Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2023.30060

313 (2023) 125–129
November

Disinfectants of plant origin: emerging application, standardization and meta-analysis

A.O. Adeeyo[a,*], B.S. Ojelade[b,*], M.A. Alabi[c,*], R. Makungo[d]

[a]*Aqua Plantae Research, Faculty of Science Engineering and Agriculture, University of Venda, Private Bag X5050, Thohoyandou (0950), Limpopo, South Africa, Tel. +27723030995; email: adeeyoao@gmail.com*
[b]*Department of Geography and Environmental Sciences, Faculty of Science Engineering and Agriculture, University of Venda, Private Bag X5050, Thohoyandou (0950), Limpopo, South Africa, Tel.: +27743846154; email: babatunde.ojelade@univen.ac.za*
[c]*Department of Microbiology, School of Sciences, Federal University of Technology, Akure, Nigeria, email: alabimercy14@gmail.com*
[d]*Department of Earth Sciences, Faculty of Science Engineering and Agriculture, University of Venda, Private Bag X5050, Thohoyandou (0950), Limpopo, South Africa, email: rachel.makungo@univen.ac.za*

Received 1 June 2023; Accepted 13 October 2023

A B S T R A C T

This review evaluated plant extracts' effectiveness in treating and disinfecting water. According to data analysis, plant secondary metabolites with complex mechanisms of action are not widely used in water treatment. Only around 25% of studies reported the use of plant extracts for water purification, compared to almost three-quarters that reported antibacterial activity. Therefore, more research into plant-based technologies to cleanse and treat drinkable and safe water is required. According to reports, plants' seeds and flowers were employed in about half of the studies (24.53% and 20.75%, respectively), but less study has been done on how to use their bulbs, resin, bark, and tubers. Limited application of plant exists in developing associated products for water treatment because of the plant's availability, difficult extraction methods, lack of standardization, need for purification, slow rate of action, poor water solubility and yield of plant extract. This has caused a gap in the adoption for large and industrial scale applications. The technology needs to be improved so that it can be used in industrial settings more widely. Genomic, metabolomic, and proteomic methodologies need to be used for phytobiotic standardization. Water can be treated using plant products, but there are limitations. These limitations must be improved to increase acceptance of these products in the industry.

Keywords: Phytochemicals; Microbial resistance; Water treatment; Standardization

1. Introduction

As an alternative to harmful chemicals, the use of active plant derivatives is promoted, with tremendous promise for the creation of products with antimicrobial and sanitizing properties. As a result, it is now possible to create products based on natural ingredients that are less toxic [1,2]. Therefore, plant-based products have been developed as an alternative to chemical coagulants. There are many plants with different mechanisms of action due to secondary metabolites such as phenols, flavonoids, tannins, alkaloids, and saponins present in them. Evidence has demonstrated that these phytochemicals can exert antibacterial, antifungal, antioxidant, antidiabetic, anti-inflammatory, immunomodulatory, and even antitumor activities in plants [3]. Globally, antimicrobial resistance is increasing [4]. There have been claims that plants can be used to disinfect and treat water, which is less expensive and safer [5–10]. Another emerging

* Corresponding authors.

area in which a plant phytochemical may double its role during disinfection is in water fortification (flavoured and fortified), preventing illness and diseases [11].

Regarding their potential for use in water treatment, several plants have been researched, including *Euclea divinorum*, *Moringa oleifera*, Guar gum, *Albizia anthelmintica*, *Acacia* spp., *Plumbago zeylanica*, and *Jatropha curcas* [12,13]. The seeds from *M. oleifera* have been demonstrated to be one of the most efficient main coagulants and disinfectants for water treatment, particularly in rural populations, out of the wide variety of plant materials that have been employed throughout the years [14]. Plant extracts have not only been tested against bacteria but also for anti-amoeba effectiveness for disinfection. Siddiqui et al. [15] reported the *in-vitro* activity of extracts of *Rinorea yaundensis* and *Salvia fruticosa* against *Acanthamoeba castellanii* with betulin, betulinic acid, and vanillic acid exerting activity of 67%, 67%, and 65% against *A. castellanii*, respectively. Extracts from plants have also been reported for great turbidity removal in line with disinfection. Kihampa et al. [16] reported the turbidity treatment activity of the extract of *Solanum incanum* in water samples of initial turbidities of 450, 300 and 105 NTU with corresponding average percentage removal of 99.78, 99.11 and 97.14 as residue. Therefore, this review aims to identify the less widely reported use of plants in water safety and disinfection. It also highlights some commercially available water disinfectants of plant origin and projects the need for more products, upon the discovery of their effectiveness, putting into consideration the standardization of these products for the safety of consumers of treated water.

2. Methodology

This review utilized English-language articles published in reputable journals. A variety of phytobiotics are discussed in these papers, including their history, types, mechanisms of action, standardization, and application. The review discusses the challenges associated with phytobiotic standardization and makes recommendations for improvement. The results of data analysis are presented in fractions and percentages.

3. Results and discussion

3.1. Emerging interventions of plants

The use of plants in water treatment and as a disinfectant against resistant bacteria in the water are growing applications of phytobiotics, however, little literature to this effect exists [17]. There have been reports of plant extracts usage for treating water, including those from Guar gum, *Terminalia glaucescens*, *Gongronema latifolium*, *M. oleifera*, *Azadirachta indica*, *J. curcas*, *Zanthoxylum zanthoxyloides* and *Luffa cylindrica* fruit extracts [9,18]. Additionally, phytochemicals have been quite effective in preventing the growth of biofilm and multidrug resistance [19]. They can also be used in adjuvant therapy, which cuts down on the need for synthetic disinfectants [20].

Secondary metabolites available in plants are influenced by signal transduction and gene expression pathways or interference with specific biological metabolic processes. Accumulation of metabolites often occurs in plants subjected to stresses including various elicitors or signal molecules. Understanding the signal transduction paths underlying elicitor-induced production of secondary metabolites is important for optimizing the commercial production of secondary metabolites [21]. When the colonised signalling system is recognised, plants are able to release endophytic bacterial molecules, which in turn activates the signalling network and biological response of the plant. This influences the related gene expression activity and mediates the synthesis and accumulation of secondary metabolites in the plant [22].

Phytochemicals interfere with the function of cell walls and membranes in a manner similar to that of synthetic antibiotics. More significantly, certain phytochemicals reduce or decrease quorum sensing, which is a workable defense against antibiotic resistance. In addition, the complexity of plant metabolites aids in microbes' disruption of protein-protein interactions, which also lowers resistance [23,24].

Natural flavoring agent *Glycyrrhiza glabra* has been shown to be effective in treating multidrug-resistant *Pseudomonas aeruginosa* (MRPA). It surpasses antibiotic amikacin's performance against resistant strains of *P. aeruginosa*, showing strong bactericidal effects. Its bactericidal action is attributed to the synthesis of quinones and superoxide ions by its bioactive phenolic compounds [25]. Also, study has examined the antimicrobial properties of *Acacia nilotica* extract in relation to cell membrane integrity, permeability, and bacterial kill time. The reports revealed that it exhibited bactericidal effects by damaging bacterial cell membranes [26]. Additionally, studies have shown that common spices including garlic, onion, coriander, pepper, and ginger, as well as their aqueous and lime extracts, have potent *in-vitro* antimicrobial action against multidrug-resistant *Escherichia coli* (MREC) strains [27].

By preventing the development of locomotive surface assembly fimbriae, phytochemicals like flavonoids have been used to stop seropathotype *E. coli* O157:H7 (STEC) from forming biofilms. For instance, genomic qRT-PCR analysis and electron microscopy tests both indicated that the flavonoid phloretin from apples significantly inhibited STEC biofilm at a dosage of 50 g/mL. Similarly, Ginkgolic acid from *Ginkgo biloba* and naringenin from grape seeds efficiently impeded the development of STEC biofilms by suppressing the curli gene. Trans-resveratrol, a different polyphenol from grape seeds, inhibited the expression of the curli gene to produce anti-biofilm effects against STEC. Trans-resveratrol at a concentration of 10 g/mL reduced *E. coli* cell adhesion to human epithelial tissue, according to transcriptional experiments [28].

3.2. Standardization of plant products

To ensure the quality, efficacy, non-toxicity, reproducibility, and excellence of the products developed from plant extracts obtained in a crude state, standardization is necessary [29]. It is of great importance that an herbal product is signed as valid and can be distinguished from a counterfeit product. Standardization ensures the efficacy and safety of herbs and helps to reduce batch-to-batch variations [30]. The standardization of plants products includes authentication (stage of collection, parts of the plant collected, botanical identity like phytomorphology, microscopical and histological analysis, taxonomical identity, etc.), foreign matter exclusion (herbs collected should be free from soil, insect parts or animal excreta, etc.), organoleptic evaluation (sensory characters such as taste, appearance, odour, feel of the drug, etc.), volatile matter, moisture content determination, determination of its heavy metals (e.g., cadmium, lead, arsenic, etc.), pesticide residue, microbial contamination and chromatographic and spectroscopic evaluation [31].

Techniques including high-performance thin layer chromatography, super critical fluid chromatography, gas chromatography, thin layer chromatography, DNA fingerprinting and chromatographic fingerprinting, are employed to standardize herbal products [32]. Thin layer chromatography provides qualitative and semi-quantitative information, as well as information on the quantity and makeup of phytochemicals. High-performance thin layer chromatography is frequently used to identify and recognize fake products, and it helps with the quality monitoring of herbal products. Additionally, DNA fingerprinting is a crucial technique used to detect adulterated plant parts that cannot be resolved phytochemically. However, the ability of processed drug samples with unresolvable phytochemical similarities to be resolved by DNA fingerprinting depends on the availability of intact genomic DNA from plant samples after processing [8].

3.3. Disinfectants of plant origin

Plant-based products have been produced as disinfectants and are reportedly effective [33]. Examples include tannins made from the polyphenolic metabolites found in plant bark, fruits, and leaves [34]. Typical tannins used to treat water include those from barks of quebracho wood, pine, eucalyptus species and mimosa trees. It has been shown that tannins can coagulate raw water to remove colloidal and suspended materials, pigments, dyes, and inks from water containing inks [35,36]. Plant gums and mucilages have also been used for flocculation of textile wastewater, sewage effluent, tannery effluent and landfill leachate [37,38]. Low chemical reactivity and poor solubility of cellulose, limit its utility and the carboxymethylation process can address this drawback [39]. Examples of commercial disinfectants from plants are Tanfloc, TANAC and SilvaFLOC [40,41]. Plant-based coagulants, such as those extracted from *M. oleifera*, *Strychnos potatorum* Linn, and *Opuntia ficus-indica*, have been researched and suggested as eco-friendly substitutes for chemical coagulants. This is because they are available, cost-effective, generate minimal sludge and can be easily biodegraded [17]. Most of these plant-based products additionally contain components like saponin, steroid rings, deoxy sugar, alkaloids, tannins, phenolic compounds and flavonoids that exhibit coagulation and flocculation properties [42].

3.4. Data analyses

Figs. 1 and 2 indicate plant part used and reported activity, respectively, from a survey of medicinal plants. From a total of 44 medicinal plants in the survey, whole plants (24.53%) and seeds (24.53%) are the most used while resin, bark, tubers and seed pods are the least used with 1.89% reported for each.

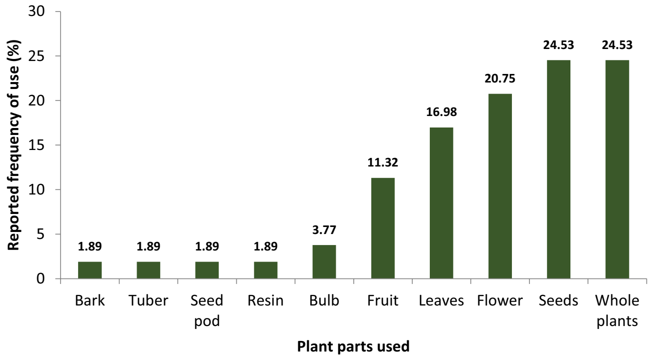

Fig. 1. Reported use of plant parts.

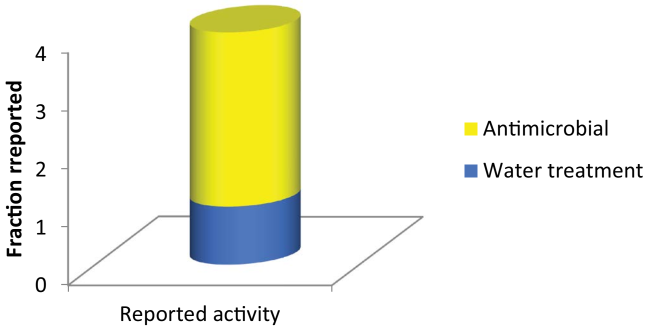

Fig. 2. Reported plant extracts activity in fraction.

The utilization of whole plants accounts for 24.53%, which can be explained by the assumption that they will have an additive or synergistic effect. However, using whole plants poses a threat to plant conservation, hence it is not recommended. The desired component in medical investigations is leaves since they have a high concentration of secondary metabolites [3]. Additionally, compared to their use in water treatment (1/4), plant extracts had much more antibacterial activity reported (3/4) (Fig. 2). This reveals that plants have been greatly studied for drug discovery (as a means of alternative chemotherapy in combatting antimicrobial resistance) than they have been studied as water disinfectants.

The use of plant extracts as water disinfectants requires extensive research because it is a promising application for plants and a potential improvement over the use of synthetic disinfectants.

4. Conclusion

This review presents the use of plant products in water treatment and disinfection. Plants are readily available, eco-friendly and possess multiple mechanisms of action that help in effective disinfection. The leaves of plants are a desired source of secondary metabolites since they have a high concentration of these compounds. Plant metabolites have been used in water treatment as a disinfectant and coagulant and few commercial products exist. However, this application in water treatment needs to be strengthened, and issues like adverse effects, purification, and standardization require rapid attention. In order to screen safe herbs and isolate pure molecules, new studies in the field of plant products should use cutting-edge approaches such as proteomics, genomics, and metabolomics. These strategies will help minimize the challenges associated with phytobiotic safety and standardization.

References

[1] P. Agarwal, S. Gaurav, Use of natural coagulants (*Moringa oleifera* and *Benincasa hispida*) for volume reduction of waste drilling slurries, Mater. Today Proc., 49 (2022) 3274–3278.

[2] A.H. Amran, M.B. Bahrodin, N.S. Zaidi, K. Muda, A. Aris, N. Azrimi Umor, M.F. Mohd Amim, A. Syafiuddin, Turbid water treatment using deshelled *Carica papaya* seed: analysis via factorial design, Biointerface Res. Appl. Chem., 12 (2022) 7787–7795.

[3] M.A. Alabi, Antibiotics sensitivity profile of wounds' bacterial isolates and antibacterial assessment of *Chromolaena odorata* aqueous and ethyl acetate extracts, South Asian Res. J. Nat. Prod., 3 (2020) 1–9.

[4] H. Chandra, P. Bishnoi, A. Yadav, B. Patni, A.P. Mishra, A.R. Nautiyal, Antimicrobial resistance and the alternative resources with special emphasis on plant-based antimicrobials - a review, Plants, 6 (2017) 1–11.

[5] A.O. Adeeyo, S.S. Ndlovu, L.M. Ngwagwe, M. Mudau, M.A. Alabi, J.N. Edokpayi, Wetland resources in South Africa: threats and metadata study, Resources, 11 (2022a) 54, doi: 10.3390/resources11060054.

[6] A.O. Adeeyo, Nano-Biomaterial Treatment of Noxious Microbial Pollutant in Water, Ph.D. Thesis Submitted to Faculty of Science, Engineering and Agriculture, University of Venda, South Africa, 2022b.

[7] A.O. Adeeyo, J.O. Odiyo, A.M. Enitan, M.M. Motsa, T.A.M. Msagati, H.D. Mkoyi, R. Makungo, Morphometric and structural properties of a sustainable plant biomass with water purification potentials, Sustainability, 13 (2021a) 11075, doi: 10.3390/su131911075.

[8] A.O. Adeeyo, J.N. Edokpayi, A.A. Mercy, T.A.M. Msagati, J.O. Odiyo, Plant active products and emerging interventions in water potabilisation: disinfection and multi-drug resistant pathogen treatment, Clin. Phytosci., 7 (2021b) 31, doi: 10.1186/s40816–021–00258-4.

[9] A.O. Adeeyo, J.O. Odiyo, T.A.M. Msagati, Antimicrobial potency of selected native African herbs against water microbes, J. King Saud Univ. Sci., 32 (2020) 2349–2357.

[10] A.O. Adeeyo, J. Odiyo, K. Odelade, Chemical profiling and antimicrobial properties of phyto-active extracts from stem against water microbial contaminants, Open Biotechnol. J., 12 (2018) 1–15.

[11] A.O. Adeeyo, T.M. Ndou, M.A. Alabi, H.D. Mkoyi, E.M. Enitan, D. Beswa, R. Makungo, J.O. Odiyo, Structure: Activity and Emerging Applications of Spices and Herbs, R.S. Ahmad, Ed., Herbs and Spices - New Processing Technologies, IntechOpen, 2021c. https://doi.org/10.5772/intechopen.99661

[12] Y. Abatneh, O. Sahu, S. Yimer, Purification of drinking water by low-cost method in Ethopia, Appl. Water Sci., 4 (2014) 357–362.

[13] J.K. Kirui, K. Kotut, P.O. Okemo, Efficacy of aqueous plant extract in disinfecting water of different phytochemical properties, J. Water Health, 13 (2015) 848–852.

[14] M. Megersa, A. Beyene, A. Ambelu, B, Woldeab, The use of indigenous plant species for drinking water treatment in developing countries: a review, *J. Biodivers. Environ. Sci.*, 5 (2014) 269–281.

[15] R. Siddiqui, N. Akbar, B. Khatoon, M. Kawish, M.S. Ali, M.R. Shah, N.A. Khan, Novel plant-based metabolites as disinfectants against *Acanthamoeba castellanii*, Antibiotics, 11 (2022) 248, doi: 10.3390/antibiotics11020248.

[16] C. Kihampa, W.J.S. Mwegoha, M.E. Kaseva, N. Marobhe, Performance of *Solanum incanum* L. as natural coagulant and disinfectant for drinking water, Afr. J. Environ. Sci. Technol., 5 (2011) 867–872.

[17] B.U. Okoro, S. Sharifi, M.A. Jesson, J. Bridgeman, Natural organic matter (NOM) and turbidity removal by plant-based coagulants: a review, J. Environ. Chem. Eng., 9 (2021) 106588, doi: 10.1016/j.jece.2021.106588.

[18] M. Pritchard, T. Mkandawire, A. Edmondson, J.G. O'Niell, G. Kululanga, Potential of using plant extracts for purification of shallow well water in Malawi, Phys. Chem. Earth, 34 (2009) 799–805.

[19] E.M. Abdallah, Plants, an alternative source of antimicrobials, J. Appl. Pharm. Sci., 1 (2011) 16–20.

[20] C. Santiago, E.L. Pang, K.H. Lim, H.S. Loh, K.N. Ting, Inhibition of penicillin-binding protein 2a (PBP2a) in methicillin resistant *Staphylococcus aureus* (MRSA) by combination of ampicillin and a bioactive fraction from *Duabanga grandiflora*, BMC Complement. Altern. Med., 15 (2015) 178, doi: 10.1186/s12906-015-0699-z.

[21] A.M. Alvarado, H. Aguirre-Becerra, M.C. Vázquez-Hernández, E. Magaña-Lopez, I. Parola-Contreras, L.H. Caicedo-Lopez, L.M. Contreras-Medina, J.F. Garcia-Trejo, R.G. Guevara-Gonzalez, A.A. Feregrino-Perez, Influence of Elicitors and Eustressors on the Production of Plant Secondary Metabolites, M. Akhtar, M. Swamy, U. Sinniah, Eds., Natural Bio-active Compounds, Vol. 1, Springer, Singapore, 2019, pp. 333–388. Available at: https://doi.org/10.1007/978-981-13-7154-7_11

[22] Y. Wang, Z. Li, M. Xu, Z. Xiao, C. Liu, B. Du, D. Xu, L. Li, Signal molecules regulate the synthesis of secondary metabolites in the interaction between endophytes and medicinal plants, Processes, 11 (2023) 849, doi: 10.3390/pr11030849.

[23] P.D. Gupta, P.G. Daswani, T.J. Birdi, Approaches in fostering quality parameters for medicinal botanicals in the Indian context, Indian J. Pharmacol., 46 (2014) 363–371.

[24] A. Upadhyay, D.P. Karumathil, I. Upadhyaya, V. Bhattaram, K. Venkitanarayanan, Controlling Bacterial Antibiotic Resistance Using Plant-Derived Antimicrobials, In: Antibiotic Resistance, 2016, pp. 205–226.

[25] A.S. Chakotiya, R. Chawla, P. Thakur, A. Tanwar, A. Narula, S.S. Grover, R. Goel, R. Arora, R.K. Sharma, *In-vitro* bactericidal activity of promising nutraceuticals for targeting multidrug resistant *Pseudomonas aeruginosa*, Nutrition, 32 (2016) 890–897.

[26] M.B. Sadiq, J. Tarning, T.Z. Aye Cho, A.K. Anal, Antibacterial activities and possible modes of action of *Acacia nilotica* (L.) Del. against multidrug-resistant *Escherichia coli* and *Salmonella*, Molecules, 22 (2017) 47, doi: 10.3390/molecules22010047.

[27] S. Rahman, A.K. Parvez, R. Islam, M.H. Khan, Antibacterial activity of natural spices on multiple drug resistant *Escherichia coli* isolated from drinking water, Bangladesh Ann. Clin. Microbiol. Antimicrob., 10 (2011) 1–4.

[28] A. Rohatgi, P. Gupta, Natural and synthetic plant compounds as anti-biofilm agents against *Escherichia coli* O157: H7 biofilm, Infect., Genet. Evol., 95 (2021) 105055, doi: 10.1016/j.meegid.2021.105055.

[29] K.C. Patra, S.K. Pareta, R.K. Harwansh, K.K. Jayaram, Traditional approaches towards standardization of herbal medicines – a review, J. Pharm. Sci. Technol., 2 (2020) 372–379.

[30] I. Ahmad, F. Aqil, M. Owais, Turning medicinal plants into drugs, Mod. Phytomed., 384 (2006) 67–72.

[31] S.S. Darvin, P. Pandikumar, S. Ignacimuthu, Standardization of natural products and drugs, Acta Sci. Pharm. Sci., 3 (2019) 19–20.

[32] A. Balekundri, V. Mannur, Quality control of the traditional herbs and herbal products: a review, Future J. Pharm. Sci., 6 (2020) 1–9.

[33] O. Bouaouine, B.F. Khalil, F. Khalil, M. Baudu, Identification of functional groups of *Opuntia ficus-indica* involved in coagulation process after its active part extraction, Environ. Sci. Pollut. Res., 25 (2018) 11111–11119.

[34] J. Beltran-Heredia, J. Sanchez-Martin, Municipal wastewater treatment by modified tannin flocculant agent, Desalination, 249 (2009a) 353–358.

[35] M. Özacar, I.A. Sengil, Evaluation of tannin biopolymer as a coagulant aid for coagulation of colloidal particles, Colloids Surf., A, 229 (2003) 85–96.
[36] J. Roussy, P. Chastellan, M.V. Vooren, E. Guibal, Treatment of ink-containing wastewater by coagulation/flocculation using biopolymers, Water SA, 31 (2005) 369–376.
[37] A. Mishra, M. Bajpai, Flocculation behaviour of model textile wastewater treated with a food grade polysaccharide, J. Hazard. Mater., 118 (2005) 213–217.
[38] Y.A.J. Al-Hamadani, M.S. Yusoff, M. Umar, M.J.K. Bashir, M.N. Adlan, Application of psyllium husk as coagulant and coagulant aid in semi-aerobic landfill leachate treatment, J. Hazard. Mater., 190 (2011) 582–587.
[39] Y. Wang, D. Wu, Q. Wei, D. Wei, T. Yan, L. Yan, L. Hu, B. Du, Rapid removal of Pb(II) from aqueous solution using branched polyethylenimine enhanced magnetic carboxymethyl chitosan optimized with response surface methodology, Sci. Rep., 7 (2017) 10264, doi: 10.1038/s41598-017-09700-5.
[40] J. Beltrán-Heredia, J. Sánchez-Martin, Removing heavy metals from polluted surface water with a tannin-based flocculant agent, J. Hazard. Mater., 165 (2009b) 1215–1218.
[41] J. Sanchez-Martin, M. Gonzalez-Velasco, J. Beltran-Heredia, Surface water treatment with tannin-based coagulants from Quebracho (*Schinopsis balansae*), Chem. Eng. J., 165 (2010) 851–858.
[42] A.N. Jones, Investigating the Potential of Hibiscus Seed Species as Alternative Water Treatment Material to the Traditional Chemicals, Doctoral Dissertation, University of Birmingham, 2017.