PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 7 No. 1 (2026) 720-726
https://publisher.uthm.edu.my/periodicals/index.php/peat

A Study of Pectin Biosorbent Effectiveness in Removing Lead in Water Samples Collected from Muar River

Khairunnisa Wadiah Mohamad Khair[1], Mas Rahayu Jalil[1]*

[1] *Department of Chemical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 86400 Pagoh, Johor, MALAYSIA*

*Corresponding Author: mrahayu@uthm.edu.my
DOI: https://doi.org/10.30880/peat.2026.07.01.079

Article Info

Received: 12 January 2026
Accepted: 20 February 2026
Available online: 25 May 2026

Keywords

Pectin, Biosorbent, Heavy Metal, Lead (Pb), Agricultural Waste

Abstract

This paper focuses on heavy metal pollution a health risk factor and its part in aquatic life destruction. It examines extracted pectin from pomelo peels, okra pods, and roselle calyces that are agricultural waste, as a natural biosorbent for Lead (Pb) removal from the Muar River in Panchor. Initial water quality analysis reported a Pb concentration of 0.9744 mg/L, exceeding both National Standard for Drinking Water Quality and Interim National Water Quality Standard Malaysia. Pectin extraction via acid hydrolysis yielded 49.98%, 14.96%, and 27.13% for pomelo peels, okra pods, and roselle calyces, respectively. FT-IR results confirmed the existence of carboxylate groups and galacturonic acids essential for chelation. Biosorbent analysis showed that Pure Pomelo pectin achieved the highest Pb removal rate at 64.64% with an adsorbent capacity (q_e) of 0.1174 mg/g. Roselle pectin maintained high dissolved oxygen levels (8.09 mg/L) while some materials increased water turbidity. Overall, the study signifies that fruit-derived pectin is an eco-friendly agent for remediating heavy metal-contaminated aquatic system.

1. Introduction

Rivers are essential water bodies that enhance sustenance through the promotion of the water cycle. Rivers are important to the sustainability of the ecosystem and the welfare of the Earth. In addition, the river acts as a source of irrigation that stimulates agriculture. Water also ideal for the production of hydropower, which is a renewable energy source. Rivers are, therefore, important sources that facilitate socioeconomic growth. However, pollution and human interaction are compromising the sustainability of the vital resource (Tong L, 2023). In Malaysia, the Muar River Basin is a trans-boundary basin that covers the states of Johor, Negeri Sembilan, Melaka, and Pahang. Notably, the lead (Pb) concentration of the Muar River is above the Malaysia Interim National Water Quality Standards (INWQS) Class II which indicates the waterways is at risk of accumulating heavy metals (Ching et al., 2015; Mulana et al., 2015).

Conventional techniques of metal ions removal by precipitation and membrane filtration are effective, but they are relatively expensive and energy- and sludge-demanding, which renders them less environment-friendly in the end. For this reason, a global interest has developed to move towards a greener method of removal, with the potential of biosorption being at the very front of this new trend. Pectin, which is a linear polysaccharide of plant cell walls naturally occurring in their tissues, has already repeatedly been shown to be efficient for adsorbing heavy metals such as copper, cadmium, and lead (Crittenden et al., 2012; Shrestha et al., 2021). The main reason for this efficiency is that it contains a generous number of carboxyl (-COOH) and hydroxyl (-OH), which strongly interact with metal ions through a model related to the so-called “egg-box” chelation theory. While citrus peel, apple, and other agricultural byproducts of citrus peels and apples have been previously shown to be effective for this goal, the total of benefits of utilizing various available natural sources of pectin, such as pomelo peels, okra pods, and roselle calyces for heavy metal removal is ill-defined (Wang et al., 2022; Wang et al., 2019). Therefore, by offering a complete evaluation of a new composite pectin, this research aids in filling this knowledge gap and offering an effective and potentially more efficient option for localized heavy metal remediation.

To address the above-mentioned problems, this research aims to investigate the remediation potential of the newly formulated low-cost pectin admixture for real samples of river water. Specifically, this study seeks to find answer to the following three research questions of prime importance such as, on the possibility to extract pectin from the peels of pomelo fruits, the pods of okra, and the calyces of roselle, the specific functional groups that exist in the above-mentioned pectin extracts that are responsible for the binding of Pb and the effectiveness of the above-mentioned pectin in the remediation of lead in the Muar River.

The aims of the proposed research are to prepare pectin from pomelo, okra, and roselle through acid hydrolysis, to identify the specific functional groups in the prepared pectin extracts through FT-IR analysis, and to determine the effectiveness of the pectin for the removal of lead in the Muar River water sample.

2. Methodology

In order to assess the efficacy of pectin as a sustainable biosorbent to treat heavy metals in actual water samples, the framework of the study shall be designed in such a way as to methodically examine the extraction of pectin from agricultural by-products.

2.1 Materials and Chemicals

Agricultural wastes, specifically the peels of pomelo fruits (*Citrus maxima*), the pods of okra (*Abelmoschus esculentus*), and roselle calyces (*Hibiscus sabdariffa*), are the raw materials employed in this study. These materials were chosen on the basis of their high pectin contents and their character as by-products of the agriculture industry based on "waste-to-wealth" philosophies (Dixit et al., 2025; Van Bao et al., 2015). A number of technical reagents were used in these extraction and analysis steps, including sodium hydroxide for pH adjustment, while hydrochloric acid and aqua regia were used in acid hydrolysis (Akachat et al., 2025). The lead levels as well as groups present in the extracted pectin were then determined using highly sensitive instruments such as Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) as well as Fourier Transform Infrared Spectrometry instruments (FT-IR) (Nur Intan Idayu, 2020; Raja et al., 2024).

2.2 Procedure of Pectin Extraction and Characterization

A sequenced acidic hydrolysis process is used in pectin synthesis to break down plant cell walls and release pectin molecules (Akachat et al., 2025). The process begins by applying an aqua regia solution to the powdered plant material for hydrolysis initiation. Next is pectin purification to ensure high-quality adsorption purity. The next process involves pectin structure analysis through the use of FT-IR methods to establish that the purified pectin has an established backbone composed of Fourier Transform Infrared active groups in this case; galacturonic acids and carboxylic acids groups that are central in heavy metal chelation; hence their confirmation is required to establish low methoxyl pectin purity (Manrique & Lajolo, 2002).

2.3 Batch Adsorption Experiment

Batch adsorption experiments were carried out using real river water taken from Panchor, Muar, to assess the efficiency of the obtained pectin. The experimental process involves four main steps. First, the initial values of the untreated water sample properties such as pH, turbidity, and Pb concentration was determined before the experiment was conducted. Secondly, 0.5 g of pectin was added to the water samples. To test for a synergy effect, the research used three source mixtures as shown in Table 3. Firstly, the individual pectin was used. Next, 0.25 g of each pectin used for the mixtures of pomelo and okra pectin, pomelo and roselle pectin and okra and roselle pectin. Lastly, a mixture of the three pectin altogether was used. Next, the mixtures were allowed to react, which makes possible the "egg-box" chelation geometry where Pb^{2+} ions were trapped by the pectin matrix. After the adsorption process, the filtered water was analyzed using the ICP-MS to establish the concentration of Pb remaining.

2.4 Data Analytic Strategy

For a quantitative measurement of the ability of the biosorbents, the removal rate (R) and adsorption capacity (qe) was calculated by the following definitions of Removal Rate (R) measures the percentage of lead that was removed from solution by pectin. Adsorption Capacity (qe) was measured by mass of Pb per mass of pectin;

calculated by taking a solution's initial and final concentrations. Furthermore, a study on mixtures was carried out to determine which mixtures provide a better response compared to a single formulation.

$$q_{e\ (mg/g)} = \frac{C_0 - C_e}{m} \times V \qquad (1)$$

$$R(\%) = \frac{C_0 - C_e}{C_0} \times 100\% \qquad (2)$$

3. Result and Discussion

This part showcases the results of the study in terms of pectin properties and the effectiveness in Pb removal in the Muar River. The results were interpreted within the framework of existing knowledge to assess the potential use of agricultural waste for construction of biosorbents.

3.1 Pectin Yield and Structural Composition

Yield of pectin extraction was strongly affected by the density of the cell wall matrix as well as botanical variety (Riyamol et al., 2023, Sangheetha et al., 2018). As shown in Table 1, the peel of the pomelo showed a yield of 49.98%, performing better than roselle calyces with a yield of 27.13% and okra pods with a yield of 14.96%. These results can be attributed to the rich protopectin found in citrus fruits rather than mucilaginous plants such as okra (Theuwissen & Mensink, 2008; Alba et al., 2015). FT-IR analysis (Fig. 1) of the prepared pectin extracts revealed their suitability for metal ions. Each of these extracts showed prominent peaks between 1600-1750 cm^{-1}, revealed the presence of galacturonic acids (Smith, 2011). These groups along with carboxyl groups was essential for facilitating the negatively charged sites required for the attraction of positively charged lead ions (Pb^{2+}) (Wang et al. 2019; Zhou et al. 2025).

Table 1 *Data of Pectin Yield*

Raw Material	Initial Weight of Raw Material (g)	Final Weight of Pectin (g)	Pectin Yield (%)
Pomelo Peels	10.054	5.025	49.98
Okra Pods	10.166	1.521	14.96
Roselle Calyces	10.110	2.743	27.13

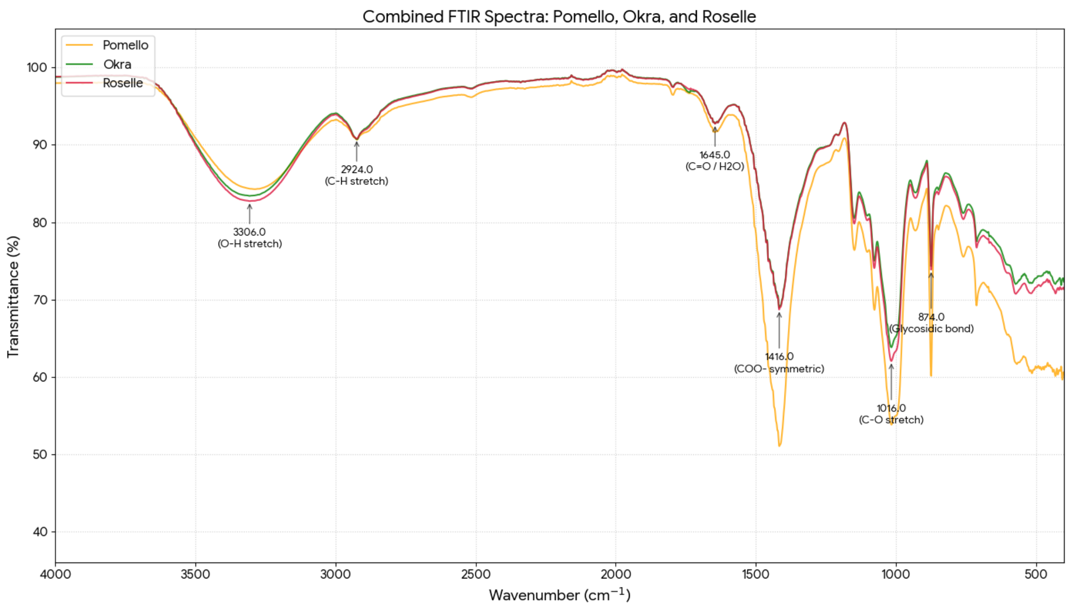

Fig. 1 *FTIR spectra of pomelo, okra and roselle pectin*

3.2 Analysis of Pb Biosorption Performance

The efficacy trials were carried out using natural river water, which initially contained a concentration level of 0.9744 mg/L of Pb, markedly higher than the safety level prescribed for INWQS Class II water in Malaysia, which was set at a maximum of 0.05 mg/L. The initial analysis of the water samples and the comparative efficiency data for different pectin preparations are given in the following Table 2 and 3.

Table 2 *Parameters of water samples*

Parameter	Unit	Panchor			National Standard for Drinking Water Quality	INWQS Malaysia Standard Class II value (raw water)
		Min.	Max.	Mean ± SD		
pH	-	7.85	7.93	7.89 ± 0.057	6.5 - 9.0	6.5 - 9.0
DO	mg/L	8.25	9.25	8.75 ± 0.707	-	5 -7
Conductivity	µS/cm	112.40	114.20	113.3 ± 1.273	-	1000
Turbidity	NTU	215	227	221 ± 8.485	5	5.0
Pb	mg/L	-	-	0.9744	0.05	0.01

Table 3 *Batch experiment data*

Run	Pectin Mixture Type	Pomelo Mass (g)	Okra Mass (g)	Roselle Mass (g)	Total Mass (g)	Pb Initial (mg/L)	Pb Final (mg/L)	Adsorption Amount, q_e (mg/g)	Removal Rate, R (%)
1	Pure Pomelo	0.5363	0	0	0.5363	0.9744	0.3445	0.1174	64.64
2	Pure Okra	0	0.5005	0	0.5005	0.9744	0.9744	0	0
3	Pure Roselle	0	0	0.5181	0.5181	0.9744	0.48372	0.08972	50.36
4	Binary (Pomelo:Okra)	0.25675	0.2506	0	0.5181	0.9744	0.7946	0.03470	18.45
5	Binary (Pomelo:Roselle)	0.2622	0	0.2556	0.5178	0.9744	0.6786	0.05719	30.36
6	Binary (Okra:Roselle)	0	0.2594	0.2711	0.5305	0.9744	0.6786	0.05576	30.36
7	Tertiary (Centroid)	0.1682	0.1735	0.1757	0.5174	0.9744	0.7250	0.04820	25.60

As shown in Table 2, the pH value (7.89 ± 0.057) and dissolved oxygen content (8.75 ± 0.707 mg/L) were found to be within the National Drinking Water and INWQS Class II standards. However, analysis of the parameters of the water sample revealed that there was considerable contamination, as indicated by other parameters. For example, the average turbidity of the water sample was found to be considerably higher (221 ± 8.485 NTU) than the permissible limit of 5 NTU. Similarly, the lead content in the water sample was found to be considerably higher (0.9744 mg/L) than the permissible limit of 0.01-0.05 mg/L. These observations suggest the need to develop effective techniques for the removal of contaminants from water samples.

The batch adsorption tests (Table 3) conducted on water samples to assess the efficiency of different pectin-based formulations in the removal of lead contaminants revealed that pure pomelo pectin was the most effective in the removal of lead contaminants, as indicated by the adsorption capacity (qe) of 0.1174 mg/g and clearance rate of 64.64%. This might be attributed to the high degree of esterification, as well as the porosity of the material, which makes the "egg-box" mechanism of chelation possible (Manrique & Lajolo, 2002). In contrast, pure okra pectin did not demonstrate any removal efficiency. Binary okra-roselle and pomelo-roselle pectin formulations were found to have removal efficiency of 30.36%. However, binary and tertiary pectin formulations were found to have intermediate efficiency in the removal of lead contaminants.

3.3 Discussion

From the results, it can be concluded that agricultural waste can remediate lead pollution in the environment because of its contributions to the development of green technology. The high lead removal efficiency of pomelo pectin (64.64%) is in agreement with another study conducted by Zhang et al. (2025), who found high affinity between pectin hydrogels and lead ions due to electrostatic attraction.

This phenomenon can be explained based on the "egg-box" model because lead ions can form "bridges" with the space between the non-methylated galacturonic acid chains in pectin molecules. The cavities formed by the cross-linking of these chains cane fit by the lead ions which resulting a stable and insoluble complex that able to effectively traps the metal (Zhou et al., 2025; Chandel et al., 2022). The FT-IR analysis as shown in Fig. 1 confirms that the presence of these galacturonic acid that act as a backbone, especially in citrus-based pectin like pomelo which make it more prevalent, therefore explained its excellent performance compared to okra and roselle (Zhou et al., 2025; Chandel et al., 2022).

In environmental perspective, by utilizing pomelo peels, okra pods and roselle calyces, two ecological issues can be address simultaneously which are waste management and water purification. This research provides an alternative to conventional energy-demanding methods such as membrane filtration or reverse osmosis. Therefore, this research supports a circular economy by converting low-value agricultural by-products into high-value biosorbents. This low-cost solution offers a feasible path for local communities and industries to mitigate the human-induced effects on aquatic biomes especially for Muar River ecosystem that faced industrial and agricultural runoff (Robledo* & Vázquez, 2019). The capability of roselle pectin to maintain high Dissolved Oxygen (DO) (8.09 mg/L), further implies that this specific biosorbent is compatible with aquatic life support systems and ensure that the treatment does not harm the river's biodiversity.

However, some limitations are also inherent in the current research despite the satisfactory removal rates. First, the final concentration of the lead in the treated water (0.3445 mg/L) was still not accordance with the strict safety requirement of INWQS Class II safety, in spite of the satisfactory rate of removal achieved. This implies that while pectin is highly effective as a primary treatment, chemical modification such as graft copolymerization or cross-linking with other biopolymers, might be needed so that its active site density can be enhance and potable standards can be reach.

Moreover, during the experiment, physical limitations were observed where okra pectin treatment increased the turbidity of the water, an effect that might lead to difficulties in the filtration process. The complication of the filtration and separation phase after adsorption was caused by the high solubility of certain okra polysaccharides which also explain the mucilaginous behavior. This implies that while okra has potential, however it may be better suited for use in a composite or immobilized from rather than a s a loose powder. Thus, by addressing this weakness of the research, both selectivity and the ease of recovery from treated water matrices can be improved by the development of pectin-based hydrogel beads in the future research (Robledo* & Vázquez, 2019).

4. Conclusion and Recommendation

Pectin extracted from agricultural waste, obtained from plants, has been shown within this paper to be a useful and effective resource for metal removal. The use of FT-IR analysis to determine functional groups essential to metal binding, including carboxyl and galacturonic acids, was shown within this paper to be essential to meeting its main goals. The data suggests that this may be an effective means of lowering levels of lead (Pb) within the Muar River, with a pure pomelo sample having the highest efficiency rate at 64.64%.

The following regulatory organizations concerned with the environment, such as the Department of Environment (DOE), SPAN, and JBA, may want to take the following steps towards the integration of biopolymer adsorbents to further the application outcomes. To improve the adsorption selectivity coefficient of pectin, future experiments could be aimed at specific chemical modifications of the pectin structure, especially with regards to model aqueous environments containing a spectrum of interfering ions. Another area that could be researched is the large-scale continuous version of pectin-based biosorbents to help facilitate a transition towards a greener approach to water purification.

Acknowledgement

Communication of this research is made possible through monetary assistance by Universiti Tun Hussein Onn Malaysia and the UTHM Publisher's Office via Publication Fund E15216.

References

Journal

Akachat, B., Himed, L., Salah, M., D'Elia, M., Zomorroda, S., Ali, R., Rastrelli, L., & Barkat, M. (2025). Optimization of pectin extraction from lemon peels using hydrochloric acid and response surface methodology. *Applied Food Research*, *5*(1), 100948. https://doi.org/10.1016/j.afres.2025.100948

Alba, K., Laws, A. P., & Kontogiorgos, V. (2015). Isolation and characterization of acetylated LM-pectins extracted from okra pods. *Food Hydrocolloids*, *43*, 726–735. https://doi.org/10.1016/j.foodhyd.2014.08.003

Chandel, V., Biswas, D., Roy, S., Vaidya, D., Verma, A., & Gupta, A. (2022). Current Advancements in Pectin: Extraction, Properties and Multifunctional Applications. *Foods*, *11*(17), 2683. https://doi.org/10.3390/foods11172683

Manrique, G. D., & Lajolo, F. M. (2002). FT-IR spectroscopy as a tool for measuring degree of methyl esterification in pectins isolated from ripening papaya fruit. *Postharvest Biology and Technology*, *25*(1), 99–107. https://doi.org/10.1016/s0925-5214(01)00160-0

Mulana, Ts. Khairun & Sao, Davy & Abdullah, Halimatul. (2015). *Localization and Availability of Cadmium, Lead and Nickel in Muar River, a Preliminary Assessment.* https://www.researchgate.net/publication/323239356_Localization_and_Availability_of_Cadmium_Lead_and_Nickel_in_Muar_River_a_Preliminary_Assessment

Nur Intan Idayu, M. (2020). *HEAVY METAL (Zn, Cu, Cr, Ni and Pb) ANALYSIS FOR MUAR RIVER WATER USING INDUCTIVELY COUPLED PLASMA-MASS SPECTROMETRY (ICP-MS)*. 1–61.

Raja, K., K. Samrat, None Arvind Bharani. R. S, M. Kavisri, Kennedy, J. F., & None Meivelu Moovendhan. (2024). Pectin-nano zero valent iron nanocomposites for efficient heavy metal removal and bactericidal action against waterborne pathogens — Innovative green solution towards environmental sustainability. *International Journal of Biological Macromolecules*, *277*, 133990–133990. https://doi.org/10.1016/j.ijbiomac.2024.133990

Riyamol, Gada Chengaiyan, J., Rana, S. S., Ahmad, F., Haque, S., & Capanoglu, E. (2023). Recent Advances in the Extraction of Pectin from Various Sources and Industrial Applications. *ACS omega*, *8*(49), 46309–46324. https://doi.org/10.1021/acsomega.3c04010

Sangheetha, S., Illeperuma, D. C. K., Navaratne, A. N., & Jayasinghe, C. (2018). Effect of pH, temperature and time combinations on yield and degree of esterification of mango peel pectin: a box-behnken design based statistical modelling. *Tropical Agricultural Research*, *30*(2), 1. https://doi.org/10.4038/tar.v30i2.8304

Shrestha, R., Ban, S., Devkota, S., Sharma, S., Joshi, R., Tiwari, A. P., Kim, H. Y., & Joshi, M. K. (2021). Technological trends in heavy metals removal from industrial wastewater: A review. *Journal of Environmental Chemical Engineering*, *9*(4), 105688. https://doi.org/10.1016/j.jece.2021.105688

Tong, L. (2023). The Importance of River Water for Environment and Society. *Journal of Hydrogeology & Hydrologic Engineering*, *2023*(2325-9647). https://www.scitechnol.com/peer-review/the-importance-of-river-water-for-environment-and-society-jo2Z.php?article_id=22446

Van Bao, N., Ward, & Minh, C. (2015). Extraction of pectin from pomelo (Citrus maxima) peels with the assistance of microwave and tartaric acid. International Food Research Journal, 22(4), 1637–1641. http://ifrj.upm.edu.my/22%20(04)%202015/(45).pdf

Wang, K., Yu, H., Zhang, X., Ye, D., Huang, H., Wang, Y., Zheng, Z., & Li, T. (2022). Hydrogen peroxide contributes to cadmium binding on root cell wall pectin of cadmium-safe rice line (Oryza sativa L.). *Ecotoxicology and Environmental Safety*, *237*, 113526–113526. https://doi.org/10.1016/j.ecoenv.2022.113526

Wang, R., Liang, R., Dai, T., Chen, J., Shuai, X., & Liu, C. (2019). Pectin-based adsorbents for heavy metal ions: A review. Trends in Food Science & Technology, 91, 319–329. https://doi.org/10.1016/j.tifs.2019.07.033

Zhang, L., Qiao, M., Zheng, H., Vancov, T., Antoniadis, V., Shaheen, S. M., Joseph, S., Chen, C., Shan, S., Chen, H., & Wang, H. (2025). Integrating spectroscopic analysis and theoretical calculations to elucidate the adsorption efficiency and mechanisms of Cd, Pb, and Cu using novel carboxymethyl cellulose/pectin-based hydrogel beads. *International Journal of Biological Macromolecules*, *Vol. 305*, 141028–141028. https://doi.org/10.1016/j.ijbiomac.2025.141028

Online Magazine Article

Ching, Y. C., Lee, Y. H., Toriman, M. E., Abdullah, M., & Yatim, B. B. (2015). Effect of the big flood events on the water quality of the Muar River, Malaysia. *Sustainable Water Resources Management*, *1*(2), 97–110. https://doi.org/10.1007/s40899-015-0009-4

Theuwissen, E., & Mensink, R. P. (2008). Water-soluble dietary fibers and cardiovascular disease. *Physiology & Behavior*, *94*(2), 285–292. https://doi.org/10.1016/j.physbeh.2008.01.001

Zhou, J., Feng, S., Zhou, Y., Huang, Z., Li, B., Pi, M., Wei, S., & Cao, L. (2025). Physicochemical and Structural Properties of Pomelo Peel Pectin from Majiayou Pomelo with Different Storage Periods. *Food Science & Nutrition*, *13*(6). https://doi.org/10.1002/fsn3.70227

Authored Book

Crittenden, J. C., Trussell, R. R., Hand, D. W., Howe, K. J., & Tchobanoglous, G. (2012). *MWH's Water Treatment*. John Wiley & Sons, Inc. https://doi.org/10.1002/9781118131473

Dixit, S. S., Muruganandam, D. L., & Ganesh, I. (2025). Pectin from fruit peel: A comprehensive review on various extraction approaches and their potential applications in pharmaceutical and food industries. *Carbohydrate Polymer Technologies and Applications*, *Vol. 9*, 100708–100708. https://doi.org/10.1016/j.carpta.2025.100708

Robledo*, V. R., & Vázquez, L. I. C. (2019). Pectin - Extraction, Purification, Characterization and Applications. *Pectins - Extraction, Purification, Characterization and Applications*, *2632-0983*. https://doi.org/10.5772/intechopen.85588

Smith, B. J. (2011). Fundamentals of Fourier Transform Infrared Spectroscopy. In *CRC Press eBooks*. Informa. https://doi.org/10.1201/b10777