agents in the biofilm by the polysaccharide matrix which coats the bacteria, or to the particular physiological state (low growth rate) of the bacteria of the biofilm, consequence of the nutritional limitation that undergo bacteria within the biofilm. The hydrated polyanionic matrix that coats bacteria in biofilms, limits the diffusion of molecules from the surrounding medium and more particularly of charged molecules. The hydrated polyanionic matrix that coats bacteria in biofilms, limits the diffusion of molecules from the surrounding medium and more particularly of charged molecules.

The physiological state of the cell and the extract concentrations are the first factors influencing the adhesion process of *E. coli* through the detachment or maintenance of cells after the stay of the polyethylene fragment in the extract solution of *E. microcorys*. The action of disinfectant solutions on microorganisms could depend

on several factors, some of which are intrinsic to the organism and others are related to the environment. Knowledge of these factors should lead to better achievement of disinfection and sterilization. Resistance of the adhered cells of *E. coli* to the plant extract is observed after 9 hours of incubation when the cells have emerged from the exponential phase of growth. The lag phase corresponds to the adaptation of the inoculum to its new environment, while the decline phase is the period corresponding to the exhaustion of all nutritional resources. There is an accumulation of toxic metabolites. Under the action of endogenous proteolytic enzymes, cell lysis leads to a decrease in viable organisms.

3. *Artemisia annua* extracts

3.1 Bioactive *Artemisia* compounds

Phytochemical analysis reveals the presence of alkaloids, free flavonoids, tannins, triterpenes and sterols, anthocyanins, reducing compounds, mucilages and coumarins in the extracts of *A. annua* [24, 25].

3.2 Effect of *Artemisia annua* leaves extract on *Escherichia coli*

The rates of change of bacterial concentrations varied in the presence and absence of light in the different media. In the dark, the rates of change of *E. coli* cell concentrations ranged from −12 to 50 cells/h. Minimum rates were obtained in pH 4 solutions. Maximum rates were recorded in pH 9 media. Negative values were noted in the pH 4 and pH 5 solutions. These negative rates indicate a relative inhibition of cell metabolisms in the presence of the plant extracts. In the control solutions, the rates of change in cell concentrations sometimes reached −19 cells/h (**Table 2**).

In the presence of light, the evolutionary rates of cell concentrations fluctuated between −14 and − 12 cells/h. Minimum rates were obtained in solutions containing *A. annua* extract at pH 4. Maximum rates were recorded at pH 8. In the control solutions, the rates of change in cell concentrations often reached −8 cells/h (**Table 2**).

The growth of *E. coli* was favored by slightly alkaline pH in the *Artemesia annua* extract solution, when grown in dark. The secondary metabolites present in the *Artemesia annua* extract are potentially involved in the physico-chemical modifications of the medium, promoting the observed cell growth. These results suggest that the *A. annua* extract does not present a bactericidal activity in water treatment in the absence of light. The study of the impact of light on *E. coli* bacteria in the presence of *A. annua* extract leads to a significant reduction in cell densities in comparison with the evolution of cell abundances in the dark. Leaves

Experimental conditions	***Escherichia coli* growth rates (CFU/h)**						
	pH 4	**pH 5**	**pH 6**	**pH 7**	**pH 8**	**pH 9**	**Witnesses**
In the dark	−12 (0,645)	−7 (0,637)	23 (0,822)	40 (0,696)	44 (0,518)	50 (0,763)	−19 (0,750)
In the presence of light	−14 (0,762)	−13 (0,836)	−13 (0,750)	−14 (0,828)	−12 (0,771)	−12 (0,767)	−8 (0,936)

Table 2.
Evolution rates of E. coli *cell concentrations (and regression coefficient) at each pH value and experimental condition [24, 25].*

of *A. annua* contain organic and inorganic substances and bioactive compounds. Molecules from extracts of *A. annua* can be a source of nutrients in the experimental conditions and allow the growth of different species. The study of the impact of light on *E. coli* bacteria in the presence of *Artemisia annua* extract leads to a significant reduction in cell densities in comparison with the evolution of cell abundances in the dark. This inhibition is explained by the effect of photosensitive compounds originating from the extract of *A. annua*. These compounds can induce a photosensitization reaction capable of inhibiting the metabolism of *E. coli* bacterial cells, since in the absence of light, no significant inhibition is observed.

4. *Moringa oleifera* extracts

4.1 Bioactive *Moringa* compounds

Phytochemical screening showed that most of the constituents obtained from aqueous and ethanoic extracts of *Moringa* spp. are alkaloids, flavonoids and phenols [26].

4.2 Effect of *Moringa oleifera* extract on *Escherichia coli*

The abundances of *E. coli* in different extract concentrations ranged from 500×10^3 to 0.92×10^3 CFU/100 mL. At 4°C, it ranged from 224.48×10^3 to 3.58×10^3 CFU/100 mL. The lowest abundance was recorded at 10 g/L and the highest at 1 g/L (**Figure 2**).

At 23°C, it ranged from 129.7×10^3 to 0.92×10^3 CFU/100 mL, with the lowest abundance recorded at 30 g/L and the highest at 1 g/L. The cell concentrations in the control (solution without seed extract) were 500×10^3 CFU/100 mL at 23°C and 4°C, respectively (**Figure 2**).

The obtained inhibition percentages and temporal variation of *E. coli* cell abundances show that *Moringa oleifera* seed extract can be used as a natural alternative for efficient water treatment. The antibacterial activity of *M. oleifera* seed extract is believed to be due to the presence of a cationic protein molecule present in the seed. This protein, commonly known as *M. oleifera* cationic protein (MOCP), is responsible for the death of bacterial cells by rapid flocculation and fusion of their inner and outer membranes. This protein would inhibit the growth of bacteria at higher concentrations, thus facilitating the antibacterial inhibition of the latter. However, this activity is dependent on the bacterial load, and an increased bacterial concentration would require a higher dose or higher concentration of the seed extract. The inhibitory effect of *M. oleifera* seed extract against bacterial cells is thought to be related to phytochemicals such as alkaloids, flavonoids and tannins, among others steroids, saponins, phenols, terpenoids and finally coumarins and anthraquinones present in the different seed extracts.

Temperature appears to be an important factor involved in cell inhibition by the aqueous extract of *M. oleifera* seeds. Incubation temperature increases the efficacy of the aqueous extract of *M. oleifera* seeds, with considerable inhibition at psychrophilic temperature. The seeds have been reported to contain calcium, magnesium, phosphorus, copper, vitamins (A, B and E) and are also rich in organic elements. These different secondary metabolites, sometimes present in large quantities in the extracts, could accumulate in the cell wall of *E. coli* and become toxic. The inhibition of bacteria could also be due to the presence of the isothiocyanate molecules α-L-rhamnosyloxy benzyl which are found in the seeds and whose antibacterial and

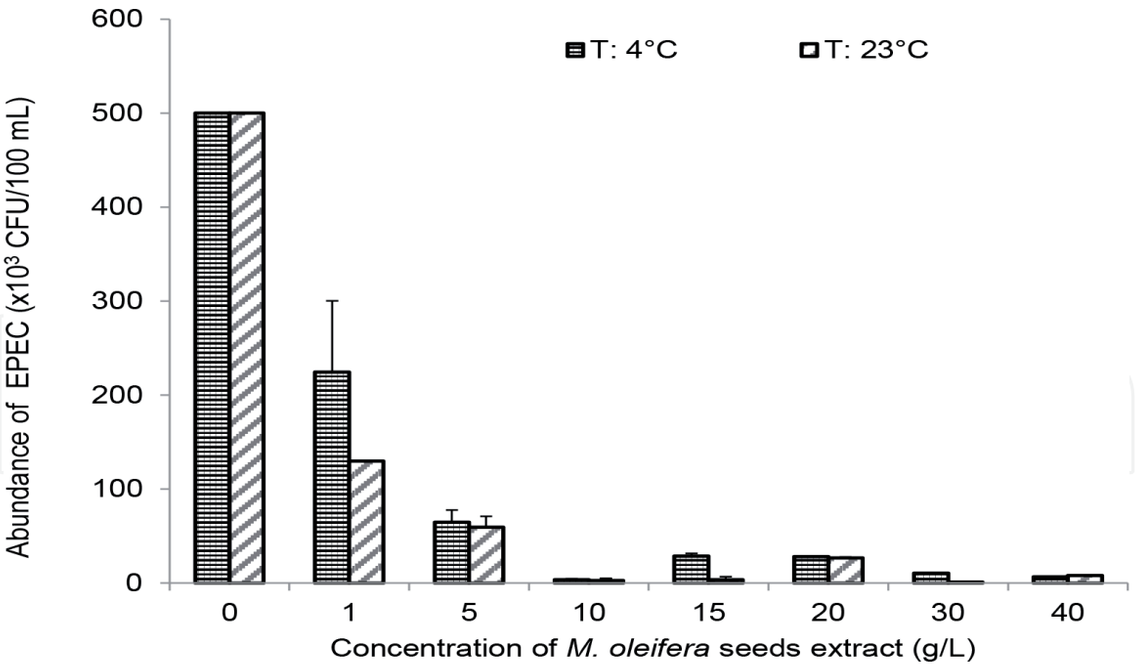

Figure 2.
Enteropathogenic E. coli *(EPEC) abundance depends on the concentration of* Moringa oleifera *seeds extracts [26].*

antifungal properties have been described. These molecules are soluble and positively charged. They can easily cross the bacterial membrane to bind to negatively charged cationic proteins on the cell membrane surface and support their inhibition. Water disinfection with Moringa seeds requires relatively high doses of 200 g/L of extract to have a germicidal effect. With a variation of extract concentrations from 1 g/L to 40 g/L, the bacterial inhibitions varied from 55.12% to 99.9% for enteropathogenic *E. coli*. This suggests that the environment, as well as the genetic characteristics of the bacteria or other abiotic properties of the water used, could affect the activity of the constituents of the seeds and other parts of the plant (root barks and stems).

5. Conclusion

Drinking water is often subject to bacteriological contamination, causing serious health problems due to diarrhoeal diseases, gastroenteritis, cholera and typhoid fever. In recent years, water disinfection methods using plant extracts have been proposed as a new alternative for household water treatment. Information on the conditions of the use of plant extracts in the treatment of bacterio-contaminated water is often not available. The chapter aimed to summarize the known effects of some plant extracts on the cultivability of *E. coli* cells.

The results show that the presence and absence of light determine the action of the plant extracts on the survival of *E. coli* bacteria in aquatic environments. In the absence of light, *A. annua* extracts can sometimes promote bacterial cell activity. This activity is influenced by the pH of the solutions, the sensitivity of the bacterial cells under monospecific conditions being observed. The impact of the pH would be linked to a variation of the assimilation coefficient of nutritive substances.

In the presence of light, the plant extract inactivates bacterial metabolism to varying degrees. This variability depends on the concentration of the extract. The rate of photo-oxidation reactions that lead to bacterial inactivation is pH dependent, and varies from one bacterial species to another. The presence of light increases the inhibitory effect of plant extracts on *E. coli* cells.

The use of medicinal plants in water disinfection offers many opportunities in a world where access to safe drinking water remains a permanent concern for public authorities, therefore it should be considered to use plant extracts as an alternative process for water disinfection.

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