Science and Technology Indonesia
e-ISSN:2580-4391 *p*-ISSN:2580-4405
Vol. 10, No. 2, April 2025

Review Paper

Antibacterial Properties of Taro: Extraction, Antibacterial Testing Method, Modification and Application

Atina[1], Idha Royani[2], Assa'idah[3], Fitri Suryani Arsyad[2]*

[1]*Doctoral Program, Faculty of Mathematics and Natural Science, Universitas Sriwijaya, Ogan Ilir, 30862, Indonesia*
[2]*Department of Material Science, Postgraduate Program, Universitas Sriwijaya, Palembang, 30139, Indonesia*
[3]*Department of Physics, Faculty of Mathematics and Natural Science, Universitas Sriwijaya, Ogan Ilir, 30862, Indonesia*
***Corresponding author**: fitri_suryani@unsri.ac.id

Abstract
Taro plants (*Colocasia esculenta*) contain secondary metabolites identified as antibacterial, antioxidant, anti-inflammatory and anticancer such as alkaloids, glucosides, terpenoids, resins, flavonoids, saponins, phenols, tannins, amino acids. This article discusses various sources related to the potential of taro as an antibacterial, the discussion includes the content of secondary metabolites along with their properties and characteristics, medicinal plant extraction methods, antibacterial testing, applications and future challenges. This review research used data in the form of articles from Scopus, PubMed and Web of Science indexed sources, published between 2015-2024. Data were analyzed descriptively to summarize trends in antibacterial activity and variability across studies. Ethanol extract of taro was screened for secondary metabolite content, antibacterial activity was tested by Kirby Bauer method. Synthesis of antibacterial medicinal plant-based nanoparticles were successfully synthesized with size range between 10-120 nm, with inhibition zones between 11.9-37 mm against pathogens such as *S. aureus*, *E. coli*, and *L. monocytogenes*. Antibacterial nanofibers were synthesized by electrospinning, self-assembly, phase separation, template synthesis, coaxial electrospinning, electrospraying. Characterization used UV-Vis Spectroscopy, FTIR, TEM, XRD, SEM-EDX, HPLC to separate, identify, and quantify bioactive compounds. Common antibacterial mechanisms include inhibition of protein and nucleic acid synthesis, cell membrane damage, and cell structure modification. The application of taro as antibacterial is investigated in pharmaceutical field, industrial field, food field, waste treatment, dentistry field, biomedical field. The development of taro as an antibacterial has great prospects in the pharmaceutical industry, especially as a safe and effective alternative to conventional antibiotics.

Keywords
Taro, Extract, Secondary Metabolite, Antibacterial, Application

Received: 24 September 2024, Accepted: 16 January 2025
https://doi.org/10.26554/sti.2025.10.2.374-401

1. INTRODUCTION

Medicinal plants have been widely used around the world in health care systems since time immemorial (Shazhni et al., 2018). Medicinal plants were chosen as an alternative treatment due to their affordable cost and abundant availability in nature (Abubakar and Haque, 2020). Research has been conducted around the world to established the medicinal properties of plants, and some potentially promising results that have already led to drug synthesis based on medicinal plants (Shazhni et al., 2018). It has been estimated that more of 150,000 plant resources have been investigated, with many containing potential therapeutics agents, the utilization of new plant derivative compounds in pharmacological purposes has increased steadily in recent years (Shazhni et al., 2018). Medicinal plants use as sources of antibacterials is increasing in the pharmaceutical field, along with the emergence of antibacterial resistance problems and the need for safer and environmentally friendly therapies. The overuse of synthetic antibiotics has contributed to the appearance of bacterial resistance, making infections more challenging to treat. Medicinal plants offer natural alternatives that have the potential to minimize this problem, as their active compounds often have different mechanisms of action from conventional antibiotics, which can inhibit the development of resistance.

Overuse of antibiotics leads to bacterial resistance, thus reducing the effectiveness of existing antibiotics (Feng et al., 2023). Antibiotic resistance is becoming an increasingly urgent global health threat. Antibacterial and antimicrobial resistance is a global issue causing serious problems in both human and animals (Rolta et al., 2021; Feng et al., 2023). According to the India Council of Medical Research (ICMR) treatment

guideline (2019) state that Asia is projected to experience 4.7 million mortalities by 2050 as a result of infections resistant to antimicrobial treatment. The utilization of medicinal plants, especially antibacterials, needs attention because according to a report issued by WHO (World Health Organization), and A global problem that is becoming a severe challenge is bacterial resistance, this challenge must be addressed immediately to cure infections related to pathogenic microorganisms (Shamsudin et al., 2022). To overcome this crisis, better strategies are needed to manage the use of antibiotics as well as continuous research to discover new antibacterial agents. Medicinal plants can be a solution to the alarming situation of antibiotic overuse in both developed and developing nations (Shazhni et al., 2018).

The demand for natural herbal medicines has increased considerably in the pharmaceutical sector as they are less likely to cause side effects. In biomedical application fields, it is important to include plant-derived components because non-toxic and antioxidant properties (Verma et al., 2024). Herbal plants are natural products that contain many pharmacologically active ingredients and are used as traditional medicines or folk remedies in different cultures and regions (Rolta et al., 2021). Since ancient times, literature has mentioned that medicinal plants used in herbal medicine are regarded as miraculous remedies for various diseases. A medicinal plant releases secondary metabolites into its rhizosphere to prevent or suppress the activities of soil-borne pathogens of plants (Shazhni et al., 2018), secondary metabolites serve as defense compounds against various biotic and abiotic stresses (Hilal et al., 2024). One of the medicinal plants indicated to contain secondary metabolites is *Colocasia esculenta* (taro).

Taro is one example of a swamp plant that can be utilized as a medicinal plant (Baro et al., 2023). Taro can traditionally be used as a cure for various conditions, such as asthma, arthritis, neurological disorders, internal bleeding, and diarrhea (Salako et al., 2015; Baro et al., 2023), antibacterial (Shazhni et al., 2018; Ghate et al., 2021; Gharib and Salman, 2023), anti-inflammatory (Beato et al., 2024). Caladium is a type of vegetable whose utilization starts from fruit, tubers (Kaith et al., 2022), roots (Baro et al., 2023), stems and leaves (Oriyomi et al., 2022; Oriyomi et al., 2023).

Caladium leaves contain a rich source of nutrients and phytochemicals, but utilization is still very limited due to insufficient awareness (Kumar et al., 2023). Taro leaves on the other hand can be utilized as a (plant-based) food source, as they contain rich protein, micronutrients and fiber, and also low in calories (Mitharwal et al., 2022), potential pest control sources (Oriyomi et al., 2022). Taro leaves are also easily available and cheaper than other vegetables, thus providing an opportunity to fulfill the green vegetable needs of the economically disadvantaged (Kumar et al., 2023). Caladium leaves can also be dried over the harvest period and can be saved for future use (Kumar et al., 2023). Household treatments such as soaking, boiling, cooking and microwaving can reduce the anti-nutrient content of taro, this decrease is positively correlated with an increase in calcium and iron levels (Kumar et al., 2023).

Colocasia esculenta (L) Schott indicates the content of active ingredients so that it can act as anti-inflammatory, antimetastatic, and anti-oxidant (Kaith et al., 2022; Baro et al., 2023). Apart from the leaves, taro tubers can be utilized as a food sources and medicinal plants (Kaith et al., 2022). The other studies have reported that *Colocasia esculenta* processing activities affect the content of nutrients or compounds including by Kumar et al. (2023) and Mitharwal et al. (2022). Oxalotrophic bacteria were isolated from the leaves of both (CE) *Colocasia esculenta* and (RV) *Remusatia vivipara* for the treatment of kidney stones by colony PCR study, the study results showed that colony PCR can act for a screening method to quickly isolate samples with endophytes that degrade, and saving time and resource (Ghate et al., 2021). Taro stem extract can improve the workability (accelerator) of cement paste (Thankaswamy and Belarmin Xavier, 2021).

The potential of taro as medicinal plant is supported by the content of secondary metabolites in this plant. This research aims to investigate the antibacterial potential of taro by reviewing the antibacterial properties of taro, extraction methods, antibacterial activity tests, modifications and potential applications.

2. EXPERIMENTAL SECTION

Data Sources: This review study compiles data from peer-reviewed articles indexed in and published on Scopus, PubMed and Web of Science, published between 2015-2024. The selection criteria included studies reporting quantitative measurements of antibacterial activity, such as inhibition zones (mm), minimum inhibitory concentration (MIC), and minimum bactericidal concentration (MBC). Data were extracted systematically from these sources using keywords such as "medicinal plants, antibacterial activities, antibacterial resistance, taro, caladium, *Colocasia esculenta*, extraction method, secondary metabolite, flavonoid, antibacterial mechanism of action". Keywords are developed according to the subject matter per subchapter.

Statistical analysis: The extracted data were analyzed descriptively to summarize trends in antibacterial activity and variability across studies. Mean values and range were included when reported in the original studies. Comparative data analysis focused on variation in antibacterial efficacy due to factors such as extraction method, bacterial strain, and bioactive compound concentration. Graphical tools such tables and bar charts were used to visualize key finding, including inhibition zone diameters and MIC values, across different bacterial strains. Statistical significance, where applicable, was taken directly from the cited studies and noted in the results to ensure accurate interpretation of the findings.

Interpretation of statistical data: variation in reported values were critically assessed to identify potential factor contributing to differences, including differences in experimental design, solvent systems, and bacterial strains. Statistical parameter such as interval and effect size were reported directly from the

original sources to maintain consistency with the referenced literature.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition of Taro

Colocasia esculenta (taro), better known as caladium, is a tuberous plant that grow in subtropical regions and tropical areas around the world. Taro grows in swampy areas, with large, heart-shaped leaves. This shape is similar to the ornamental taro plant (*Colocasia spp.*). *Colocasia esculenta* is one of the most commonly recognized species, with many different varieties and cultivars found around the world. Other taro varieties include Colocasia antiquorum as a waste treatment material (Shende and Chidambaram, 2023), *Colocasia gigantea* (Zilani et al., 2021) and many hybrid varieties. *Colocasia esculenta* is a type of vegetable whose utilization starts from fruits, tubers, roots, stems and leaves. *Colocasia esculenta* phytochemically also contains apigenin, flavones, anthocyanins and luteolin (Al-Kaf et al., 2019).

***Colocasia esculenta* can be utilized as:**

- **Food and Nutrition Source:** the tuber can be processed into an important food source in many tropical and subtropical countries. Taro tubers contain carbohydrates mainly in the form of starch, contain fiber that plays a role in maintaining digestive health, vitamins that function to maintain immunity, and contain minerals such as potassium, magnesium and iron. The results of chemical analysis of taro tubers contain 70-80% carbohydrates, taro tubers and fibrous roots also contain micro and macronutrients (Kaith et al., 2022). *Colocasia esculenta* leaves contain nutrients in the form of carbohydrates, protein, fat, and energy of 43.5 Kcal/100 grams (Mitharwal et al., 2022). The potential of taro as a future food crop lies in its significant nutritional and antioxidant benefits (Aditika et al., 2022). Colocasia leaves significantly contribute to satisfying the need potassium, as well as manganese, calcium, and iron (Aditika et al., 2022). Taro flour has characteristics that make it suitable for use in foods such as porridge, bread and as a thickener (Boahemaa et al., 2024).
- **Traditional Medicine:** extracts of taro leaves and tubers, utilized as traditional medicine as local wealth including for the treatment of digestion and wounds. Taro is known to contain phytochemical compounds such as phytates, tannins, flavonoids that act as antioxidants, antibacterials and have effects on nutrient absorption and gut health. Qualitative analysis of phytochemicals indicated the concentration of alkaloids, terpenoids, resins, glycosides, saponins, flavonoids, tannins, amino acids, phenols in methanol extracts, and the absence of glycosides as well as amino acids in aqueous extracts of *Colocasia esculenta* leave (Al-Kaf et al., 2019). The active ingredients found in caladium indicate anti-inflammation, anti-metastasis, and anti-oxidation (Kaith et al., 2022). Pre-treatment of leg inflammation with *Colocasia esculenta* Methanol Root Extract (CEMRE) or methanol extract of caladium root (400 mg/kg) can significantly inhibit the inflammation of the foot induced by carrageenan and this is comparable to the conventional drug Indomethacin (Baro et al., 2023). *Colocasia esculenta* has shown potential as agent of antihyperlipidemic, potentially due to its inhibition of cholesterol synthesis and increased breakdown and excretion of other lipids. Its richness in essential nutrients and phytochemicals, such as flavonoids and saponins, further supports its hypolipidemic properties (Lad and Kolhe, 2023).
- **Pest Control:** taro leaf extract as a staple preservative against *Sitophilus zeamais* attack (Oriyomi et al., 2022). The utilization of taro leaf extract was also investigated by Oriyomi et al. (2023), who mentioned about the *Colocasia esculenta* leaf extract (CELE) potential as an alternative of natural materials for insects control where the amount of CELE regulated with repeated dose <800 mg/kgBB can be recommended to be used as an agent in the control of integrated pest *Sitophilus zeamais*.

The results of phytochemical screening of taro proved that taro contains secondary metabolites that can act as anti-inflammatory (Baro et al., 2023; Mitharwal et al., 2022), anti-metastasis and anti-oxidative (Kaith et al., 2022) such as terpenoids, alkaloids, glucosides, resins, flavonoids, saponins, tannins, amino acids, and phenols (Al-Kaf et al., 2019; Oriyomi et al., 2022; Shazhni et al., 2018). Taro powder showed high content of secondary metabolites namely tannins, flavonoids and saponins (Mitharwal et al., 2022). Screening of phytochemical of taro includes the presence of flavonoids in the leaves (Al-Kaf et al., 2019; Mitharwal et al., 2022), tubers and roots (Kaith et al., 2022; Baro et al., 2023) which states that these parts of taro can act as anti-inflammatory, anti-metastatic and antioxidant, anti-cancer and antidiabetic.

Alkaloids:

Alkaloids represent groups of natural nitrogen containing organics compounds with intense physiological activity, alkaloids are frequently effective materials in many medical plants (Jiang et al., 2024a). Evaluation of toxicological and anti-fungal activity of alkaloids from Neltuma nigra leaves was investigated by Sequin et al. (2023), it was stated that alkaloids have the potential to become anti-fungal plants because the alkaloid fraction is able to inhibit various types of fungi with high sensitivity. Isoquinoline alkaloids are a widespread natural productive group and essential as secondary metabolites of various plant species, namely antibacterial, anti-cancer, anti-parasitic, anti-fungal, and anti-inflammatory (Tuzimski and Petruczynik, 2023). The Dragendorff test is performed to detection of alkaloids presence by mixing Dragendorff's of 2-3 drops perekation into 0.1 mL extract of medicinal plant, an orange-colored precipitate indicates the alkaloids presence (Al-Kaf et al., 2019).

Figure 1 shows the compound structure of the alkaloid frac-

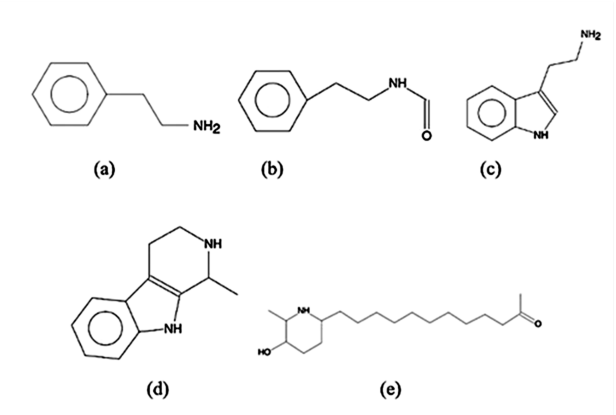


Figure 1. Compound Structure of the Alkaloid Fraction: (a) Phenetylamine; (b) N-Formylphenylethylamine; (c) Tryptamine; (d) Tetrahydroharman; (e) Cassine (Sequin et al., 2023)

tion of *Neltuma nigra* leaves GC-MS results. Analysis using EDX and SEM indicated variations in the particle size distribution of the synthesized nanoparticles, showing a gradual decrease in size from sample (a) to sample (c). The nucleation process and the involvement of Cu, Ce, and Zn ions play a crucial role in restricting nanoparticle growth, aligning with the XRD findings. The formation of Zn-Ce-Cu-O bonds within the crystal lattice further slows growth and reduces nanoparticle size. Moreover, differences in the ionic radii of Cu^{2+}, Zn^{2+}, and Ce^{3+} significantly affect nanoparticle size reduction, with Cu^{2+} ions potentially substituting Zn^{2+} sites and Ce^{3+} ions residing on the crystal lattice surface. GC-MS analysis showed that the alkaloid fraction is composed of 5 compounds, namely Phenetylamine (11.1%), N-Formylphenylethylamine (0.8%), Tryptamine (63.9%), Tetrahydroharman (13.8%), dan Cassine (10.4%) (Sequin et al., 2023).

Flavonoids

Flavonoids are groups of compounds with diverse biological functions and are significant sources for developing new pharmaceutical products, including those for treating skin wounds (Carvalho et al., 2021). These flavonoids have enormous bioactive potential (Shazhni et al., 2018). Flavonoids have potential as natural antibacterials that are safe to use, with synthesis methods from flavonoids making it possible to produce antibacterial drugs that can overcome bacterial resistance (Shamsudin et al., 2022). Flavonoids are metabolized by plants in response to microbial infection (Górniak et al., 2019), antibacterial (Carvalho et al., 2021; Shamsudin et al., 2022), anti-oxidant, anti-inflammatory (Górniak et al., 2019).

Flavonoids include flavonols, flavanones, flavones, isoflavones, isoflavanols, dihydroflavonols, biflavonoids, dihydroisoflavones, chalcones, flavanols, and were investigated for potential activity against bacterial plants and showed antibacterial effects invitro and invivo (Yan et al., 2023). The presence of flavonoids can be detected by Shinoda test by mixing the extract with magnesium powder and hydrochloric acid drop by drop, orange, pink, purple, or red color indicates the flavonoids presence (Al-Kaf et al., 2019). Hydrochloric acid added into 1 mL of extract, and then 0.5 mg of Rimandoium was rotated and shaken, flavonoids were indicated by the appearance of pink color (Abubakar and Haque, 2020). Flavonoids, also referred to as polyphenolic compounds, for their antibacterial properties have been studied extensively, as they are capable of suppressing the excessive growth of various pathogenic microorganisms, including those resistant to multiple antibiotics (Shamsudin et al., 2022).

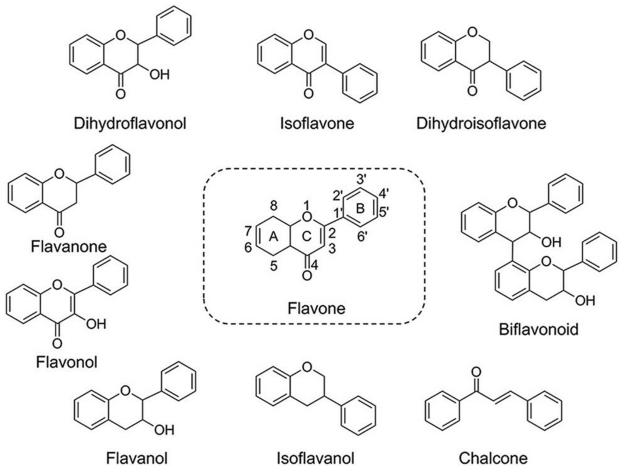


Figure 2. Structure and Classification of Flavonoids (Li et al., 2022a)

Flavonoids have a standardized structure consisting of two phenyl rings (A and B) which are linked to a heterocyclic ring (C, which contains oxygen). This carbon skeleton is often represented as $C_6-C_3-C_6$. Typically, flavonoids exhibit hydroxylation at the 5 and 7 positions on the A Ring, and oxidation at the 3, 4, or 3, 4, 5 positions on the B Ring, reflecting their biosynthetic pathway. Flavonoids are categorized based on their chemical structure into flavanones, chalcones, flavanonols, flavonols, flavones, flavan-3-ols (catechins), isoflavones, and anthocyanidins. Figure 2 also shows the numbering system for basic flavonoid structures. The classification of flavonoids is primarily determined by the presence of a ketone group at position 4, a double bond between the carbon atoms at positions 2 and 3 ($C_2=C_3$), and a hydroxyl group at position 3 ($_3-OH$) on the C ring.

Saponins

Saponins are amphiphilic glycosides comprising triterpene or single or double steroid aglycones, and they are commonly found in plants and certain marine organisms. Saponins have been incorporated into skin care products, and research indicates their potential due to their physicochemical and biological variations (Jolly et al., 2023). The formation of foam that persists for ten minutes after mixing 5 mL of the extract with 2

mL of distilled water indicates the presence of saponins (Al-Kaf et al., 2019).

Terpenoids

Terpenes (terpenoids) are secondary metabolites that are generally insoluble in water, are constituents of essential oils and are antibacterial in nature. Essential oils from leaf extracts of *Eucalyptus globulus*, *E. exserta*, *Pimenta pseudocaryophyllus* and essential citrus oils, citrus terpenes were tested on pathogenic bacteria of *S. aureus*, *E. coli*, *E. faecalis* and *L. innocua* and 2 beneficial bacteria of *L. rhamnosus* and *B. subtilis* where essential citrus oils and citrus terpenes showed the least activity on beneficial bacteria and the best activity on pathogenic bacteria (Ambrosio et al., 2017). Terpenoids can bind to the Mpro (main protease enzyme) of SARS-CoV-2 so that terpenoids have the potential to act as anti SARS-CoV-2 effective drugs (Lokhande et al., 2023). The Salkowski assay was conducted to identify terpenoids. A 5 mL extract was mixed with 2 mL of chloroform, and then 3 mL of concentrated sulfuric acid was added, resulting in the formation of distinct layers. The appearance of a brown color at the surface indicated of terpenoids presence (Al-Kaf et al., 2019).

Steroids

Steroids are biomolecules that take an essential role in various biological processes and drug discovery, within the last few decades heterocyclic steroid conjugates have been continuously investigated as anticancer agents (Ahn et al., 2023). Steroids are known as anti-inflammatories for cancer treatment, the combination therapy of MMF and steroids is promising as a potential treatment for IgAN patients especially those showing active inflammation on kidney biopsy (Miao et al., 2023). Serum steroid profile based on Liquid Chromatography-Mass Spectrometry (LC-MS) can be a biomarker to estimate metabolic of risk in adult patients in Congetinal Adrenal Hyperplasia (CAH) for deficiency of 21-hydroxylase (Ahn et al., 2023). Libermann Burchard assay is used to detection of steroids presence, the extract should be evaporated to dryness then re-extracted with chloroform and added a few drops of acetic anhydrite and then sulfuric acid on the side of test tube. The formation of purple to blue color, indicates the presence of steroids.

Detection of secondary metabolite compounds in taro can be done through various chemical analysis methods, in general, namely sample preparation in the form of extraction, identification of secondary metabolite compounds, antibacterial testing.

3.2 Medicinal Plants Extraction Techniques

Medicinal plant extraction is the process of isolating active ingredients or secondary metabolites, such as flavonoids, alkaloids, terpenes, steroids, saponins, and glycosides, from inactive materials using appropriate solvents and standardized methods (Abubakar and Haque, 2020). This process entails isolating the active molecular components of drugs from plant tissues through either conventional or modern solvent extraction techniques, environmentally friendly extraction methods (Bitwell et al., 2023). This procedure is usually to release bioactive compounds by immersion of the desired plant part in a solvent, filter the filtrate to separate the solid residue separated from the liquid extract. Zengin et al. (2020) evaluated five extraction methods; Accelerated Solvent Extraction (ASE), Microwave-Assisted Extraction (MAE), Maceration, Soxhlet Extraction, Ultrasound-Assisted Extraction (UAE)-based on their pharmacological properties and phytochemical profiles.

3.2.1 Traditional Extraction Technique

One drawback of conventional extraction techniques is the lengthy extraction time required, very large quantities of solvent, and sometimes many steps of extraction. In addition, a large number of thermolabile phytochemicals are found to decompose or degrade during heating (Bitwell et al., 2023).

Maceration: Maceration is the procedure of extraction in which the medicinal material is coarsely ground and placed in a vessel, the solvent is added until it fully covers the medicinal material (Abubakar and Haque, 2020). The maceration process facilitates the softening and breaking of plant cell walls, enabling the release of soluble phytochemicals from the plant material (Wong et al., 2023). Maceration should preferably be done in a container with a lid to minimize solvent loss through evaporation (Bitwell et al., 2023). Shazhni et al. (2018) extracted rat caladium by smoothing the tuber into powder, this powder was extracted to investigated its secondary metabolites using multiple solvents such as ethanol and acetone chloroform dimethyl sulfoxide, 10 grams of powder was extracted for 3 hours with about 500 mL of solvent and then evaporated by rotary evaporator and analyzed. *Colocasia esculenta* root powder about 100 g was soaked in methanol 70% (1000 mL) and stored for 48 hours, the solution then filtered and the filtrate was concentrated using a rotary evaporator to obtain the crude extract (Baro et al., 2023).

Digestion: Digestion: an method of extraction that involves using moderate heat throughout the extraction process where the solvent of extraction was added into a separate clean vessel followed by the powdered medicinal material (Shazhni et al., 2018). The temperature is kept at a 35-40°C range but can be upscaled to 50°C of maximum for harder plants material like bark and the material that contains soluble phytochemicals (Bitwell et al., 2023).

Infusion and Percolation: The infusion method is suitable for soluble extraction of bioactive ingredients, this extraction is like maceration where the medicinal materials are ground into smooth powder and placed in a clean vessel (Abubakar and Haque, 2020). Tea can be the best example for infusion (Bitwell et al., 2023). In the method of infusion, samples are immersed in hot or cold water for a period of time (Wong et al., 2023). Percolation method in which finely ground plants are soaked with extraction solvent in a clean vessel and stored for 4 hours before being transferred into the percolator, after 24 hours at the bottom of a percolator is opened and liquid is

allowed to drop slowly (Abubakar and Haque, 2020).

Decoction: The material is dried, ground and placed in a clean vessel, then water is poured as a solvent in a ratio of 4: 1 or 16: 1 and stirred and heated for about 15 minutes (Abubakar and Haque, 2020). The mixture was boiled, cooled and filtered to obtain a liquid extract (Bitwell et al., 2023).

Soxhlet Extraction: An extraction process also known as sustainable heat extraction (Wong et al., 2023), using a Glass Soxhlet extractor consisting of a spherical base flask, an extraction chamber, a suction tube, and also condenser at the top (Abubakar and Haque, 2020). Soxhlet extraction begins with a milled plant sample placed on filter paper, and then put into a porous bag (thimble) (Wong et al., 2023). This extraction technique is the phytochemicals extraction continuously using hot solvents, solvents in the form of ethanol or methanol are put into the base flask and heated, then evaporated in the condenser above the tool and then dripped back to produce extraction of phytochemicals (Bitwell et al., 2023). Powder of stevia leaves (5 grams) extracted using 50 mL of solvent in Soxhlet equipment at 100°C for 15 minutes, filter the extract using filter paper and the supernatant obtained was evaporated using a rotary evaporator under reduced pressure at 45°C (Chakma et al., 2023). The solvent in the Soxhlet extractor was heated to near boiling point for 6 hours to extract the dried and ground *P. macrocarpa* seed sample (20 grams) (Jinoni et al., 2024). Soxhlet extraction method is the most extensively used method for the laboratory scale of plant extraction because of its simple to use and less costly operation (Wong et al., 2023). Melon seed powder (30 grams) was extracted by Soxhlet method with petroleum ether for 6 hours at 40°C, then the filtrate and residue were separated by rotary evaporator (Anwar et al., 2021).

3.2.2 Modern Extraction Technique

Accelerated Solvent Extraction (ASE); it requires less solvent with high yield and relatively faster time, this technique was found to better perform in recovery of lipophilic and hydrophilic phytochemicals from pomace raspberry compared to (SFE) Supercritical Fluid Extraction (Bitwell et al., 2023).

Microwave-Assisted Extraction (MAE) (Shahzadi et al., 2022; Shazhni et al., 2018; Bitwell et al., 2023; Suksaeree et al., 2024): MAE needs relatively less solvent and more efficient in terms of time in comparison to maceration and Soxhlet extraction methods (Wong et al., 2023). Wang et al. (2024b) performed pectin extraction from feijoa powder with microwave and enzyme. 10 g feijo powder was blended in 150 mL of sodium citrate solution (50 mmol/L)/citric acid buffered solution (pH of 6.0, 6.5, and 7.0), the extraction process utilized a microwave oven of 7, 9, and 11 minutes. The solutions were allowed at room temperature to cool and combined to digest 25 mg of cellulase. Furthermore, the solutions were incubated at 50°C for 75, 90, and 120 minutes while stirring. Cellulase was deactivated at 90°C for 10 min. The pectin extract-containing solution underwent a centrifugation process to remove residue, the supernatant was filtered and sedimented using ethanol (2:1). Centrifuged and filtered, the pectin was followed by three ethanol rinses. Finally, the pectin was oven dried at 50°C until constant weight. This method showed results of superior thermal stability, lower crystallinity, and higher total phenolics. *Colocasia esculenta* plant was extracted by utilizing microwave technology to prepare ZnO nanopowders doped with copper and cerium, the synthesized of nanoparticles exhibited properties of antibacterial and antioxidant (Verma et al., 2024).

Ultrasound-Assisted Extraction/UAE (Sonication Extraction) (Shazhni et al., 2018; Abubakar and Haque, 2020; Bitwell et al., 2023; Bai et al., 2024): Ultrasonic extraction is ideally suited to extract phenolic components (Wong et al., 2023).

Supercritical Fluid Extraction (SFE) (Shazhni et al., 2018; Bitwell et al., 2023): This technique is one of the most advanced extraction technologies used in the extraction of food and natural products using liquids including water, carbon dioxide (CO_2), methane, ethanol, and acetone (Wong et al., 2023).

Enzyme-Assisted Extraction (EAE): Phytochemicals in certain plants are difficult to separate from the lignin polysaccharide network so that the phytochemicals cannot be accessed by the solvent extraction process, for which the addition of enzymes is required to increase the yield of phytochemicals by breaking down the cell wall (Bitwell et al., 2023). For example: enzyme-assisted extraction of rice bran protein, this method is efficient to produce high protein rice bran hydrolysis (Lasrichan et al., 2024). This method showed higher viscosity and antioxidant properties compared to conventional extraction (Wang et al., 2024b). Amulya and ul Islam (2023) compared the results of eggplant peel extraction by conventional methods with enzyme-assisted extraction (EAE) methods. The parameters observed were total yield (TY), antioxidant activity (AOA), total anthocyanin content (TA), and total phenolic content (TPC) and optimization using Central-Composite design with variations in temperature, enzyme concentration and extraction time. EAE outperforms the performance of the overall extraction process, EAE facilitates the breakup of eggplant skin cells resulting in better extraction yields and reduced extraction time.

Pressurized Hot Water Extraction (PHWE): high-pressure hot water is used as an extractant in this technique, this technique based on the principle that water's liquid state is kept under pressure and can be used as an option to replace conventional extraction techniques as it only requires shorter extraction time, produces better quality extracts, and cheaper solvents (Bitwell et al., 2023).

3.3 Identification of Secondary Metabolite Compounds

- **Thin Layer Chromatography (TLC)** (Abubakar and Haque, 2020): TLC is a simple and rapid technique to detect of secondary metabolite compounds including alkaloids, flavonoids, tannins, and phenolics. TLC is used for qualitative analysis of secondary metabolite compounds (Kustiati et al., 2022). Extract samples are applied to glass plates coated with silica gel, and then these plates are dipped in a developer solvent. The com-

pounds will move along the plate at different speeds, producing a pattern that can be identified with the help of a UV lamp or a specific coloring reagent. TLC is an easy and inexpensive method for preliminary screening of bioactive compounds.

- **UV-Vis Spectroscopy:** This method is used to detect compounds that absorb ultraviolet or visible light. UV-Vis spectra can provide information about the structure of compounds, especially for flavonoids and phenolics. Data from spectroscopy results are analyzed quantitatively (Kustiati et al., 2022). This technique provides quick information on the type of compounds present in a sample.
- **Fourier Transform Infrared (FTIR) Spectroscopy:** FTIR is used to identify functional groups in bioactive compounds based on their infrared absorption patterns. Each functional group absorbs a specific wavelength, which can be analyzed to determine the structure of the compound. Mehmood et al. (2020) predicted antibacterial activity in ionic liquids through FTIR spectroscopy with wave number selection by Partial Least Squares (PLS). FTIR analysis of pimenta leaves showed the presence of carboxylic acid, alkyl halide alkane functional groups (Murali et al., 2021). FTIR spectroscopy was used to assess the antibacterial activity of chitosan on *Listeria innocua* cells (Tantala et al., 2019). FTIR is effectively used to identify specific functional groups such as hydroxyl, carbonyl and others in organic compounds.
- **High Performance Liquid Chromatography (HPLC)** (Abubakar and Haque, 2020): HPLC is used to separate, identify, and quantify of bioactive compounds in taro extracts. The extracted sample is then injected into an HPLC column with a stationary phase, where the compounds are separated according to their interaction with the stationary and mobile phase. HPTLC can be utilized for chemical profiling of natural products in combination with metabolomics (Wulandari et al., 2023). HPLC provides highly accurate results and can be used to identify and quantify the concentration of specific compounds.
- **Mass Spectrometry (MS)** (Abubakar and Haque, 2020): MS is used to define the molecular mass and structure of compounds by breaking them down into small fragments and analyzing the resulting mass patterns. MS is often used in conjunction with HPLC (HPLC-MS) to identify compounds with high precision. MS is one of the most sensitive methods and can be used to analyze compounds in very low concentrations.
- **Nuclear Magnetic Resonance (NMR)** (Abubakar and Haque, 2020): NMR is used to determine the three-dimensional structure of compounds by analyzing the interactions between atomic nuclei in a magnetic field. It provides detailed information about the structure of complex organic compounds. NMR is highly accurate and useful for determining the complete structure of molecules.
- **Gas Chromatography (GC)** (Abubakar and Haque, 2020): GC is used for the quantification of volatile compounds in taro extracts. The compounds detected by GC can then be identified and measured for concentration. GC is very sensitive and can be used for quantification of compounds in very low concentrations.

3.4 Antibacterial Activity

Antibacterial activity tests are performed to confirm the antibacterial activity of the detected compounds. Laboratory tests need to be performed such as disc diffusion test or microdilution test to determine the effectiveness of the compound against pathogenic bacteria. Antibacterial activity can be investigated by in-vivo studies and in-vitro studies (Hernández-Nolasco et al., 2024; Zhang et al., 2024c; Liu et al., 2024). The antibacterial activity test was performed by Disc Diffusion Method (Kirby and Bauer diffusion method) (Wong et al., 2023; Palladini et al., 2023; Lazou and Chaintoutis, 2023), Liquid Dilution Method (Wong et al., 2023), Bioautography Method (Hilaire et al., 2022; Legerská et al., 2020; Dudoit et al., 2020), Total Plate Count (TPC) Method (Anderson et al., 2024; Somerton and Morgan, 2024).

3.5 Antibacterial Mechanism of Action

Taro contains several important bioactive compounds, like saponins, flavonoids, alkaloids, essential oils, and tannins. These compounds are known to have antibacterial potential. Flavonoids are polyphenolic compounds that have antibacterial activity by inhibiting bacterial protein synthesis. They can also modify bacterial cell membranes, increase their permeability, and disrupt cell metabolism (Rao et al., 2024). Saponins have antibacterial properties that can damage bacterial cell membranes, disrupt lipoprotein membrane structures, and inhibit bacterial growth (Dong et al., 2020; Ayyanaar and Kesavan, 2023). Saponins can facilitate the release of bacterial cell components and disrupt the integrity of bacterial cells membranes (Wei et al., 2021). Tannins are polyphenolic compounds that can bind to proteins and interfere with bacterial enzyme function. This results in inhibition of bacterial growth and activity. Tannins can also precipitate bacterial proteins and interfere with microbial metabolism. Alkaloids have an antibacterial mechanism of action that involves inhibiting bacterial DNA and RNA synthesis. They can affect the function of bacterial enzymes and damage bacterial cell structures. Essential oils in taro, such as oils containing compounds such as eugenol, can have antibacterial effects by disrupting bacterial cell membranes, damaging membrane structures, and inhibiting bacterial metabolism.

Flavonoids, as polyphenolic compounds, are recognized for their antibacterial activity through multiple mechanisms, such as disrupting cytoplasmic membrane function and energy metabolism, inhibiting nucleic acid synthesis, reducing adhesion and biofilm formation, affecting porins and membrane permeability, and impairing pathogenicity-all crucial for bacterial growth (Shamsudin et al., 2022). Flavonoid interactions with proteins (enzymes, receptors, transporters, and transcrip-

tion factors) play a key role in their beneficial effects. One of the most extensively researched pharmacological properties of flavonoids are their antibacterial effects, extensively evaluated through structure activity relationships (SAR) to identify more potent, safe antibacterial agents from natural sources.

Mechanism and antibacterial activity of cinnamon essential oil nanoemulsion (CON) against Pseudomonas deceptionensis CM2 were evaluated (Zhao et al., 2023). CON significantly compromised of *P. deceptionensis* CM2 membrane permeability after 4 hours incubation, causing intracellular components leakage like proteins and electrolytes, by disrupting the integrity and function of the bacterial membrane, CON inactivated *P. deceptionensis* CM2, likely exhibiting its antibacterial effect through membrane damage and oxidative stress induction.

In Figure 3a, cells of *P. deceptionensis* CM2 were exposed to varying of CON concentrations at 25°C at 4 hours. *P. deceptionensis* population was significantly reduced when treated with CON at 1×MIC, 2×MIC, 4×MIC, and 6×MIC. Figure 3B shows the bacterial mortality curves at different CON concentrations. No significant changes were observed in the control group during 10 h of incubation at 25°C. However, the number of bacteria decreased significantly after exposure to CON at 1×MIC or 1×MBC depending on the exposure time. The population of *P. deceptionensis* CM2 decreased significantly (p<0.05) after 10 hours of incubation with CON at 1×MIC or 1×MBC, respectively (Figure 3b). These results indicated that CON was effectively inactivating cell of *P. deceptionensis* CM2 in a concentration and time dependent manner.

Figure 4a. shows SEM images of the cells control revealed intact rod-like structures with a plump (smooth surface). Cells exposed to CON at 1×MIC or 2 × MIC for 4 hours displayed significant surface structural damage. Cells treated at MIC levels showed some shrinkage and depressions (Figure 4b). The most severe damage occurred in cells exposed to CON at 2×MIC, where shrinkage, membrane perforation, disintegration, and loss of normal shape were observed, leading to cell lysis and leakage of cellular contents (Figure 4).

Tang et al. (2023) analyzed the chemical composition of Citrus medica limonum essential oil (LEO) using GC-MS, identifying D-limonene, β-pinene, and γ-terpinene as the primary components. They evaluated the antibacterial activity of these compounds against *E. coli* K99 and *L. acidophilus* while also investigating LEO's antibacterial mechanisms. MIC and MBC of LEO were determined to be 5 mg/mL and 10 mg/mL for *E. coli* K99, and 80 mg/mL and 160 mg/mL for *L. acidophilus*, indicating notable selective antibacterial efficacy compared to the other essential oils studied. LEO was found to disrupt bacterial cell membranes, leading to the leakage of intracellular proteins and nucleic acids.

Figure 5 shows the inhibition effect curves of LEO against *E. coli* K99 and *L. acidophilus*. LEO totally inhibited the growth of both bacteria at MIC and 2 MIC concentrations. However, at lower concentration (0.125 MIC and 0.5 MIC), the growth of both bacteria was not significantly different from the control. In addition, *L. acidophilus* showed better tolerance to LEO than *E. coli* K99, with higher colony densities at MIC and 2MIC.

SEM analysis showed that LEO damaged the cell structures of E. coli K99 and L. acidophilus differently depending on the concentration. Figure 6 displays SEM micrographs of *E. coli* K99 and L. acidophilus bacteria, where Figure 6a and Figure 6b show both bacteria in intact condition without LEO treatment. In *E. coli* K99, treatment with MIC (Figure 6c) and 2MIC (Figure 6e) LEO caused shrinkage of cell wall and membrane, uneven distribution of cytoplasm, and leakage of cytoplasmic contents, with more severe damage under 2MIC. Meanwhile, *L. acidophilus* treated with LEO MIC (Figure 6d) and 2 MIC (Figure 6f) experienced slight shrinkage of cell wall and membrane and shortening of cell length, but the damage was not as severe as in *E. coli* K99. This suggests that *E. coli* K99 is more susceptible to the effects of LEO than *L. acidophilus*.

Limsolactobacillus reuteri was genetically modified by Ma et al. (2023) using random mutagenesis with ARTP (atmosphere and room temperature plasma). The variants were then screened on their antibacterial activity towards *E. coli* through HTS (high-throughput screening), which led to the identification of AR-148 mutant strain. The AR-148 cell-free supernatant (MCFS) showed up to 37% greater antibacterial activity against *E. coli* than that of the wild-type strain. Further investigation at the cellular level revealed that MCFS disrupted the bacterial membrane, impacted key intracellular biomolecules such as DNA and proteins, and reduced the levels of enzymes (AKPase and β-galactosidase). Transcriptomic analysis also confirmed that MCFS significantly affected gene expression in *E. coli*, affecting pathways related to oxidative stress, energy metabolism, membrane integrity and cell wall and genetic information.

Here is the general mechanism of caladium antibacterial:

- **Inhibition of Protein Synthesis:** Compounds in caladium can inhibit bacterial protein synthesis by interfering with ribosomes or translational mechanisms, which in turn inhibits bacterial growth and replication (Sehgal et al., 2024).
- **Damage to Cell Membranes** (El-Baky et al., 2021)**:** Active compounds such as saponins and essential oils can cause damage to the bacterial cell membrane. This results in leakage of cell components and bacterial cell death.
- **Inhibition of Nucleic Acid Synthesis:** Some compounds in caladium can interfere with the synthesis of bacterial DNA and RNA, inhibiting the reproduction and metabolic processes of bacteria.
- **Modification of Cell Structure:** Some compounds can modify the structure of bacterial cells, disrupt enzyme functions, and affect cell integrity.

Figure 7 shown the antibacterial mechanism action of CuNPs which was synthesized from *Rosa andeli* extract. Transmembrane potential occurs after CuNPs come into contact with the cell wall, the change of electric microcurrent causes weakening of the membrane and creates holes in the cell wall. Next,

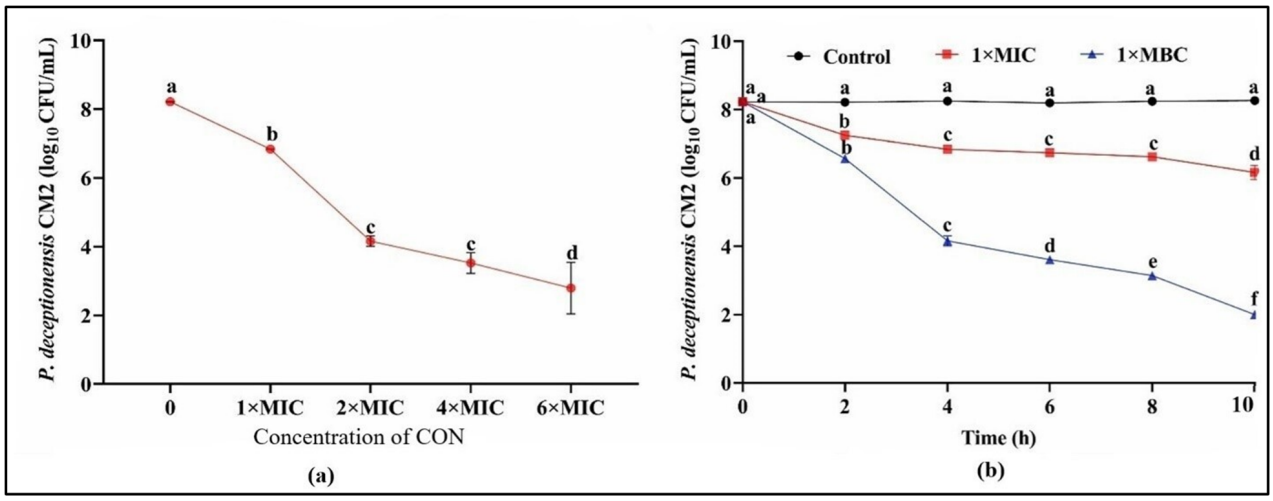


Figure 3. The Impact of CON on the Viability of *P. deceptionensis* CM2 (Zhao et al., 2023)

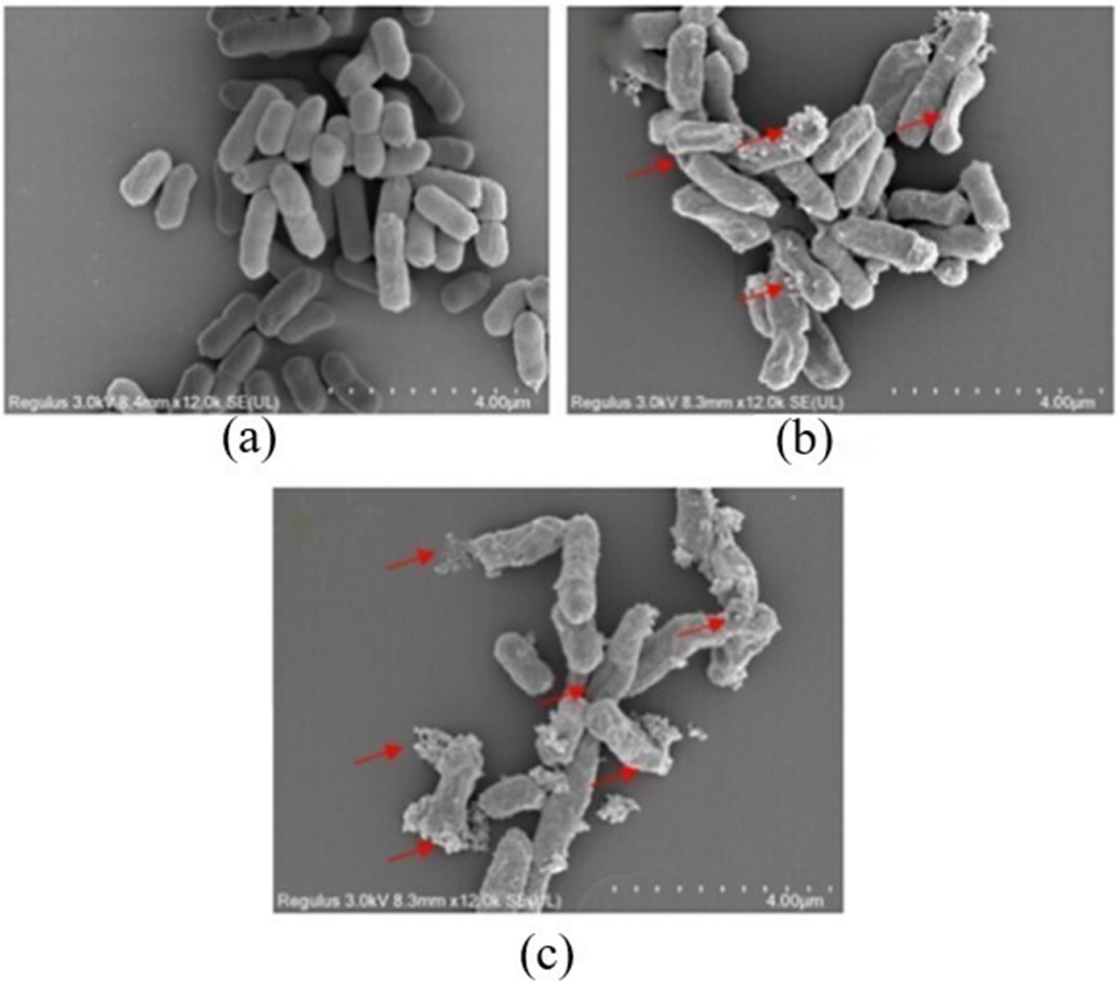


Figure 4. Results of Field Emission Scanning Electron Microscopy of *P. deceptionensis* CM2 Cells (Zhao et al., 2023)

Cu ions entered the cell through the holes and hindered cell metabolism and inhibited enzymatic action so that the cell could not digest nutrients and caused death.

Antibacterial properties are influenced by the molecular

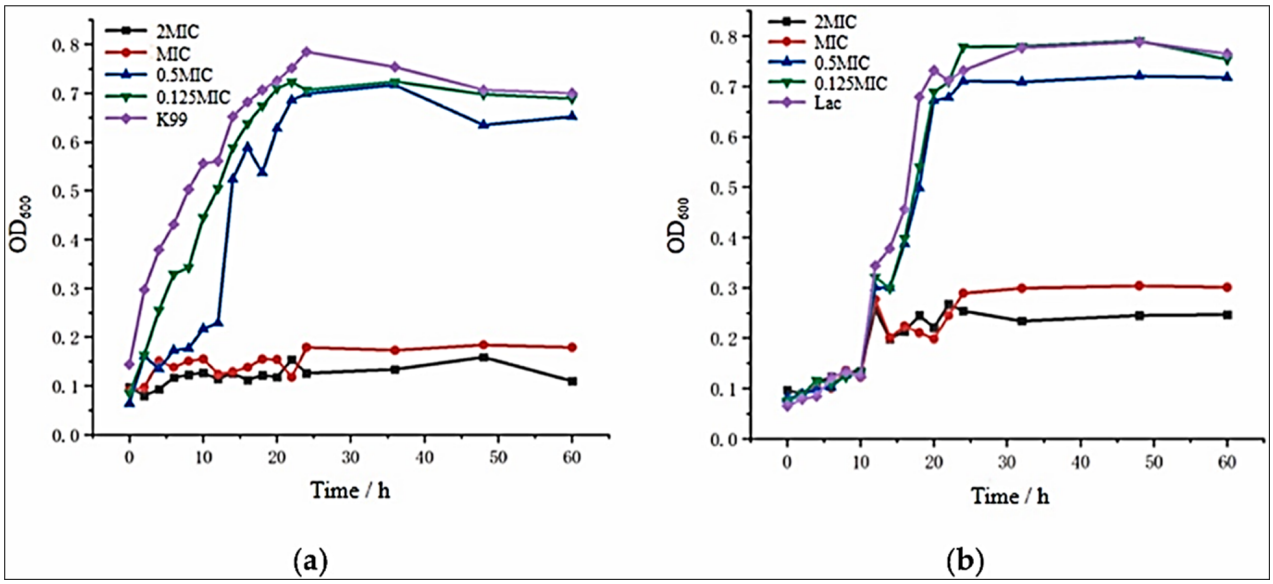


Figure 5. Impact of LEO on the Growth of (a) *E. coli* K99; and (b) *L. acidophilus* (Tang et al., 2023)

shape or chemical structure of a compound because the structure determines how the compound interacts with the target in bacterial cells. The study Le et al. (2024) showed graphene oxide (GO) has a higher antibacterial performance against Gram-positive than Gram-negative bacteria due to differences in the membrane structure of microorganisms with an antibacterial ratio of 85.9% against *E.coli* and 95.9% against *S. aureus*. Docking studies point to the fact that the behavior of the structure as an antibacterial agent results in higher scores against gram-positive samples (Yazdani Nyaki et al., 2024). The size and shape of the molecule determine whether the compound can enter into the bacterial cell or penetrate the cell wall layer which is different in Gram-positive and Gram-negative bacteria. The enhanced antibacterial activity of Y/GQDs-doped MgO NPs can be attributed to the smaller particle size and larger surface area, which allows greater penetration into the bacteria and destruction of its internal structure thereby causing cell death (Siddique et al., 2024). The relationship between the amount of α-pinene in rosemary essential oil and its ability to combat both Gram positive and Gram negative bacteria was investigated by Wahba et al. (2024), α-pinene as the main agent of rosemary essential oil is responsible for damaging cell membranes. Functional groups (Jannesari et al., 2024), such as $-OH$, $-NH_2$, $-COOH$, and $-SH$, play a role in molecular interactions with targets inside bacterial cells, such as proteins or nucleic acids. The modification of QAS groups gives the nanomaterial surface a negative charge property, which effectively increases the affinity between the nanomaterial and bacteria, and significantly improves the performance of photodynamic therapy, which then cooperates with the physical destruction of cell membrane properties by QAS groups to achieve a more thorough antibacterial effect (Zhou et al., 2024). Molecular polarity affects the solubility of compounds in aqueous media, which is important for compounds to reach and penetrate the bacterial cell wall or membrane. Polar compounds tend to be more soluble in water, while nonpolar compounds interact more easily with the lipid layer of the cell membrane. The positive or negative charge on the antibacterial molecule affects its interaction with the bacterial membrane or intracellular components (Jannesari et al., 2024). Gram-negative bacteria, for example, have a negatively charged outer wall that is more easily penetrated by positively charged molecules. Electrostatic interactions between charged antibacterial molecules and charged parts of the cell wall are also important in determining antibacterial activity. The precise molecular shape allows antibacterial compounds to interact effectively and selectively with essential targets inside bacterial cells, such as enzymes, membranes, or DNA, leading to more potent and specific antibacterial effects.

3.6 The Potential Application of Taro as an Antibacterial Plants

- **Pharmaceutical and Biomedical**
  Phytochemical screening of bicolor leaf extract showed the presence of saponins, tannins, steroids, flavonoids, phenolics and alkaloids (Salako et al., 2015), tests on rats showed that taro leaf extract has antidiarrheal activity so that it can be used for the development of traditional diarrhea treatment. The Crude extract of taro stimulates in-vitro proliferation of mouse splenocytes, intraperitoneal inoculation induces splenomegaly, bone marrow cells and spleen's total proliferation, represents a powerful immunostimulatory protein source, a new candidate as an additive for pharmaceutical and food industry (Pereira et al., 2015). Crude extract of *C. esculenta* and *A. paeonifolius* as the intracanal drug showed great antibacterial efficiency toward *E. faecalis* biofilm compared with CH,

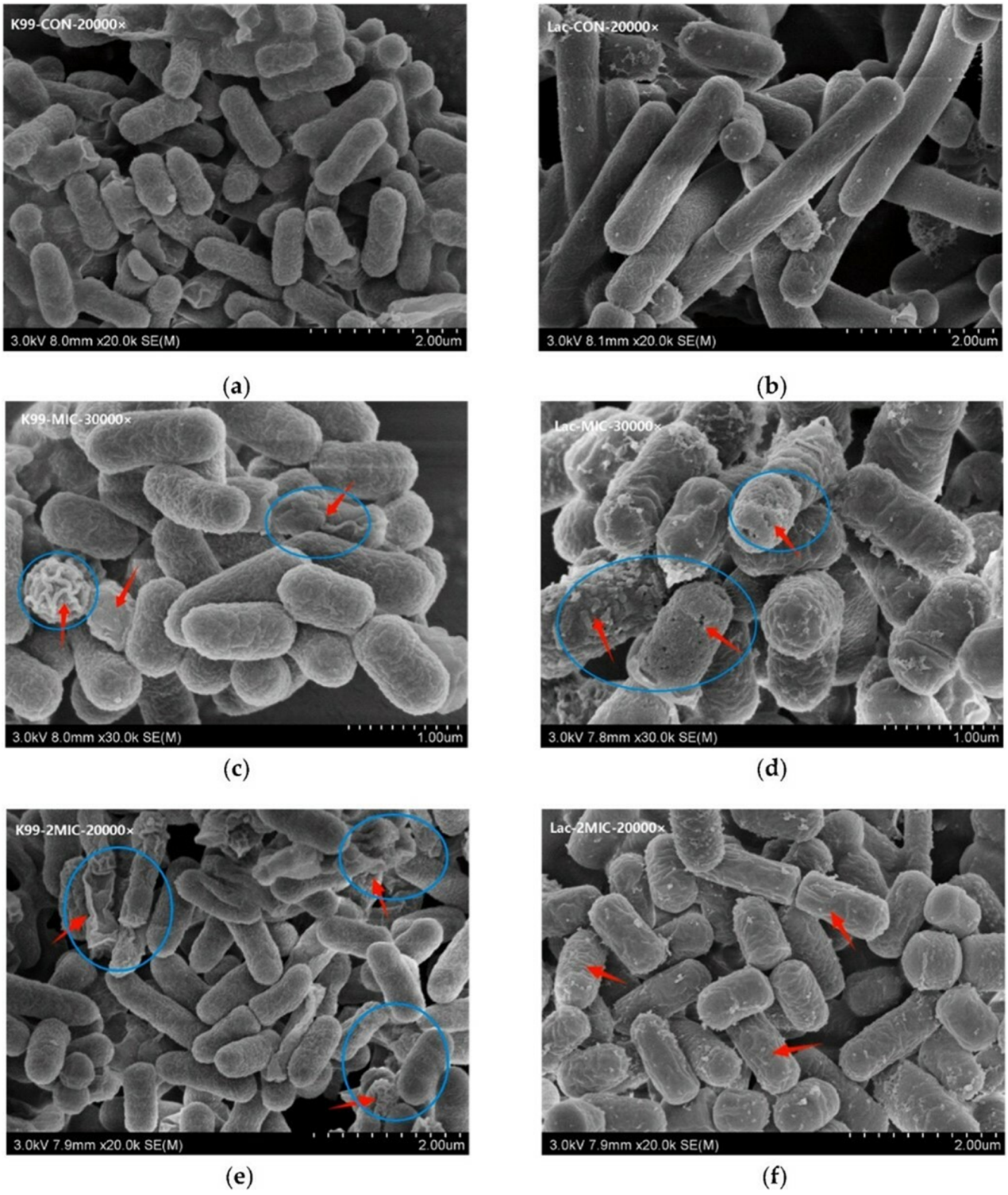


Figure 6. SEM Characterization Results of *E. coli* K99 and *L. acidophilus* at Different LEO Concentrations (Tang et al., 2023)

CHX 2% gel and 940 nm diode laser (Gharib and Salman, 2023). SEM images of the sample methods are shown in Figure 8, with white arrows indicating *E. faecalis* cells, whereas the crude extracts of *C. esculenta* and *A. paeoniifolius* as intracanal drugs have higher antibacterial ability against *E. faecalis* biofilm than Calcium hidroxide, but still less effective than 2% Chorhexidine gel and 940 nm diode laser. Among the two plant extracts, *A. paeoniifolius*

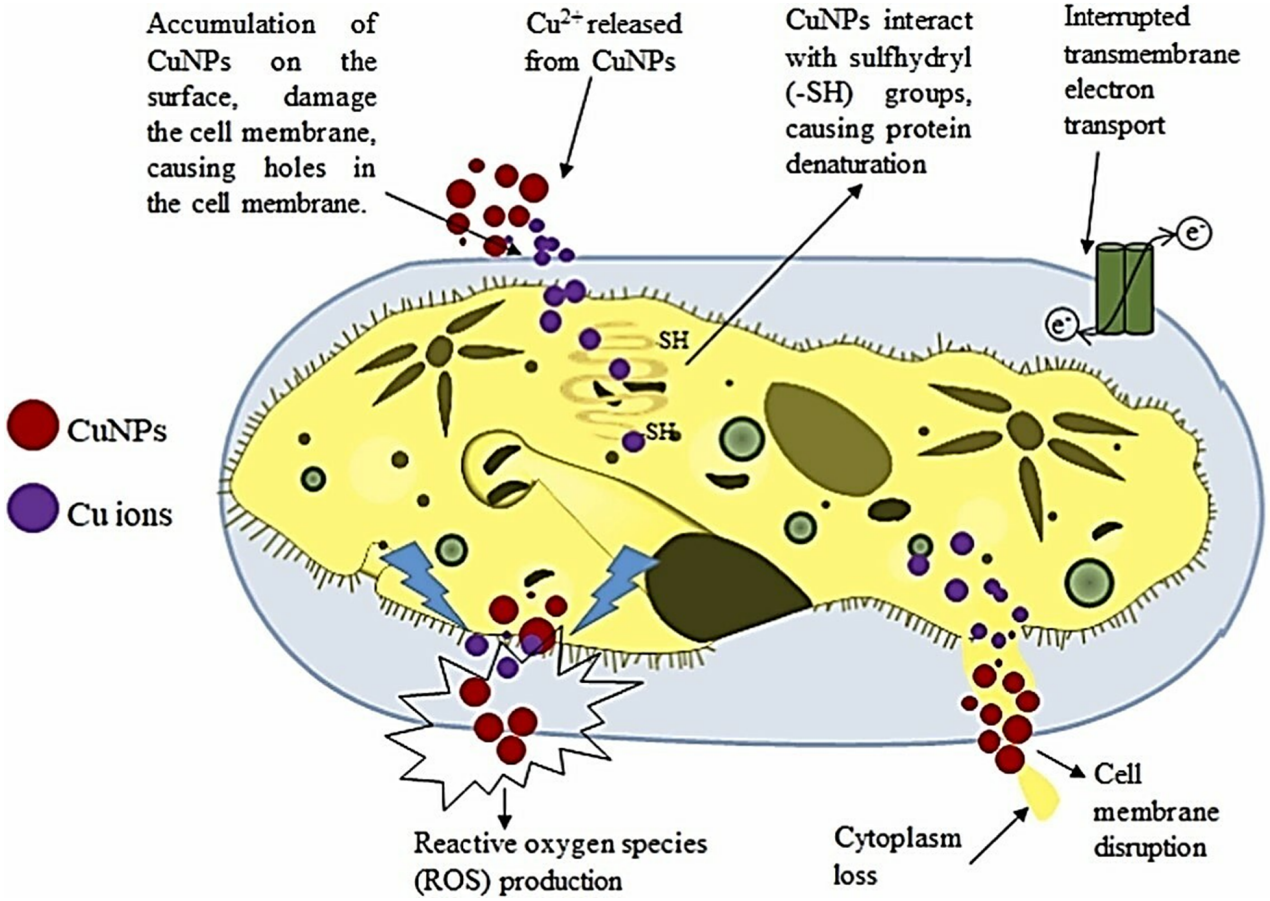


Figure 7. Antibacterial Mechanism Action (Nieto-Maldonado et al., 2022)

(Suran) showed superior antibacterial activity compared to *C. esculenta* (Aravi) and CH.

- **Industrial Field**
  Antibacterial applications of taro in the industrial field were presented by Hernández-Nolasco et al. (2024). A biodegradable taro starch film (OBF) was optimized using Response Surface Methodology through Box-Behnken design, the optimized biofilm composition was 0.5% taro starch, 1.04% alginate, 0.75% glycerol and 1.25% lactic acid and showed antibacterial activity against *E. coli* and *L. monocytogenes*. The interaction of the components was confirmed by FTIR and SEM results. OBF was used as an active packaging system (T3) in a Spanish chorizo-type meat product to evaluate its physicochemical and microbiological properties. This biofilm not only provide an eco-friendly alternative to synthetic packaging but also enhance food preservation by minimizing microbial contamination. Active packaging ensures the quality and microbiological properties of meat products.
  Additionally, taro extract has been used as capping agent in the green synthesis of nanoparticles. ZnO(Cu, Ce) nanoparticles synthesized using *Colocasia esculenta* extract as a doping agent (Verma et al., 2024). The extract served as a capping agent throughout the synthesis process, ensuring the nanoparticles were non-toxic and environmentally safe. XRD characterization revealed that increasing the cerium concentration resulted in smaller nanoparticles. TEM, SEM-EDX used to analysis of nanoparticles size and structure, these nanoparticles confirmed as UV protection application, antibacterial dan antioxidant for food packaging.
  Figure 9 illustrated the composition and peak intensities observed in the Energy Dispersion X-ray spectra of the synthesized samples. The spectra confirmed the presence of Zn, Cu, Ce, and O elements in the samples. The lower atomic weight and percentage of Ce and Cu elements in Figure 9 support the incorporation of these elements into the crystal lattice of ZnO.
- **Food Sector**
  Taro Leaves Extract (TLE) was used Shehata et al. (2023) to produce two fermented milk beverages in concentrations of 250 and 500 mg/L. The results showed the incorporation of TLE and probiotics in fermented beverage fermentation provided an excellent food model with many health benefits, increased antioxidant potential, with stabilized probiotics through the digestion process

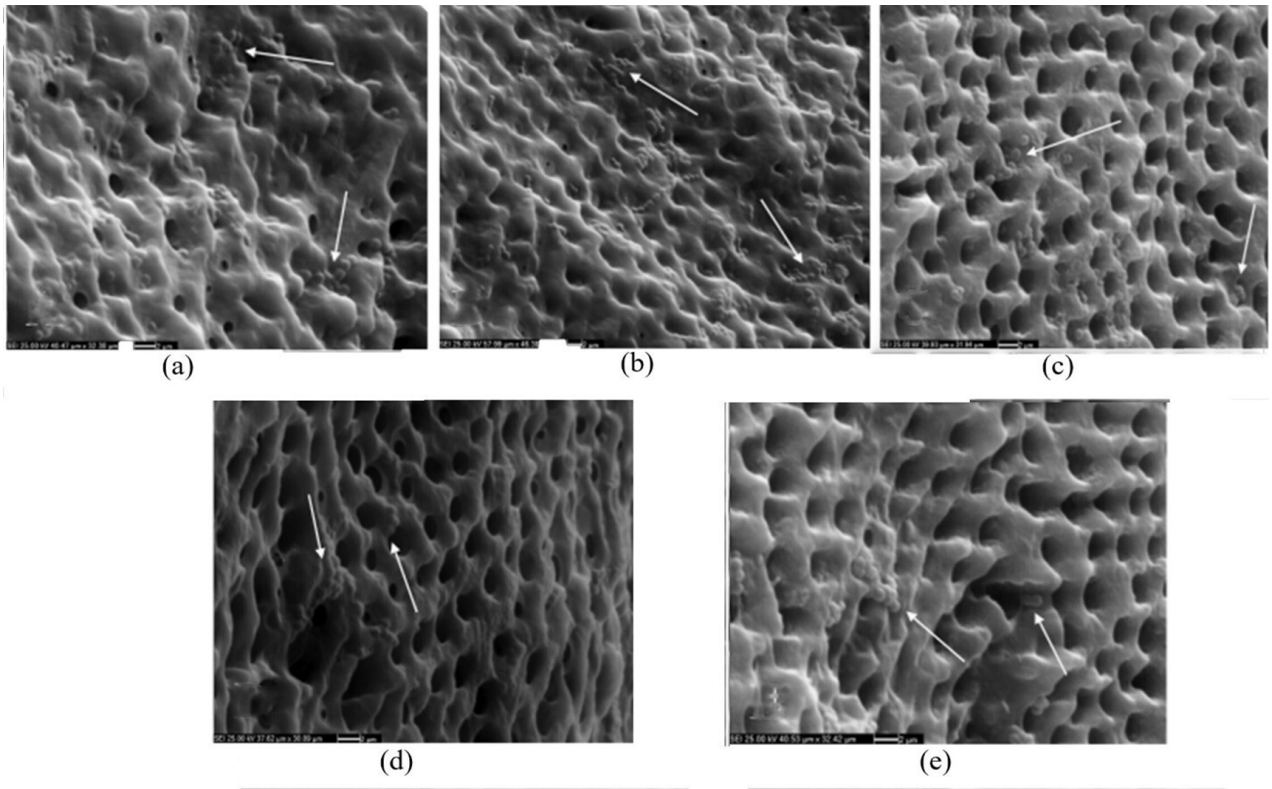


Figure 8. SEM Images of Experimental Groups Intracanal Sampling Method, White Arrow Shows *A.faecalis* Cell, (a) Suran, (b) Aravi, (c) Calcium Hydroxide, (d) 2% Chorhexidine, (e) Diode laser (Gharib and Salman, 2023)

of the supplemented beverage and increased polyphenol concentration in the beverage.

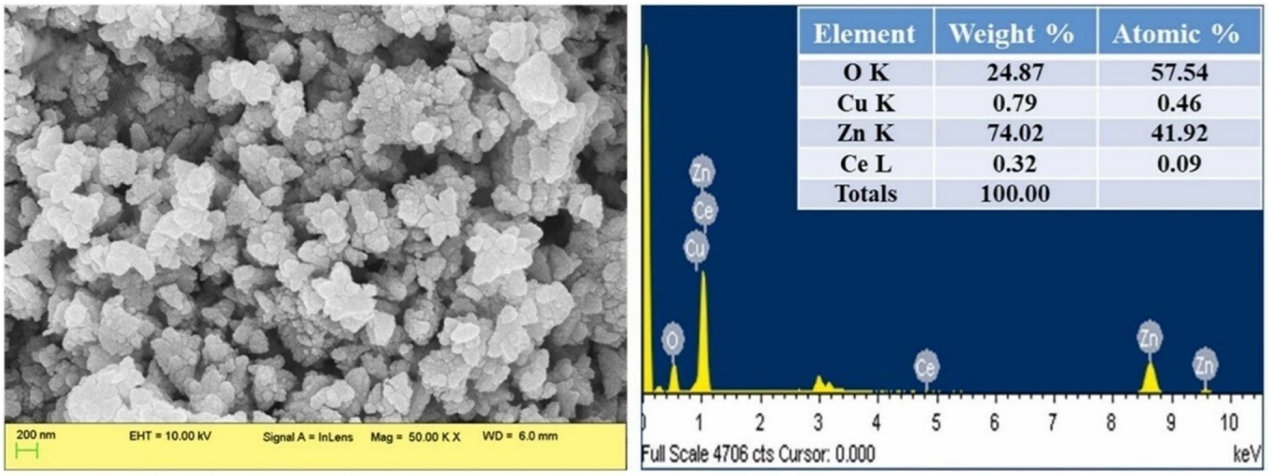
Aditika et al. (2022) has highlighted taro's scope as a food crop of the future with considerable nutritional and antioxidant potential, advances in biotechnology, and scopes for breeding biologically enriched taro. The recording of traditional taro food product usage in rural communities, along with the measurement of bioactive compound levels, shows the immense potential of taro as a functional food product and medicinal development over other root crops especially baby food due to its easy digestibility.

Boahemaa et al. (2024) evaluated the physico-chemical properties and functional characteristics of flour and starch from two taro varieties for potential use in food formulations. The proximate composition results revealed significant differences, with the exception of fiber and energy. This study indicates that taro flour and starch possess qualities that make them well-suited for the food industry, thus contributing to addressing food security issues in Ghana.

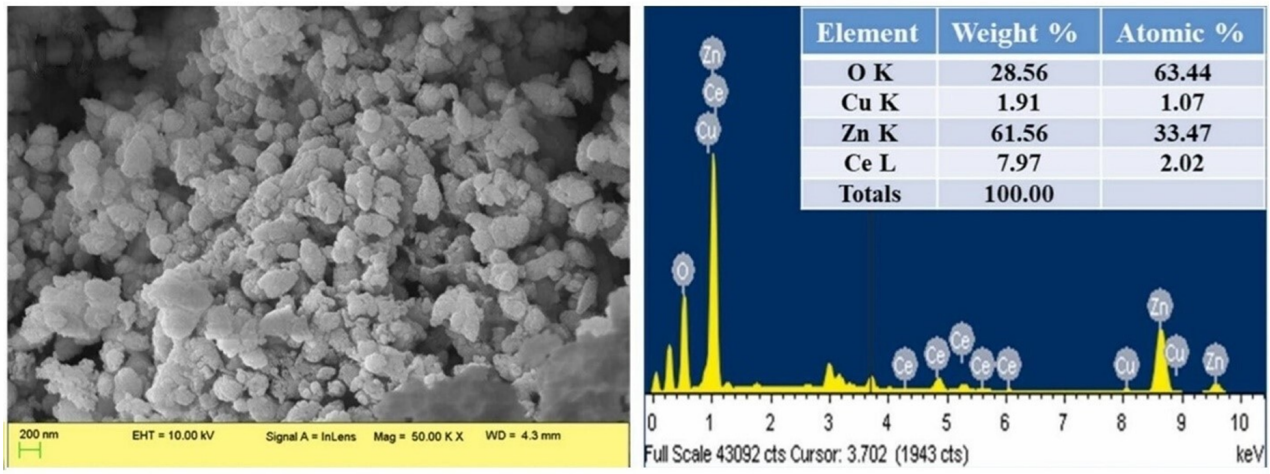
Research by Gerrano et al. (2021) aimed to evaluate the content of mineral elements as proxies for the nutritional values of various genotypes of taro. This study evaluated 14 taro genotypes in Roodeplaat and Umbumbulu, South Africa, focusing on their calcium, iron, potassium, magnesium, manganese, sodium, phosphorus, and zinc contents. Additional research has highlighted taro's nutritional value and its capacity to meet microelement requirements in the human diet, indicating its potential to combat food and nutrition insecurity.

- **Waste Treatment**

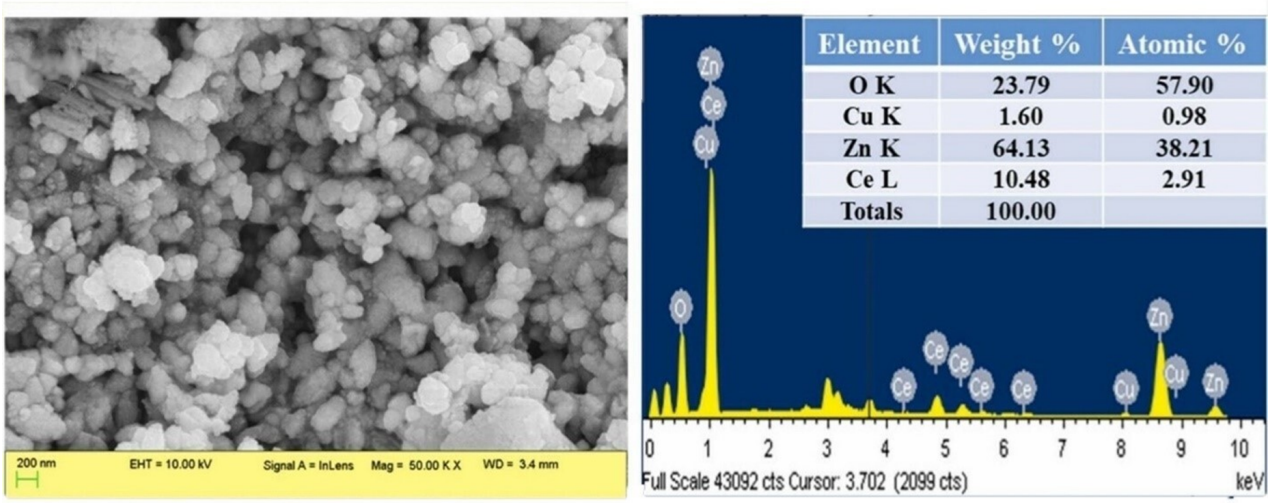
  The efficiency of Colocasia as well as the addition of cow dung biochar in constructed wetlands (Chand et al., 2021), In this study, a vertical subsurface flow constructed wetland (VSSFCW) using *Colocasia esculenta*, filled with heterogeneous gravel and cow dung biochar, was set up to wastewater treatment application. To achieve this, three VSSFCW configurations were established: SB (medium + biochar (10% v/v)); SBP (medium + biochar + Colocasia); and SP (medium + Colocasia). Wastewater characteristics were monitored at 24-hour intervals for 40 days, following a 70-day initial acclimatization period. The SBP setup demonstrated the highest average removal efficiencies for COD (92.6%), $NO_3{-}N$ (81.7%), $NH_4{\equiv}{-}N$ (81.2%), $SO_4{-}_2$ (85.4%), $PO_4{-}_3$ (69.5%), and total coliform (97%) compared to SB and SP over the treatment period. Plant uptake rates were also assessed, with the biochar-amended VSSFCW showing the highest leaf area, biomass growth (2.58-3.44 times), N uptake (36.81 gNm^{-2}), and P uptake (12.3 gPm^{-2}) compared to the SP setup. Biochar-treated domestic wastewater en-



(a)



(b)



(c)

Figure 9. SEM-EDX Micrographs for Synthesized of (Cu, Ce) Dual-Doped ZnO Nanoparticles (Verma et al., 2024)

hanced VSSFCW's compliance with standards set by India's national pollution monitoring agencies. The impact of aeration and different wastewater strengths (particularly COD load) on the performance of Colocasia-based constructed wetlands can be explored in future research to develop more effective wetland systems for on-site wastewater treatment.

3.7 Modification of Plants Antibacterial Synthesis

Antibacterial modification based on medicinal plants continues to be developed by research, including nanoparticle synthesis and antibacterial nanofiber synthesis with the aim of biomedical applications.

3.7.1 Biosynthesis of Nanoparticles (Assefa et al., 2024; Inamuddin and Kanchi, 2020; Revathi et al., 2024)

The synthesis of medicinal plant-based nanoparticles can be done through various approaches, including encapsulation in polymers, coating with metals, or incorporation with other materials. These modifications aim to improve the bioavailability, stability, and effectiveness of natural antibacterials, and enable wider applications in healthcare, cosmetics, and the environment. Here are some commonly used modification techniques for medicinal plant-based antibacterial nanoparticles: Green Synthesis Nanoparticles (Mirza et al., 2023), Modifications with Biocompatible Polymers (Sathyanarayanan et al., 2024; Qin et al., 2024), Nanoencapsulation of Plant Compounds in Polymer Nanoparticles (Farnad and Farhadi, 2023; Zhuang et al., 2024; Jiang et al., 2024b), Synthesis modification of antibacterial medicinal plants with Metal Nanoparticles or Metal Oxides (Saini and Kumar, 2023), Surface Functionalization Modification (Pradhan et al., 2022), Coupling with Nanofiber or Hydrogel (Plant-based Nanocomposite Synthesis) (Peng et al., 2024; Sajid et al., 2024; Ding et al., 2024), Coating Nanoparticles with Antioxidants (Lakshmi Pravallika et al., 2019).

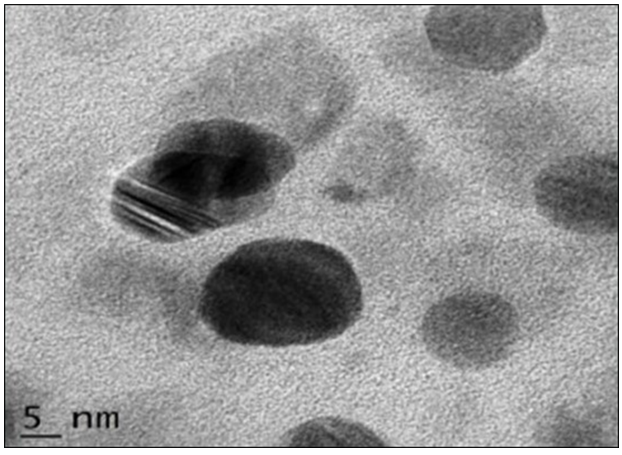


Figure 10. Silver Nanoparticles using *Acacia nilotica* (Revathi et al., 2024)

Figure 10 shown SEM image of sized silver nanoparticle (AgNPs) *Acacia nilotica* size using green synthesis method. Green synthesis of silver nanoparticles (AgNPs) based on Acacia nilotica plant extract to treat bacterial resistance, SEM image confirming the presence of very small nanoparticles with irregular shapes that resemble colloidal particles. XRD, SEM, EDAX, TEM, UV-Vis spectroscopy and FTIR analysis showing green synthesis of AgNPs is promising for future antibacterial use (Revathi et al., 2024). Green synthesis is an environmentally friendly approach that uses plant extracts as reducing agents (Mirza et al., 2023) and stabilizers in the synthesis of metal nanoparticles (such as silver, gold, or zinc oxide nanoparticles) (Ijaz et al., 2022). This process replaces the use of toxic chemicals, making it safer and more sustainable (Das et al., 2018).

Reduction Process by Active Compounds: Plant extracts contain compounds such as polyphenols, flavonoids, alkaloids, and terpenoids that can reduce metal ions into nanoparticle form (Revathi et al., 2024). These compounds also serve as stabilizers to prevent clumping of the nanoparticles (Assefa et al., 2024).

Metal Nanoparticles: Metal nanoparticles such as silver nanoparticles (AgNPs) (Revathi et al., 2024) and zinc oxide nanoparticles (ZnO) (Verma et al., 2024) was often used due to their strong antibacterial activity. Example: Neem leaf extract can be used to biosynthesize silver nanoparticles with effective antibacterial properties against Gram-positive and Gram-negative bacteria. CuO is important in the pharmaceutical industry as it has strong bacteria-killing properties. Green synthesized CuO nanoparticles using plant extract biomolecules eliminate the need for stabilizing agents and coatings, and exhibit effective antibacterial activity depending on their shape and size (Assefa et al., 2024). Green synthesis of silver nanoparticles (AgNPs) based on Acacia nilotica plant extract to treat bacterial resistance, spherical and homogeneous AgNPs with an average size of 23.65 nm were confirmed by XRD, SEM, EDAX, TEM, UV-Vis spectroscopy and FTIR analysis showing green synthesis of AgNPs is promising for future antibacterial use (Revathi et al., 2024). *Colocasia esculenta* plant extract was used to prepare ZnO nanopowder with double doping of copper (Cu) and cerium (Ce), the structure and size of nanoparticles were investigated by XRD with size range of 16-19 nm, these nanoparticles showed significant antibacterial and antioxidant properties and have potential in biomedical applications (Verma et al., 2024).

Biocompatible polymers such as chitosan (Sathyanarayanan et al., 2024; Qin et al., 2024), alginate ((Islam et al., 2024; Kumar et al., 2021; Ashtariyan et al., 2024), polyvinyl alcohol (PVA) (Ragab et al., 2024; Abdulrahman et al., 2024; Revathi et al., 2024), or polylactic acid (PLA) (Russo et al., 2024; Shankar et al., 2018) are often used to coat or blend nanoparticles containing natural antibacterial compounds from medicinal plants. These polymers function to increase the stability of nanoparticles (Wang et al., 2024a), control the release of bioactive compounds (Gong et al., 2024), so that the antibacterial effect can last longer, reduce toxicity (Choopani et al., 2024) on human body cells, making it safer for medical applications. Example: Nanoparticles containing curcumin (an

antibacterial compound from turmeric) were modified with chitosan to improve solubility and antibacterial activity against pathogenic bacteria (Fahimirad et al., 2021). The synthesis, characterization and antibacterial activity of CuO nanoparticles using plant extract biomolecules were carried out by Assefa et al. (2024), CuO is important in the pharmaceutical industry because it has strong bacteria-killing properties.

Nanoencapsulation is a technique in which antibacterial compounds from plants are incorporated to a polymer matrix nanoscale. Polymeric nanoparticles can improve the stability of active compounds, provide controlled release, and extend the time of antibacterial activity. Encapsulation in lipid nanoparticles (e.g., liposomes or solid lipid nanoparticles) can: Protect the active compound from environmental degradation, increase the bioavailability of the compound in the body, increase uptake in target cells. Example: Essential oil from betel leaf that has antibacterial properties can be encapsulated in lipid nanoparticles to enhance its effectiveness in inhibiting the growth of Gram-positive and Gram-negative bacteria (Aayush et al., 2024).

Polymeric Nanoparticles: Biocompatible and biodegradable polymers such as poly(lactide-co-glycolid) (PLGA), poly(ε-caprolactone) (PCL), and chitosan are often used to make nanoparticles containing plant antibacterial compounds.

Controlled Release: Nanoencapsulation enables controlled release of antibacterial compounds, which results in increased efficiency and reduced application frequency. Turmeric extract (*curcumin*) was encapsulated in chitosan nanoparticles to enhance its antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* (Zhang et al., 2024b; Huang et al., 2024).

The combination of medicinal plant compounds with metal nanoparticles (silver, gold, zinc oxide) is a commonly used strategy to enhance antibacterial properties. Metal nanoparticles have strong antimicrobial activity and can be synergized with medicinal plant components. Metal oxide nanoparticles, such as titanium dioxide (TiO_2) and zinc oxide (ZnO), can also be produced using plant extracts. These oxide nanoparticles have outstanding antibacterial ability and good thermal stability.

Silver Nanoparticles (AgNPs) (Sathyanarayanan et al., 2024): Silver nanoparticles can be prepared with plant extracts as reducing and stabilizing agents, resulting in nanoparticles with strong antimicrobial properties.

Zinc Oxide Nanoparticles (ZnO NPs) (Verma et al., 2024): Plant extracts can be used to make zinc oxide nanoparticles that have good antimicrobial activity, especially for applications in cosmetic products or wound dressings.

Metal Oxide Nanoparticles(Saini and Kumar, 2023): TiO_2 and ZnO can be synthesized using plant extracts to produce oxide nanoparticles that are effective against bacterial pathogens. They work by generating reactive oxygen species (ROS) that damage bacterial cell membranes. Silver nanoparticles synthesized using neem (*Azadirachta indica*) leaf extract showed enhanced antibacterial activity against pathogenic bacteria due to synergy between the antimicrobial properties of silver and bioactive components of neem (Singhal et al., 2024). Zinc oxide nanoparticles synthesized with papaya leaf extract showed antibacterial activity against *Streptococus sp.* (Subha et al., 2024).

The surface functionality of nanoparticles can be modified with functional groups or bioactive compounds from medicinal plants, thereby enhancing the interaction with the bacterial cell membrane.

This Modification can Help in: specific targeting of certain bacteria, strengthening the adhesion of nanoparticles on the bacterial cell surface, which improves antibacterial efficiency, reducing antibiotic resistance through novel mechanisms of damaging bacterial cell walls or inhibiting their metabolic functions. Example: Plant-based nanoparticles modified with phenolic or flavonoid compounds (Pradhan et al., 2022) can enhance penetration and direct bacterial cell damage. Silver nanoparticles coated with chitosan showed enhanced antibacterial activity against Gram-negative bacteria through increased interaction with the bacterial cell wall.

Medicinal plant-based antibacterial nanoparticles can be combined with other materials such as nanofiber or hydrogel, thus forming a more sophisticated delivery system (Sajid et al., 2024). These systems can be used in wound dressing applications, antibacterial films, or packaging materials that have controlled release and enhanced effectiveness. Plant-based nanofibers with antibacterial nanoparticles can be used to enhance microbial resistance on the material surface. Hydrogels containing plant extract-based antibacterial nanoparticles can be used as wound healing in medical applications with improved release control. Example: The combination of green tea leaf extract nanoparticles in chitosan-based hydrogels showed effective antibacterial properties in food packaging applications (Ma et al., 2024).

Some antibacterial compounds from medicinal plants also have strong antioxidant properties. Nanoparticles can be modified with natural antioxidants from plants such as vitamin E, ascorbic acid, or phenolic compounds. These modifications can improve: Stability of nanoparticles against oxidation or environmental degradation. Antimicrobial activity through a dual mechanism, i.e. antioxidant and antibacterial. Example: Nanoparticles containing extracts from the Centella asiatica plant coated with ascorbic acid showed enhanced antimicrobial (Lakshmi Pravallika et al., 2019), anticancer (Linima et al., 2024), anti-HIV (Maduray et al., 2022).

Table 1 shows several studies of nanoparticle synthesis by utilizing plants for antibacterial purposes. The size of the resulting nanoparticles varies with a range of 10-120 mm and is able to inhibit the growth of *E. coli*, *S. aureus*, and *L. monocytogenes*bacteria.

Figure 11 shows the synthesis of ZnO(Cu,Ce) nanoparticles (NPs) doped with Colocasia esculenta plant extracts for antioxidant and antibacterial purposes, SEM-EDS was used for surface characterization of NPs, XRD for crystallite size analysis and UV-Vis for analyzing the forbidden energy gap of the samples. XRD analysis showed the size of NPs ranged from 16-19 nm. Spectra validated the presence of Cu-Ce elements as doping in the synthesized samples. Higher concentration

of NPs with smaller size has effective antibacterial behavior, enables these NPs to be used in foods packaging industry. The NPs showed antibacterial activity with an inhibition zone of 22 mm against *S. aureus* and 10 mm against *E. coli* at a concentration of 5 mg/mL.

3.7.2 Antibacterial Nanofiber Synthesis

Synthesis of nanofibers made from antibacterial medicinal plants uses various methods, one of the most common is electrospinning. Nanofibers containing antibacterial medicinal plant compounds offer various advantages such as large surface area, controlled drug release capacity, and enhanced bioactivity. The following are some appropriate methods for the synthesis of nanofibers made from antibacterial medicinal plants: Electrospinning (Yang et al., 2024; Dede et al., 2022; Pires et al., 2022; Chen et al., 2021), Self-Assembly (Wang et al., 2024c; Liu et al., 2024; Qian et al., 2024), Phase Separation (Zhang et al., 2024a; Seyfi et al., 2019), Template Synthesis (Zheng et al., 2023; Li et al., 2022c), Coaxial Electrospinning (Zhu et al., 2024; Qin et al., 2022; Li et al., 2022c; Lan et al., 2021), Electrospraying (Spray Drying) (Lenzuni et al., 2024; Li et al., 2023; Dai et al., 2019; Buga et al., 2021).

Electrospinning is the most commonly used method to make nanofibers, including nanofibers containing antibacterial ingredients from plants. This technique uses an electric field to draw thin fibers from a polymer solution containing active compounds from plants.

Preparation of Polymer Solution: Antibacterial compounds from medicinal plants are mixed with an electrospinable polymer solution, such as polyvinyl alcohol (PVA) (Shahzadi et al., 2022), poly(ε-caprolactone) (Qin et al., 2024), or chitosan (Tien et al., 2022). These solutions serve as a matrix that will carry the antibacterial compounds.

High Voltage Application: the polymer solution is put into a syringe, and a high electrical voltage is applied between the syringe and the collector. This voltage creates an electric field that attracts the fibers from the polymer solution (Haider et al., 2018).

Formation of Nanofibers: Thin fibers are formed from the polymer solution and collected above the collector in the form of a nanofiber membrane. The medicinal plant compounds will be trapped inside the fiber or distributed on the surface of the fiber.

The synthesis of chitosan/acetic acid and PEO solution for wound healing was carried out by Tien et al. (2022), the solution for spinning was prepared by mixing chitosan and PEO solution in the ratio of 98/2, 95/5, 90/10, 80/20, 70/30, 50/50. The morphology of the nanofibers was examined using scanning electron microscopy (SEM) (Figure 12). The SEM results showed the chitosan nanofibers consisting of 10-50 wt% PEO appeared as homogeneous fibers with almost tissue defect-free fibers as shown in Figure 12.

Plant antibacterial compounds like alkaloids, flavonoids, tannins, and essential oils can be incorporated with polymer solutions for electrospinning modification. Incorporation of these compounds in nanofibers ensures better stability and controlled release. Electrospinning nanofibers can be designed to release antibacterial compounds slowly, ensuring a longer duration of effect in topical applications such as wound dressings. For example, nanofibers containing essential oils from thyme plant or neem leaves showed slow release and effectively inhibits the growth of S. aureus and *E. coli* bacteria (Yavari Maroufi et al., 2021). The other method for synthesis of nanofiber is self-assembly.

Self-assembly (Wang et al., 2024c; Liu et al., 2024; Qian et al., 2024) is a method that relies on molecular interactions between medicinal plant compounds and fiber-forming agents, such as surfactants or polymers. This technique can be used to spontaneously form nanofibers containing active compounds from plants. Antibacterial compounds from medicinal plants, such as essential oils or polyphenol extracts, are mixed with fiber-forming agents (such as surfactants or amphiphilic polymers) in solution. The compounds will interact non-covalently, through hydrogen bonding or van der Waals forces, forming nanofiber structures with specific sizes and morphologies. The advantages of self-assembly are environmentally friendly process because it does not require tools or high energy like electrospinning, fiber structure can be well controlled through modification of material concentration or solution conditions. For example, self-assembly of natural polymers such as chitosan modified with medicinal plant extracts to produce antibacterial nanofibers for pharmaceutical applications.

Phase separation method (Zhang et al., 2024a; Seyfi et al., 2019) is used to produce of nanofibers through the process of separating polymer solutions and antibacterial compounds from plants in a cooled mother liquor. This method have 2 stages, mixing of plant compound with polymer and phase separation. Medicinal plant extracts were mixed with biodegradable polymers in solution. The solution is cooled or phase changed by solvent evaporation, leading to the formation of nanofibers from the polymer and plant compound. The Advantages of phase separation are High Biocompatibility and Pore Structure. The polymers used are generally natural or biodegradable polymers, such as gelatin, chitosan, or polycaprolactone. This method can produce fibers with a porous structure that allows for the absorption and gradual release of medicinal plant compounds. Example, Chitosan-based nanofibers containing medicinal plant extracts have high porosity, which enables controlled release of active substances and prolongs antibacterial activity.

Template synthesis (Zheng et al., 2023; Li et al., 2022b) is a method in which plant compounds and polymers are produced in a mold or template, resulting in nanofibers with a defined shape and size. The process of template synthesis included template preparation and polymer and plant solution filling. The first, a template or mold that has a micro or nanostructure is prepared first, usually using materials such as anodized alumina or silica, and the solution containing plant antibacterial compounds is charged into the template, and nanofibers are formed in the mold after solidification. In this method, size and mor-

Table 1. Synthesis of Some Antibacterial Medicinal Plant-Based Nanoparticles

Plants	Nanoparticles	Size of Nanoparticles (nm)	Characterization	Antibacterial Activity (Inhibition Zone)	References
Acacia nilotica	AgNp	23.65	XRD, SEM, EDX, TEM, UV-Vis Spectroscopy, FTIR	*E. coli* 30 mm	(Revathi et al., 2024)
Colocasia esculenta	ZnO	16-19	XRD, SEM, EDX, TEM, UV-Vis Spectroscopy	*E. coli* 37 mm	(Verma et al., 2024)
Lupinus albus	ZnO	19.70	UV-Vis Spectroscopy, XRD, FTIR, SEM	*E. coli*	(Mirza et al., 2023)
Lupinus pilosus	ZnO	19.70	Uv-Vis Spectroscopy, XRD, FTIR, SEM	*E. coli*	(Mirza et al., 2023)
Tinospora cordifolia	TiO_2	15.02	FTIR, SEM, XRD, UV-Vis Spectroscopy	*E. coli* 26.5 ±0.79	(Saini and Kumar, 2023)
Ephedra alata	CuO	10-16	XRD, UV-Vis, FTIR, FESEM-EDX	*S. aureus* 20.4 mm	(Atri et al., 2023)
Sambucus ebulus	AgNPs	18.6	XRD, UV-Vis, SEM, FTIR	*L. monocytogenes* 12 mm	(Karan et al., 2024)
Kalanchoe pinnata leaves	AgNPs	38	XRD, zeta potential, FESEM, HRTEM	*E. coli* 11.9 mm	(Aryan et al., 2021)
Rosa andeli (RAFE) and *Gardenia jasminoides* Ellis (GJLE)	CuNPs	11.7 (RAFE) 3 (GJLE)	FTIR-ATR, XRD, FE-SEM/EDS, FE-TEM	*S. aureus*	(Nieto-Maldonado et al., 2022)
Madhuca longifolia	CuO	120 and 20	XRD, TEM, FTIR, UV-Vis	*E. coli*	(Das et al., 2018)
Banana pseudo stem	AgNPs	12,19±1,62	TEM, SEM, UV-Vis, FTIR, DLS	*S. aureus*	(Sathyanarayanan et al., 2024)

phology can be controlled, this method enables excellent control of nanofibers's shape and size, produces fibers with a more consistent and uniform structure. Example, Plant essential oil-based nanofibers were synthesized using an alumina template and showed effective antibacterial activity against pathogenic bacteria.

Coaxial electrospinning (Zhu et al., 2024; Qin et al., 2024; Li et al., 2022c; Lan et al., 2021) is a variation of traditional electrospinning, in which two polymer solutions with different properties are used to form skin-core fibers. This technique

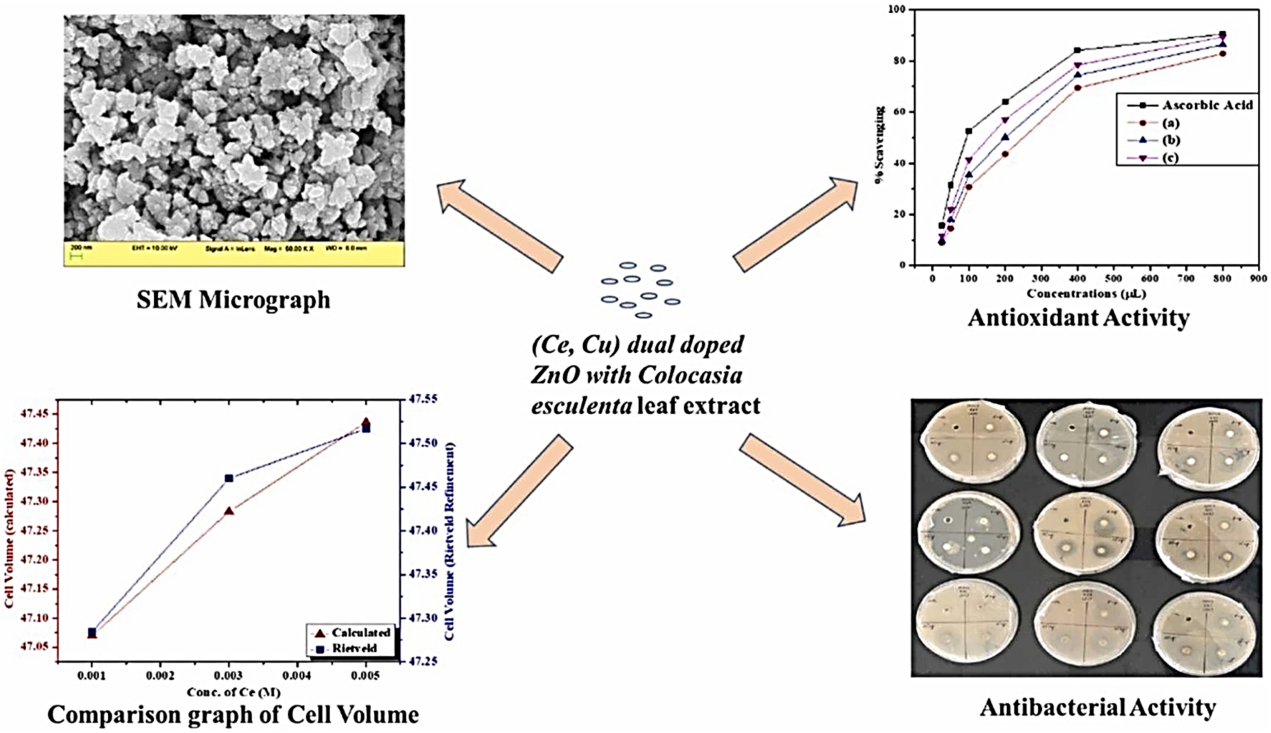


Figure 11. Green Synthesis of (Cu, Ce) Dual-Doped ZnO Nanoparticles with *Colocasia esculenta* Extract (Verma et al., 2024)

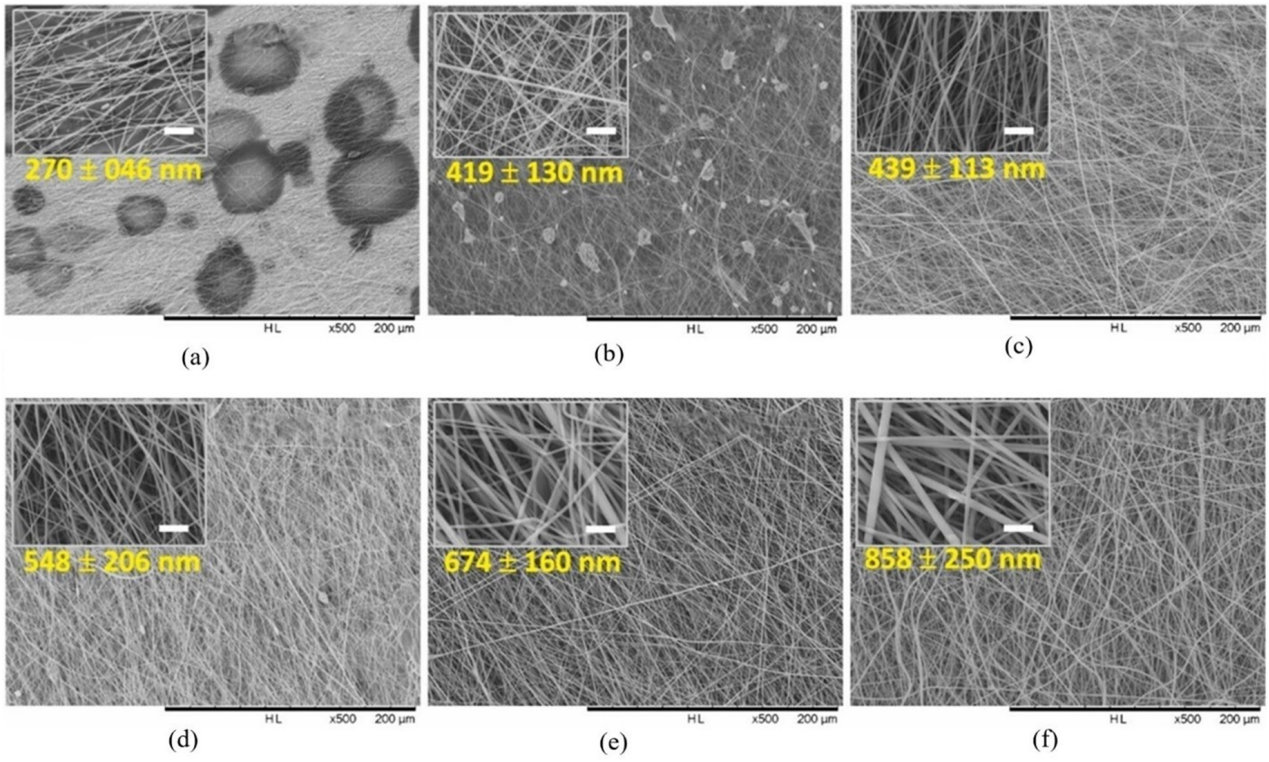


Figure 12. SEM Image of Chitosan/PEO Nanofiber's Diameter Using Variation Chitosan/PEO Composition: (a) 98/2; (b) 95/5; (c) 90/10; (d) 80/20; (e) 70/30; (f) 50/50 (Tien et al., 2022)

is particularly useful for producing nanofibers with controlled release of plant antibacterial compounds. Coaxial Electrospinning Stages consists of two different polymer solutions are used in a coaxial needle, where the core solution contains the plant antibacterial compound and the skin solution acts as a carrier matrix. With an electric field, core-skin fibers are formed where the antibacterial compound is trapped in the core, allowing controlled release and protection from the external environment. In this method, skin-core fibers provide better control over the release of active compounds than single fibers, nanofibers can protect medicinal plant compounds from environmental degradation (e.g. light, oxidation). Example, Core-shell fibers containing essential oil from rosemary plant in the core and polycaprolactone (PCL) as the skin layer showed slow release with effective antibacterial activity.

Electrospraying or spray drying (Lenzuni et al., 2024; Li et al., 2023; Dai et al., 2019; Buga et al., 2021) is a method to produce nano particles or fibers by using the technique of spraying a solution containing antibacterial plant compounds into an electric field. It is similar to electrospinning but produces particle structures more than continuous fibers. The stages of this method included solution spraying and fast drying. Solution spraying, a solution of polymers and plant compounds is sprayed through a nozzle at high voltage, producing nanoparticles that can be short fibers or spherical particles. Fast drying, the particles or fibers formed dry instantly as they reach the collector. Advantages of electrospraying: electrospraying can produce short fibers or particles, which can increase the bioavailability of plant compounds, electrospraying method is suitable for large scale production and allows customization for industrial applications. Example: Essential oil from oregano plant was synthesized into nano particles via electrospraying, which exhibited high antibacterial activity against Gram-positive bacteria.

3.8 Challenges and Opportunities

3.8.1 Challenges

The development of natural antibacterial sources presents significant challenges including the complexity of active ingredients contained in medicinal plants, the development of bacterial resistance, technology and regulation and standardization. The complexity of active ingredients is an obstacle in the development of natural antibacterials. Studies found that plants contain many bioactive compounds that are difficult to isolate and produce consistently on a large scale. Environmental variations can affect the content of active compounds in plants, making it difficult to maintain quality and efficacy standards. Obstacles in the development of natural antibacterial sources are limited sources and isolation of compounds takes a long time (Berida et al., 2024; Bucataru and Ciobanasu, 2024). One of the biggest challenges is the development of bacterial resistance to natural antibacterial agents. For example, bacteria can alter their membrane structure or use efflux pumps to remove antibacterial agents before they reach their target. Antimicrobial resistance, which continues to grow and become a global problem, is an obstacle in the development of new antibacterial sources (Bucataru and Ciobanasu, 2024). The complexity of these active ingredients requires innovative technologies for their processing to be more effective.

Developing appropriate formulations to enhance the bioavailability of antibacterial compounds from plants also requires advanced technologies. The use of nanoparticle biosynthesis technology and other innovative formulations are often required to improve effectiveness. Proper selection of antimicrobials requires knowledge of local and international guidelines, as well as considering patient conditions such as previous infections and exposures, microbiological epidemiology, toxicity risks, drug adjustments according to organ dysfunction (Giacobbe et al., 2024). Regulation and standardization are other obstacles in the development of natural antibacterials. Plant-based products face strict regulations that require strong scientific and clinical evidence regarding their safety and effectiveness. Regulation and standardization are other challenges in the development of natural antibacterials. Antibiotic development is often time-consuming and costly, involving expensive research, pre-clinical testing, clinical trials, and regulatory approval processes, all of which contribute to considerable time and cost (Bucataru and Ciobanasu, 2024).

3.8.2 Opportunities

Plants such as taro offer great potential as a new source of antibacterials. Research shows that phytochemical compounds such as alkaloids, flavonoids, and saponins in plants have significant antibacterial activity. Studies showed antibacterial activity of *C. esculenta* extracts against gram-positive and gram-negative bacteria, including pathogens like *Escherichia coli* (Al-Kaf et al., 2019; Verma et al., 2024), *Staphylococcus aureus* (Al-Kaf et al., 2019), *E. faecalis* (Gharib and Salman, 2023). The development of *C. esculenta* as an antibacterial source needs to be supported by modern technological innovations and further research, thus making this plant a solution to deal with antibacterial resistance and the need for sustainable antibacterials.

Modern technologies, such as bioactivity-guided fractionation, virtual screening, and molecular modeling, enable more efficient discovery and development of antibacterial compounds based on natural materials. The development of artificial intelligence-based technologies is an opportunity to facilitate the discovery and development of new antimicrobials, AI provides empirical datasets such as biological target information, chemical compounds, pharmacological activities, protein structures, clinical outcomes so that it can be an efficient solution to antimicrobial resistance (Bucataru and Ciobanasu, 2024). Opportunities to utilize the help of Machine Learning (ML) algorithms, to accelerate the collection, processing and summarization of relevant data from administrative electronic medical records and laboratory information systems (Giacobbe et al., 2024). Modern technology can also enable the combination of medicinal plant-based antibacterial sources with conventional antibiotics.

Plant-based antibacterials can be used in combination with conventional antibiotics to increase effectiveness and reduce

the risk of bacterial resistance. This combination has the potential to utilize synergistic mechanisms between plant compounds and antibiotics. Yao et al. (2023) designed a peptide antimicrobial drug delivery system to selectively remove peptide molecules so that they can accumulate rapidly at the target without affecting healthy cells, this innovation is a prospective solution to combat bacterial infections. Antibacterial resistance is a global problem, so the demand for antibacterial products based on natural ingredients continues to increase. This opens up great opportunities for the development of natural antibacterial products that can be widely accepted by consumers.

4. CONCLUSIONS

Taro or Caladium (*Colocasia esculenta*) shows great potential as an antibacterial agent based on various studies, especially as a safe and effective alternative to conventional antibiotics. Several bioactive components found in taro, such as flavonoids, saponins, and alkaloids, have been shown to have antibacterial activity against various pathogens. These compounds are able to inhibit bacterial growth by disrupting bacterial cell membrane integrity, inhibiting protein synthesis, and even affecting bacterial resistance mechanisms. Antibacterial modification of medicinal plants can be done by nanoparticle synthesis and antibacterial nanofiber synthesis, by green synthesis method, encapsulation of antibacterial nanoparticles, electrospinning, self-assembly, electrospraying. Challenges faced in the development of taro-based antibacterials include efficient isolation of active compounds and standardization of dosage and product effectiveness. Nevertheless, with the utilization of modern technologies such as nanoparticles, taro has great opportunities to be developed as a natural antibacterial solution in the future. Challenges related to standardization, research, regulation and technology need to be addressed through collaborative efforts between researchers, industry and government. Although challenges such as bacterial resistance and regulatory standards remain obstacles, taro still has promising potential as a natural antibacterial, especially if supported by continued research and technological innovation.

5. ACKNOWLEDGEMENT

Thank you to Universitas Sriwijaya, which is author's affiliate for providing services and facilities in writing this article.

REFERENCES

Aayush, K., G. P. Singh, I. Chiu, M. Joshi, K. Sharma, S. Gautam, P. Chavan, N. Jha, A. K. Singh, A. Babaei, S. Sharma, and T. Yang (2024). Development and Characterization of Sodium Alginate and β-Cyclodextrin Nanoemulsions Encapsulating Betel Leaf (*Piper betle* L.) Extract for Enhanced Antimicrobial Efficacy Against Foodborne Pathogen. *Food Chemistry*, **September**; 110984

Abdulrahman, M. F., A. S. Al-Rawi, L. L. Hamid, A. M. Aljumialy, W. M. Saod, and A. M. Al-Fahdawi (2024). Preparation of Polyvinyl Alcohol (PVA) Aerogel Microsphere Loaded with Biogenic Zinc Oxide Nanoparticles as Potential Antibacterial Drug. *Journal of Molecular Structure*, **1306**; 137901

Abubakar, A. R. and M. Haque (2020). Preparation of Medical Plants: Basic Extraction and Fractionation Procedures for Experimental Purposes. *Journal of Pharmacy and Bioallied Science*, **12**(1); 1–10

Aditika, B. Kapoor, S. Singh, and P. Kumar (2022). Taro (*Colocasia esculenta*): Zero Wastage Orphan Food Crop for Food and Nutritional Security. *South African Journal of Botany*, **145**; 157–169

Ahn, C. H., J. Shim, H. N. Jang, Y. A. Lee, S. W. Lee, M. H. Choi, and J. H. Kim (2023). Serum Steroid Profile Captures Metabolic Phenotypes in Adults with Classic Congenital Adrenal Hyperplasia. *Journal of Steroid Biochemistry and Molecular Biology*, **234**; 106374

Al-Kaf, A. G., A. M. T. Al-Deen, S. A. A. ALhaidari, and F. A. Al-Hadi (2019). Phytochemical Analysis and Antimicrobial Activity of *Colocasia esculenta* (Taro) Medicinal Plant Leaves Used in Folk Medicine for Treatment of Wounds and Burns in Hufash District Al Mahweet Governorate-Yemen. *Universal Journal of Pharmaceutical Research*, **4**(2); 29–33

Ambrosio, C. M. S., S. M. de Alencar, R. L. M. de Sousa, A. M. Moreno, and E. M. Da Gloria (2017). Antimicrobial Activity of Several Essential Oils on Pathogenic and Beneficial Bacteria. *Industrial Crops and Products*, **97**; 128–136

Amulya, P. R. and R. ul Islam (2023). Optimization of Enzyme-Assisted Extraction of Anthocyanins from Eggplant (*Solanum melongena* L.) Peel. *Food Chemistry: X*, **18**; 100643

Anderson, T., A. Haggerty, E. Silva, C. Mason, D. Bell, and K. S. Denholm (2024). Validation of the Diagnostic Accuracy of the 3M^{TM} Petrifilm^{TM} Coliform and Aerobic Count Plates to Measure Colostrum Bacterial Contamination on Scottish Dairy Farms. *Veterinary Journal*, **308**; 106230

Anwar, M., S. Mros, M. McConnell, and A. E. D. A. Bekhit (2021). Effects of Extraction Methods on the Digestibility, Cytotoxicity, Prebiotic Potential and Immunomodulatory Activity of Taro (*Colocasia esculenta*) Water-Soluble Non-Starch Polysaccharide. *Food Hydrocolloids*, **121**; 107068

Aryan, Ruby, and M. S. Mehata (2021). Green Synthesis of Silver Nanoparticles Using *Kalanchoe pinnata* Leaves (Life Plant) and Their Antibacterial and Photocatalytic Activities. *Chemical Physics Letters*, **778**; 138760

Ashtariyan, A., H. Mollania, N. Annabestani, N. Mollania, F. Malayjerdi, M. Dolatabadi, E. R. Ghomi, A. Khoshsima, and R. E. Neisiany (2024). Synergistic Effect of *Cydonia oblonga* and Its Extracted Silver Nanoparticles for Improving Antioxidant and Antibacterial Activity of 3D Printed Alginate-Based Hydrogel as Wound Dressing. *International Journal of Biological Macromolecules*, **276**; 133989

Assefa, E. T., G. Humi, K. Mohammed Gendo, G. Kenasa, and N. Roba (2024). Review on Green Synthesis, Characterization, and Antibacterial Activity of *CuO* Nanoparticles Using Biomolecules of Plant Extract. *Results in Chemistry*, **8**; 101606

Atri, A., M. Echabaane, A. Bouzidi, I. Harabi, B. M. Soucase, and R. Ben Chaâbane (2023). Green Synthesis of Copper Oxide Nanoparticles Using *Ephedra alata* Plant Extract and a Study of Their Antifungal, Antibacterial Activity and Photocatalytic Performance Under Sunlight. *Heliyon*, **9**(2); 1–16

Ayyanaar, S. and M. P. Kesavan (2023). One-Pot Biogenic Synthesis of Gold Nanoparticles@*Saponins* Niosomes: Sustainable Nanomedicine for Antibacterial, Anti-Inflammatory and Anticancer Therapeutics. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, **676**; 132229

Bai, J., Y. Xie, M. Li, X. Huang, Y. Guo, J. Sun, Y. Tang, X. Liu, C. Wei, J. Li, and Y. Yang (2024). Ultrasound-Assisted Extraction of Emodin from *Rheum officinale Baill* and Its Antibacterial Mechanism Against *Streptococcus Suis* Based on *CcpA*. *Ultrasonics Sonochemistry*, **102**; 106733

Baro, M. R., M. Das, A. Kalita, B. Das, and K. Sarma (2023). Exploring the Anti-Inflammatory Potential of *Colocasia esculenta* Root Extract in In-Vitro and In-Vivo Models of Inflammation. *Journal of Ethnopharmacology*, **303**; 116021

Beato, Z., L. N. Gitonga, E. O. Amonsou, and V. Reddy (2024). Nutritional Evaluation of *Colocasia esculenta (L.) Schott* Leaves and Corms from KwaZulu-Natal, South Africa. *Journal of Food Composition and Analysis*, **126**; 105831

Berida, T. I., Y. A. Adekunle, H. Dada-Adegbola, A. Kdimy, S. Roy, and S. D. Sarker (2024). Plant Antibacterials: The Challenges and Opportunities. *Heliyon*, **10**(10); e31145

Bitwell, C., S. S. Indra, C. Luke, and M. K. Kakoma (2023). A Review of Modern and Conventional Extraction Techniques and Their Applications for Extracting Phytochemicals from Plants. *Scientific African*, **19**; e01585

Boahemaa, L. V., B. Dzandu, J. G. N. Amissah, P. T. Akonor, and F. K. Saalia (2024). Physico-Chemical and Functional Characterization of Flour and Starch of *Taro* for Food Applications. *Food and Humanity*; 100245

Bucataru, C. and C. Ciobanasu (2024). Antimicrobial Peptides: Opportunities and Challenges in Overcoming Resistance. *Microbiological Research*, **286**; 127822

Buga, C., C. C. Chen, M. Hunyadi, A. Csík, C. Hegedűs, and S. J. Ding (2021). Electrosprayed Calcium Silicate Nanoparticle-Coated Titanium Implant with Improved Antibacterial Activity and Osteogenesis. *Colloids and Surfaces B: Biointerfaces*, **202**; 111699

Carvalho, M. T. B., H. G. Araújo-Filho, A. S. Barreto, L. J. Quintans-Júnior, J. S. S. Quintans, and R. S. S. Barreto (2021). Wound Healing Properties of Flavonoids: A Systematic Review Highlighting the Mechanisms of Action. *Phytomedicine*, **90**; 153636

Chakma, A., F. Afrin, M. G. Rasul, H. Maeda, C. Yuan, and A. K. M. A. Shah (2023). Effects of Extraction Techniques on Antioxidant and Antibacterial Activity of Stevia (*Stevia rebaudiana* Bertoni) Leaf Extracts. *Food Chemistry Advances*, **3**; 100494

Chand, N., S. Suthar, K. Kumar, and V. K. Tyagi (2021). Enhanced Removal of Nutrients and Coliforms from Domestic Wastewater in Cattle Dung Biochar-Packed *Colocasia esculenta*-Based Vertical Subsurface Flow Constructed Wetland. *Journal of Water Process Engineering*, **41**; 101994

Chen, K., H. Pan, D. Ji, Y. Li, H. Duan, and W. Pan (2021). Curcumin-Loaded Sandwich-Like Nanofibrous Membrane Prepared by Electrospinning Technology as Wound Dressing for Accelerate Wound Healing. *Materials Science and Engineering C*, **127**; 112245

Choopani, L., A. Mohammadi, H. A. M. Aliabadi, A. Kashtiaray, R. Eivazzadeh-Keihan, A. Maleki, and M. Mahdavi (2024). Functionalization of Zinc Ferrites Nanoparticles by Cyclic Aromatic Polyimide Chains as a Novel Star Polymer with Antibacterial Activity and Low Toxicity. *Journal of Industrial and Engineering Chemistry*, **137**; 243–251

Dai, F., J. Huang, W. Liao, D. Li, Y. Wu, J. Huang, Y. Long, M. Yuan, W. Xiang, F. Tao, Y. Cheng, and H. Deng (2019). Chitosan-TiO_2 Microparticles LBL Immobilized Nanofibrous Mats via Electrospraying for Antibacterial Applications. *International Journal of Biological Macromolecules*, **135**; 233–239

Das, P., S. Ghosh, R. Ghosh, S. Dam, and M. Baskey (2018). *Madhuca longifolia* Plant Mediated Green Synthesis of Cupric Oxide Nanoparticles: A Promising Environmentally Sustainable Material for Waste Water Treatment and Efficient Antibacterial Agent. *Journal of Photochemistry and Photobiology B: Biology*, **189**; 66–73

Dede, S., O. Sadak, M. Didin, and S. Gunasekaran (2022). Basil Oil-Loaded Electrospun Biofibers: Edible Food Packaging Material. *Journal of Food Engineering*, **319**; 110914

Ding, Q., Z. Mo, X. Wang, M. Chen, F. Zhou, Z. Liu, Y. Long, X. Xia, and P. Zhao (2024). The Antibacterial and Hemostatic Curdlan Hydrogel–Loading Epigallocatechin Gallate for Facilitating the Infected Wound Healing. *International Journal of Biological Macromolecules*, **266**; 133

Dong, S., X. Yang, L. Zhao, F. Zhang, Z. Hou, and P. Xue (2020). Antibacterial Activity and Mechanism of Action Saponins from *Chenopodium quinoa* Willd. Husks Against Foodborne Pathogenic Bacteria. *Industrial Crops & Products*, **149**; 112350

Dudoit, A., C. Mertz, M. Chillet, N. Cardinault, and P. Brat (2020). Antifungal Activity of Brazilian Red Propolis Extract and Isolation of Bioactive Fractions by Thin-Layer Chromatography-Bioautography. *Food Chemistry*, **327**; 127060

El-Baky, N. A., M. A. Elkhawaga, E. S. Abdelkhalek, M. M. Sharaf, E. M. Redwan, and H. R. Kholef (2021). De Novo Expression and Antibacterial Potential of Four Lactoferricin Peptides in Cell-Free Protein Synthesis System. *Biotechnology Reports*, **29**; e00583

Fahimirad, S., H. Abtahi, P. Satei, E. Ghaznavi-Rad, M. Moslehi, and A. Ganji (2021). Wound Healing Performance of PCL/Chitosan Based Electrospun Nanofiber Electrosprayed with Curcumin Loaded Chitosan Nanoparticles. *Carbohydrate Polymers*, **259**; 117640

Farnad, N. and K. Farhadi (2023). Introducing Potato Starch-

Ecofriendly Silver Nanoparticles as a Novel Binary System for Nanoencapsulation of Riboflavin. *Food Chemistry*, **398**; 133910

Feng, J., Y. Zheng, W. Ma, A. Ihsan, H. Hao, G. Cheng, and X. Wang (2023). Multitarget Antibacterial Drugs: An Effective Strategy to Combat Bacterial Resistance. *Pharmacology and Therapeutics*, **252**; 108550

Gerrano, A. S., I. Mathew, A. I. Shayanowako, S. Amoo, J. J. Mellem, W. J. Van Rensburg, M. W. Bairu, and S. L. Venter (2021). Variation in Mineral Element Composition of Landrace Taro (*Colocasia esculenta*) Corms Grown Under Dryland Farming System in South Africa. *Heliyon*, **7**(4); e06727

Gharib, D. S. H. and R. F. Salman (2023). Feasibility of the Crude Extracts of *Amorphophallus paeoniifolius* and *Colocasia esculenta* as Intracanal Medicaments in Endodontic Therapy in Comparison to the 940 nm Diode Laser: An In Vitro Antimicrobial Study. *Journal of Dental Sciences*, **18**(1); 145–156

Ghate, S. D., R. P. Shastry, and P. D. Rekha (2021). Rapid Detection of Oxalotrophic Endophytic Bacteria by Colony PCR from *Colocasia esculenta* and *Remusatia vivipara*. *Ecological Genetics and Genomics*, **21**; 100102

Giacobbe, D. R., C. Marelli, S. Guastavino, S. Mora, N. Rosso, A. Signori, C. Campi, M. Giacomini, and M. Bassetti (2024). Explainable and Interpretable Machine Learning for Antimicrobial Stewardship: Opportunities and Challenges. *Clinical Therapeutics*, **46**(6); 474–480

Gong, X., N. D. Jadhav, V. V. Lonikar, A. N. Kulkarni, H. Zhang, B. R. Sankapal, J. Ren, B. B. Xu, H. M. Pathan, Y. Ma, Z. Lin, E. Witherspoon, Z. Wang, and Z. Guo (2024). An Overview of Green Synthesized Silver Nanoparticles Towards Bioactive Antibacterial, Antimicrobial and Antifungal Applications. *Advances in Colloid and Interface Science*, **323**(November 2023); 103053

Górniak, I., R. Bartoszewski, and J. Króliczewski (2019). Comprehensive Review of Antimicrobial Activities of Plant Flavonoids. *Phytochemistry Reviews*, **18**(1)

Haider, A., S. Haider, and I. K. Kang (2018). A Comprehensive Review Summarizing the Effect of Electrospinning Parameters and Potential Applications of Nanofibers in Biomedical and Biotechnology. *Arabian Journal of Chemistry*, **11**(8); 1165–1188

Hernández-Nolasco, Z., M. A. Ríos-Corripio, J. V. Hidalgo-Contreras, P. H. Castellano, E. Rubio-Rosas, and A. S. Hernández-Cázares (2024). Optimization of Sodium Alginate, Taro Starch and Lactic Acid Based Biodegradable Films: Antimicrobial Effect on a Meat Product. *LWT*, **192**; 115718

Hilaire, V., G. Michel, A. Majoor, F. Hadji-Minaglou, A. Landreau, and X. Fernandez (2022). New Method for Screening Anti-*Leishmania* Compounds in Plant Extracts by HPTLC-Bioautography. *Journal of Chromatography B: Analytical Technologies in the Biomedical and Life Sciences*, **1188**(November 2021); 123061

Hilal, B., M. M. Khan, and Q. Fariduddin (2024). Recent Advancements in Deciphering the Therapeutic Properties of Plant Secondary Metabolites: Phenolics, Terpenes, and Alkaloids. *Plant Physiology and Biochemistry*, **211**; 108674

Huang, B., Q. Hu, G. Zhang, J. Zou, P. Fei, and Z. Wang (2024). Exploring the Emulsification Potential of Chitosan Modified with Phenolic Acids: Emulsifying Properties, Functional Activities, and Application in Curcumin Encapsulation. *International Journal of Biological Macromolecules*, **263**(P2); 130450

Ijaz, I., A. Bukhari, E. Gilani, A. Nazir, H. Zain, R. Saeed, S. Hussain, T. Hussain, A. Bukhari, Y. Naseer, and R. Aftab (2022). Green Synthesis of Silver Nanoparticles Using Different Plant Parts and Biological Organisms, Characterization and Antibacterial Activity. *Environmental Nanotechnology, Monitoring and Management*, **18**(June 2021); 100704

Inamuddin and S. Kanchi (2020). One-Pot Biosynthesis of Silver Nanoparticle Using *Colocasia esculenta* Extract: Colorimetric Detection of Melamine in Biological Samples. *Journal of Photochemistry & Photobiology A: Chemistry*, **391**(October 2019); 112310

Islam, M., A. Javed, Z. U. Rahman, Y. O. Al-Ghamdi, and S. A. Khan (2024). Antibacterial Composite Films of Oxidized Alginate-Chitosan-ZnO Anchored Cu Nanoparticles for the Degradation of Organic Pollutants. *International Journal of Biological Macromolecules*, **278**(P2); 134764

Jannesari, M., F. Ejehi, N. J. English, R. Mohammadpour, O. Akhavan, and S. Shams (2024). Triggering Triboelectric Nanogenerator Antibacterial Activities: Effect of Charge Polarity and Host Material Correlation. *Chemical Engineering Journal*, **486**(November 2023); 150036

Jiang, X., Q. Wang, J. Yang, B. Du, Z. Yuan, H. Liu, J. Yuan, Y. Zhang, L. Chen, and L. Liu (2024a). Deep Integration of Metabolome and Transcriptome Characterizes Alkaloid Metabolism in *Houttuynia cordata*. *Genomics*, **116**(5); 110881

Jiang, X., Y. Yu, S. Ma, L. Li, M. Yu, M. Han, Z. Yuan, and J. Zhang (2024b). Chitosan Nanoparticles Loaded with *Eucommia ulmoides* Seed Essential Oil: Preparation, Characterization, Antioxidant and Antibacterial Properties. *International Journal of Biological Macromolecules*, **257**(P2); 128820

Jinoni, D. A., M. A. Z. Benjamin, A. A. Mus, L. P. W. Goh, N. A. Rusdi, and M. A. Awang (2024). *Phaleria macrocarpa* (Scheff.) Boerl. (Mahkota Dewa) Seed Essential Oils: Extraction Yield, Volatile Components, Antibacterial, and Antioxidant Activities Based on Different Solvents Using Soxhlet Extraction. *Kuwait Journal of Science*, **51**(2); 100173

Jolly, A., H. Kim, J. Moon, A. Mohan, and Y. Lee (2023). Exploring the Imminent Trends of Saponins in Personal Care Product Development: A Review. *Industrial Crops & Products*, **205**(July); 117489

Kaith, B. S., A. Singh, and D. Sud (2022). A New Horizon for Structural Modifications and Comprehensive Applications of *Colocasia esculenta* (L.) Schott. *Materials Today: Proceedings*, **53**; 269–272

Karan, T., Z. Gonulalan, R. Erenler, U. Kolemen, and O. Em-

inagaoglu (2024). Green Synthesis of Silver Nanoparticles Using *Sambucus ebulus* Leaves Extract: Characterization, Quantitative Analysis of Bioactive Molecules, Antioxidant and Antibacterial Activities. *Journal of Molecular Structure*, **1296**(P1); 136836

Kumar, A., K. Gupta, M. A. I. Apu, G. S. Abrol, and V. Tomer (2023). Effect of Household Processing on Nutritional and Antinutritional Composition, Mineral-Mineral Ratios, and Functional Properties of *Colocasia* Leaves. *Heliyon*, **9**(6); e17137

Kumar, D., S. Kumar, S. Kumar, S. Rohatgi, and P. P. Kundu (2021). Synthesis of Rifaximin Loaded Chitosan-Alginate Core-Shell Nanoparticles (Rif@CS/Alg−NPs) for Antibacterial Applications. *International Journal of Biological Macromolecules*, **183**; 962–971

Kustiati, U., H. Wihadmadyatami, and D. L. Kusindarta (2022). Dataset of Phytochemical and Secondary Metabolite Profiling of *Holy Basil* Leaf (*Ocimum sanctum* Linn) Ethanolic Extract Using Spectrophotometry, Thin Layer Chromatography, Fourier Transform Infrared Spectroscopy, and Nuclear Magnetic Resonance. *Data in Brief*, **40**; 10774

Lad, S. S. and S. U. Kolhe (2023). Evaluation of Antihyperlipidemic Potential of Aqueous Corm Extract of *Colocasia esculenta* in Experimental Model of Rats. *Pharmacological Research - Modern Chinese Medicine*, **9**(August); 100307

Lakshmi Pravallika, P., G. Krishna Mohan, K. Venkateswara Rao, and K. Shanker (2019). Biosynthesis, Characterization and Acute Oral Toxicity Studies of Synthesized Iron Oxide Nanoparticles Using Ethanolic Extract of *Centella asiatica* Plant. *Materials Letters*, **236**; 256–259

Lan, X., Y. Liu, Y. Wang, F. Tian, X. Miao, H. Wang, and Y. Tang (2021). Coaxial Electrospun PVA/PCL Nanofibers with Dual Release of Tea Polyphenols and ε-Poly (*L*-lysine) as Antioxidant and Antibacterial Wound Dressing Materials. *International Journal of Pharmaceutics*, **601**(January); 120525

Lasrichan, S., A. E. M. Janssen, and R. Boom (2024). Contribution of Sequential Pretreatments and Enzyme-Assisted Extraction to Rice Bran Protein Yield Improvement. *Journal of Cereal Science*; 141634

Lazou, T. P. and S. C. Chaintoutis (2023). Comparison of Disk Diffusion and Broth Microdilution Methods for Antimicrobial Susceptibility Testing of *Campylobacter* Isolates of Meat Origin. *Journal of Microbiological Methods*, **204**(November 2022); 106649

Le, L. T., H. T. Nguyen, H. T. T. Bui, H. Q. Tran, and T. T. T. Nguyen (2024). Drug Release System Based on a Composite Polycaprolactone Nanofiber Membrane with Dual Functionality of Shape Memory Effect and Antibacterial Ability. *RSC Advances*, **14**(37); 26884–26895

Legerská, B., D. Chmelová, and M. Ondrejovič (2020). TLC-Bioautography as a Fast and Cheap Screening Method for the Detection of α-Chymotrypsin Inhibitors in Crude Plant Extracts. *Journal of Biotechnology*, **313**(February); 11–17

Lenzuni, M., F. Fiorentini, M. Summa, R. Bertorelli, G. Suarato, G. Perotto, and A. Athanassiou (2024). Electrosprayed Zein Nanoparticles as Antibacterial and Anti-Thrombotic Coatings for Ureteral Stents. *International Journal of Biological Macromolecules*, **257**(P2); 128560

Li, A. P., Y. H. He, S. Y. Zhang, and Y. P. Shi (2022a). Antibacterial Activity and Action Mechanism of Flavonoids Against Phytopathogenic Bacteria. *Pesticide Biochemistry and Physiology*, **188**(August); 105221

Li, P., Y. Feng, D. Cheng, and J. Wei (2022b). Self-Template Synthesis of Mesoporous Vanadium Oxide Nanospheres with Intrinsic Peroxidase-Like Activity and High Antibacterial Performance. *Journal of Colloid and Interface Science*, **625**; 435–445

Li, X., X. Niu, Y. Chen, K. Yuan, W. He, S. Yang, T. Tang, and D. G. Yu (2023). Electrospraying Micro-Nano Structures on Chitosan Composite Coatings for Enhanced Antibacterial Effect. *Progress in Organic Coatings*, **174**(September 2022); 107310

Li, Y., D. Wang, E. Yan, J. Gao, Y. Wang, S. Li, Y. Wang, L. Fan, S. Chen, and D. Zhang (2022c). Biodegradable and Biocompatible Xylan/Polycaprolactone Core–Shell Nanofibers via Coaxial Electrospinning for Antibacterial Applications. *Materials Letters*, **316**(March); 132049

Linima, V. K., R. Ragunathan, and J. Johney (2024). Biofabrication of *Centella asiatica* Mediated Metal (Silver and Iron) Nanoparticles and Their Enhanced Antimicrobial, Anticancer Activity in Retinoblastoma Y79 Cancer Cells. *Nano-Structures and Nano-Objects*, **39**(March); 101226

Liu, Y., Z. Shen, Y. Xu, Y. W. Zhu, W. Chen, and J. Qiu (2024). Layer-by-Layer Self-Assembly of PLL/CPP-ACP Multilayer on SLA Titanium Surface: Enhancing Osseointegration and Antibacterial Activity in Vitro and in Vivo. *Colloids and Surfaces B: Biointerfaces*, **240**(December 2023); 113966

Lokhande, K. B., A. Kale, B. Shahakar, A. Shrivastava, N. Nawani, K. V. Swamy, A. Singh, and S. V. Pawar (2023). Terpenoid Phytocompounds from Mangrove Plant *Xylocarpus moluccensis* as Possible Inhibitors Against SARS-CoV-2: In Silico Strategy. *Computational Biology and Chemistry*, **106**(May); 107912

Ma, E., Y. An, G. Zhang, M. Zhao, M. W. Iqbal, H. M. Zabed, and X. Qi (2023). Enhancing the Antibacterial Activity of *Lactobacillus reuteri* Against *Escherichia coli* by Random Mutagenesis and Delineating Its Mechanism. *Food Bioscience*, **51**(October 2022); 102209

Ma, M., M. Gu, S. Zhang, and Y. Yuan (2024). Effect of Tea Polyphenols on Chitosan Packaging for Food Preservation: Physicochemical Properties, Bioactivity, and Nutrition. *International Journal of Biological Macromolecules*, **259**(P2); 129267

Maduray, K., R. Moodley, S. Ramdhani, and R. Parboosing (2022). The Anti-HIV Activity of Biogenic Silver Nanoparticles Synthesized from *Centella asiatica* Extracts. *Journal of Herbal Medicine*, **35**(May 2021); 100592

Mehmood, T., M. Iqbal, and R. Hassan (2020). Prediction of

Antibacterial Activity in Ionic Liquids Through FTIR Spectroscopy with Selection of Wavenumber by PLS. *Chemometrics and Intelligent Laboratory Systems*, **206**(July); 104124

Miao, J., P. Duriseti, Y. Radhakrishnan, L. Vaughan, F. C. Fervenza, and L. Zand (2023). Mycophenolate Mofetil and Steroid for Treatment of Patients with IgA Nephropathy. *Kidney International Reports*, **October**; 1–9

Mirza, S., A. A. Hussaini, G. Öztürk, M. Turgut, T. Öztürk, O. Tugay, D. Ulukuş, and M. Yıldırım (2023). Photocatalytic and Antibacterial Activities of ZnO Nanoparticles Synthesized from *Lupinus albus* and *Lupinus pilosus* Plant Extracts via Green Synthesis Approach. *Inorganic Chemistry Communications*, **155**(June)

Mitharwal, S., A. Kumar, K. Chauhan, and N. K. Taneja (2022). Nutritional, Phytochemical Composition and Potential Health Benefits of Taro (*Colocasia esculenta L.*) Leaves: A Review. *Food Chemistry*, **383**(April 2021); 132406

Murali, V. S., V. N. M. Devi, P. Parvathy, and M. Murugan (2021). Phytochemical Screening, FTIR Spectral Analysis, Antioxidant and Antibacterial Activity of Leaf Extract of *Pimenta dioica Linn. Materials Today: Proceedings*, **45**; 2166–2170

Nieto-Maldonado, A., S. Bustos-Guadarrama, H. Espinoza-Gomez, Z. Flores-López, K. Ramirez-Acosta, G. Alonso-Nuñez, and R. D. Cadena-Nava (2022). Green Synthesis of Copper Nanoparticles Using Different Plant Extracts and Their Antibacterial Activity. *Journal of Environmental Chemical Engineering*, **10**(2)

Oriyomi, V. O., O. F. Fagbohun, F. T. Akinola, M. B. Adekola, and T. T. Oyedeji (2023). Assessment of *Colocasia esculenta* Leaf Extract as a Natural Alternative for *Sitophilus zeamais* Control: Toxicological, Biochemical, and Mechanistic Insights. *Pesticide Biochemistry and Physiology*, **195**(June); 105545

Oriyomi, V. O., O. F. Fagbohun, T. T. Oyedeji, and F. K. Agboola (2022). Biotoxicity of *Colocasia esculenta* [Linn.]: Involvement of *Colocasia esculenta* Leaf in Preservation of Staple from *Sitophilus zeamais* [Motschulsky] Attack. *Industrial Crops and Products*, **182**(April); 114897

Palladini, G., C. Garbarino, A. Luppi, S. Russo, A. Filippi, N. Arrigoni, E. Massella, and M. Ricchi (2023). Comparison Between Broth Microdilution and Agar Disk Diffusion Methods for Antimicrobial Susceptibility Testing of Bovine Mastitis Pathogens. *Journal of Microbiological Methods*, **212**(July); 106796

Peng, G., J. Hu, J. Guo, J. Dong, Y. Zhao, T. Ye, F. Xiao, Z. Meng, H. Gan, R. Gu, P. Han, W. Sun, G. Dou, Y. Sun, and S. Liu (2024). Injectable Exosome-Loaded Quaternized Chitosan/Oxidized Sodium Alginate Hydrogel with Self-Healing, Bioadhesive, and Antibacterial Properties for Treating Combined Radiation-Wound Injury. *Chemical Engineering Journal*, **494**(February); 152933

Pereira, P. R., J. T. Silva, M. A. Verícimo, V. M. F. Paschoalin, and G. A. P. B. Teixeira (2015). Crude Extract from Taro (*Colocasia esculenta*) as a Natural Source of Bioactive Proteins Able to Stimulate Haematopoietic Cells in Two Murine Models. *Journal of Functional Foods*, **18**; 333–343

Pires, J. B., L. M. Fonseca, T. J. Siebeneichler, R. L. Crizel, F. N. d. Santos, H. C. d. S. Hackbart, D. H. Kringel, A. D. Meinhart, E. d. R. Zavareze, and A. R. G. Dias (2022). Curcumin Encapsulation in Capsules and Fibers of Potato Starch by Electrospraying and Electrospinning: Thermal Resistance and Antioxidant Activity. *Food Research International*, **162**(August); 112111

Pradhan, S. P., S. Swain, N. Sa, S. N. Pilla, A. Behera, P. K. Sahu, and S. Chandra Si (2022). Photocatalysis of Environmental Organic Pollutants and Antioxidant Activity of Flavonoid Conjugated Gold Nanoparticles. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, **282**(July); 121699

Qian, K., C. Wang, M. Yang, X. Zou, Y. Zhang, Q. Dong, X. Wang, Y. Shao, Z. Cheng, J. Ju, C. Chu, Q. Chen, F. Xue, and J. Bai (2024). Self-Assembly Zn-Containing Layer on PEO-Coated Mg with Enhanced Corrosion Resistance, Antibacterial Activity, and Osteogenic Property. *Corrosion Science*, **226**(September 2023); 111674

Qin, Z., W. Fang, Q. Jiang, J. Li, and H. Zhang (2024). The Urchin-Like Gold Nanoparticles/Poly(ε−caprolactone)/Chitosan Electrospun Nanofibers for Antibacterial Active Packaging. *International Journal of Biological Macromolecules*, **274**(P1); 133287

Qin, Z., S. Wang, L. Wang, J. Yao, G. Zhu, B. Guo, J. Militky, M. Venkataraman, and M. Zhang (2022). Nanofibrous Membranes with Antibacterial and Thermoregulatory Functions Fabricated by Coaxial Electrospinning. *Journal of Industrial and Engineering Chemistry*, **113**; 373–379

Ragab, H. M., N. S. Diab, S. T. Obeidat, A. M. Alghamdi, A. M. Khaled, M. O. Farea, and M. A. Morsi (2024). Improving the Optical, Thermal, Mechanical, Electrical Properties and Antibacterial Activity of PVA-Chitosan by Biosynthesized Ag Nanoparticles: Eco-Friendly Nanocomposites for Food Packaging Applications. *International Journal of Biological Macromolecules*, **264**(P2); 130668

Rao, W., J. Wu, Z. Fang, Z. Chen, J. Wu, and X. Fang (2024). Antibacterial Mechanism of Metabolites of *Lactobacillus plantarum* against *Pseudomonas lundensis* and Their Application in Dry-Aged Beef Preservation. *Food Chemistry*, **460**(P1); 140463

Revathi, S., S. Sutikno, A. F. Hasan, A. B. Altemimi, Q. H. ALKaisy, A. J. Phillips, M. A. Hesarinejad, and T. G. Abedelmaksoud (2024). Green Synthesis and Characterization of Silver Nanoparticles (AgNP) Using *Acacia nilotica* Plant Extract and Their Anti-Bacterial Activity. *Food Chemistry Advances*, **4**(December 2023); 100680

Rolta, R., A. Sharma, A. Sourirajan, P. K. Mallikarjunan, and K. Dev (2021). Combination Between Antibacterial and Antifungal Antibiotics with Phytocompounds of *Artemisia annua* L: A Strategy to Control Drug Resistance Pathogens. *Journal of Ethnopharmacology*, **266**(September 2020); 113420

Russo, S., M. Muscetta, P. Amato, V. Venezia, M. Verrillo, R. Rega, S. Lettieri, M. Cocca, R. Marotta, and G. Vitiello (2024). Humic Substance/Metal−oxide Multifunctional Nanoparticles as Advanced Antibacterial-Antimycotic Agents and Photocatalysts for the Degradation of PLA Microplastics under UVA/Solar Radiation. *Chemosphere*, **346**(October 2023); 140605

Saini, R. and P. Kumar (2023). Green Synthesis of TiO_2 Nanoparticles Using *Tinospora cordifolia* Plant Extract & Its Potential Application for Photocatalysis and Antibacterial Activity. *Inorganic Chemistry Communications*, **156**(November 2022); 111221

Sajid, A., M. Amjad, Q. Manzoor, S. Wazir, A. Sajid, N. Alwadai, M. Iqbal, and N. Tamam (2024). Synthesis of Bimetallic Oxides (SrO-CoO) Nanoparticles Decorated Polyacrylamide Hydrogels for Controlled Drug Release and Wound Healing Applications. *International Journal of Biological Macromolecules*, **274**(P1); 133194

Salako, O. A., A. J. Akindele, O. M. Shitta, O. O. Elegunde, and O. O. Adeyemi (2015). Antidiarrhoeal Activity of Aqueous Leaf Extract of *Caladium bicolor* (*Araceae*) and Its Possible Mechanisms of Action. *Journal of Ethnopharmacology*, **176**; 225–231

Sathyanarayanan, H., M. Vaiyapuri, R. Kumar, and M. Gnanadesigan (2024). Standardization of Silver Nanoparticle Synthesis: Photocatalytic Application (Immobilized with Chitosan Complex) with Textile Dyes and Antibacterial Activity Against *Staphylococcus aureus* Using Banana Pseudo Stem. *Chemosphere*, **364**(September); 143246

Sehgal, R., A. K. Sharma, B. J. Singh, R. V. Saini, A. K. Saini, and V. Beniwal (2024). Augmenting the Antioxidant, Anti-Bacterial and Anti-Carcinogenic Potential of *Terminalia chebula* and *Terminalia bellirica* after Tannin Acyl Hydrolase Mediated Biotransformation. *Biocatalysis and Agricultural Biotechnology*, **56**(January); 103045

Sequin, C. J., S. C. Appelhans, M. S. Heis, W. A. Torrent, J. A. Trossero, C. A. N. Catalan, D. A. Sampietro, and P. G. Acenolaza (2023). Antifungal and Toxicology Evaluation of the Alkaloids Fraction from *Neltuma nigra* Leaves. *Biocatalysis and Agricultural Biotechnology*, **October**; 102914

Seyfi, J., M. Panahi-Sarmad, A. OraeiGhodousi, V. Goodarzi, H. A. Khonakdar, A. Asefnejad, and S. Shojaei (2019). Antibacterial Superhydrophobic Polyvinyl Chloride Surfaces via the Improved Phase Separation Process Using Silver Phosphate Nanoparticles. *Colloids and Surfaces B: Biointerfaces*, **183**(August); 110438

Shahzadi, L., A. Ramzan, A. Anjum, F. Jabbar, A. F. Khan, F. Manzoor, S. A. Shahzad, A. A. Chaudhry, I. u. Rehman, and M. Yar (2022). An Efficient New Method for Electrospinning Chitosan and Heparin for the Preparation of Pro-Angiogenic Nanofibrous Membranes for Wound Healing Applications. *Journal of Applied Polymer Science*, **139**(48); 1–14

Shamsudin, N. F., Q. U. Ahmed, S. Mahmood, S. A. A. Shah, A. Khatib, S. Mukhtar, M. A. Alsharif, H. Parveen, and Z. A. Zakaria (2022). Antibacterial Effects of Flavonoids and Their Structure-Activity Relationship Study: A Comparative Interpretation. *Molecules*, **27**(4); 2–43

Shankar, S., L. F. Wang, and J. W. Rhim (2018). Incorporation of Zinc Oxide Nanoparticles Improved the Mechanical, Water Vapor Barrier, UV-Light Barrier, and Antibacterial Properties of PLA-Based Nanocomposite Films. *Materials Science and Engineering C*, **93**(October 2017); 289–298

Shazhni, J. R. A., A. Renu, and P. Vijayaraghavan (2018). Insights of Antidiabetic, Anti-Inflammatory and Hepatoprotective Properties of Antimicrobial Secondary Metabolites of Corm Extract from *Caladium x hortulanum*. *Saudi Journal of Biological Sciences*, **25**(8); 1755–1761

Shehata, M. G., N. M. Abd El-Aziz, T. Mehany, and J. Simal-Gandara (2023). Taro Leaves Extract and Probiotic Lactic Acid Bacteria: A Synergistic Approach to Improve Antioxidant Capacity and Bioaccessibility in Fermented Milk Beverages. *LWT*, **187**(August); 115280

Shende, A. P. and R. Chidambaram (2023). Cocoyam Powder Extracted from *Colocasia antiquorum* as a Novel Plant-Based Bioflocculant for Industrial Wastewater Treatment: Flocculation Performance and Mechanism. *Heliyon*, **9**(4); e15228

Siddique, M. A. B., M. Imran, A. Haider, A. Shahzadi, A. Ul-Hamid, W. Nabgan, M. Batool, K. Khan, M. Ikram, H. H. Somaily, and A. Mahmood (2024). Enhancing Catalytic and Antibacterial Activity with Size-Controlled Yttrium and Graphene Quantum Dots Doped MgO Nanostructures: A Molecular Docking Analysis. *Materials Today Sustainability*, **25**(January); 100690

Singhal, M., L. Loveleen, R. Manchanda, A. Syed, A. H. Bahkali, L. S. Wong, S. Nimesh, and N. Gupta (2024). Design, Synthesis and Optimization of Silver Nanoparticles Using *Azadirachta indica* Bark Extract and Its Antibacterial Application. *Journal of Agriculture and Food Research*, **16**(March); 101088

Somerton, B. T. and B. L. Morgan (2024). Comparison of Plate Counting with Flow Cytometry, Using Four Different Fluorescent Dye Techniques, for the Enumeration of *Bacillus cereus* in Milk. *Journal of Microbiological Methods*, **223**(June); 106978

Subha, T., M. Srilatha, P. Naveen, and R. Thirumalaisamy (2024). Green Synthesis, Characterization and Optimization of Silver Nanoparticles from *Carica papaya* Using Box Behnken Design and Its Activity Against Dental Caries Causing *Streptococcus* sp. *Chemical Data Collections*, **51**(March); 101139

Suksaeree, J., T. Wunnakup, L. Charoenchai, and C. Monton (2024). Antibacterial Film-Forming Spray Containing *Caesalpinia sappan* L. Extract Obtained Through Eco-Friendly Microwave-Assisted Extraction. *Journal of Drug Delivery Science and Technology*, **92**(December 2023); 105317

Tang, W., Z. Zhang, D. Nie, S. Liu, Y. Li, M. Liu, Y. Zhang, N. Ou, and Y. Li (2023). Selective Antibacterial Activity of *Citrus Medica limonum* Essential Oil Against *Escherichia coli* K99 and *Lactobacillus acidophilus* and Its Antibacterial

Mechanism. *Lwt*, **186**(July); 115215
Tantala, J., K. Thumanu, and C. Rachtanapun (2019). An Assessment of Antibacterial Mode of Action of Chitosan on *Listeria innocua* Cells Using Real-Time HATR-FTIR Spectroscopy. *International Journal of Biological Macromolecules*, **135**; 386–393
Thankaswamy, A. and C. S. Belarmin Xavier (2021). Investigation on the Effect of *Colocasia esculenta* Extract on the Fresh Properties of Cement Paste. *Materials Today: Proceedings*, **45**; 4712–4718
Tien, N. D., T. Geng, C. A. Heyward, J. E. Reseland, S. P. Lyngstadaas, J. J. Blaker, and H. J. Haugen (2022). Solution Blow Spinning of Highly Deacetylated Chitosan Nanofiber Scaffolds for Dermal Wound Healing. *Biomaterials Advances*, **137**(May); 212871
Tuzimski, T. and A. Petruczynik (2023). New Trends in the Practical Use of Isoquinoline Alkaloids as Potential Drugs Applied in Infectious and Non-Infectious Diseases. *Biomedicine and Pharmacotherapy*, **168**(October); 115704
Verma, N., D. Pathak, and N. Thakur (2024). Eco-Friendly Green Synthesis of (Cu, Ce) Dual-Doped ZnO Nanoparticles with *Colocasia esculenta* Plant Extract Using Microwave Assisted Technique for Antioxidant and Antibacterial Activity. *Next Materials*, *5*(May); 100271
Wahba, R. H., A. Z. El-Sonbati, M. A. Diab, E. A. Gomaa, and E. M. AbouElleef (2024). Electrochemical Sensing of Strontium Ions Cyclic Voltammetry and Investigation of *Rosemary* Extract's Effects on Their Behavior: Antibacterial Properties of *Rosemary* Extract and Molecular Docking Analysis for Potential COVID-19 Therapeutic Benefits. *Microchemical Journal*, **200**(March); 110398
Wang, C., J. Pan, H. Xu, Q. Chen, S. Zhou, L. Tang, L. Qiu, and P. Jiang (2024a). Facilely Prepared Ferric-Curcumin Complex Nanoparticles Exert Improved Stability and Photothermal Enhanced Antibacterial Effects for Food Preservation. *Lwt*, **205**(July); 116418
Wang, D., B. Wang, X. Jin, Y. Peng, J. Zhao, M. Zhang, Y. Wei, Z. Long, and Q. Chen (2024b). Microwave-Enzyme-Assisted Extraction of Pectin from *Feijoa* (*Acca sellowiana*) Fruit: Extraction Optimization, Physicochemical and Functional Properties. *Lwt*, **204**(July); 116445
Wang, Y., J. Ren, M. Ou, J. Piao, R. Lian, J. Cui, H. Guan, C. Jiao, and X. Chen (2024c). Construction of Composite Self-Assembly Coating Based on *Chitosan* for Enhancing the Flame-Retardant and Antibacterial Performances of Cotton Fabric. *International Journal of Biological Macromolecules*, **275**(P2); 133355
Wei, M. p., H. Yu, Y. h. Guo, Y. l. Cheng, Y. f. Xie, and W. r. Yao (2021). Antibacterial Activity of *Sapindus* Saponins Against Microorganisms Related to Food Hygiene and the Synergistic Action Mode of *Sapindoside A* and *B* Against *Micrococcus luteus* In Vitro. *Food Control*, **130**(June); 108337
Wong, S. X. E., S. F. Kiew, S. Y. Lau, and P. W. Pottas (2023). Procedures to Investigate Potential of Plants as Natural Food Preservatives: Extraction Technology, Phytochemical Characterisation, and Antimicrobial Bioassays. *Food Chemistry Advances*, **3**(January); 100435
Wulandari, W. P., Y. Ji, O. Erol, and Y. H. Choi (2023). Identification of Variety-Specific Metabolites of *Basil* by High Performance Thin Layer Chromatography-Assisted Metabolic Profiling Techniques. *Journal of Chromatography A*, **1710**(September); 464425
Yan, J., S. He, L. Chen, H. Chen, and W. Wang (2023). Characterization, Antioxidant and Antibacterial Activities of Gelatin-*Chitosan* Edible Coated Films Added with *Cyclocarya paliurus* Flavonoids. *Biological Macromolecules*; 127664
Yang, Y., C. Peng, D. Zeng, Z. Yang, X. Wang, S. Zhang, Y. Bai, L. Kuang, L. Guo, Y. Qin, H. Xiong, J. Wan, C. Yin, T. Ai, Q. Rui, H. Liu, S. Peng, and J. Liu (2024). Electrospinning is a Potential Way for Preparing Edible Plant Protein-Based Nanofibers with Porous Surface Using *Safflower* Seed Meal. *Food Hydrocolloids*, **146**(PA); 109201
Yao, L., Q. Liu, Z. Lei, and T. Sun (2023). Development and Challenges of Antimicrobial Peptide Delivery Strategies in Bacterial Therapy: A Review. *International Journal of Biological Macromolecules*, **253**(P3); 126819
Yavari Maroufi, L., M. Ghorbani, M. Mohammadi, and A. Pezeshki (2021). Improvement of the Physico-Mechanical Properties of Antibacterial Electrospun Poly Lactic Acid Nanofibers by Incorporation of *Guar Gum* and *Thyme* Essential Oil. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, **622**(March); 126659
Yazdani Nyaki, H., N. O. Mahmoodi, and H. Taherpour Nahzomi (2024). Investigation of Solvatochromic, Optical, Organic Field Effect Transistor (OFET), Antibacterial, and Molecular Bonding of Some *Azothiazolidine-2,4-dione* (AZOTZD) Dyes. *Journal of Photochemistry and Photobiology A: Chemistry*, **450**(January); 115476
Zengin, G., A. Cvetanović, U. Gašić, A. Stupar, G. Bulut, I. Şenkardes, A. Dogan, K. Ibrahime Sinan, S. Uysal, Z. Aumeeruddy-Elalfi, A. Aktumsek, and M. Fawzi Mahomoodally (2020). Modern and Traditional Extraction Techniques Affect Chemical Composition and Bioactivity of *Tanacetum parthenium* (L.) Sch.Bip. *Industrial Crops and Products*, **146**(October 2019); 112202
Zhang, J., Z. Fu, Q. Zhu, S. Zhou, L. Xia, C. Zhang, X. Liu, and W. Xu (2024a). Highly Stable, Antibacterial and Antiviral Composites Films via Improved Non-Solvent Induced Phase Separation for Textile Application. *Chemical Engineering Journal*, **492**(February); 151824
Zhang, Y., D. Guo, X. Shen, Z. Tang, and B. Lin (2024b). Recoverable and Degradable Carboxymethyl *Chitosan* Polyelectrolyte Hydrogel Film for Ultra Stable Encapsulation of *Curcumin*. *International Journal of Biological Macromolecules*, **268**(P1); 131616
Zhang, Z., D. He, X. Wang, X. Ma, Y. Zheng, X. Gu, and Y. Li (2024c). In Vitro and In Vivo Evaluation of Osteogenesis and Antibacterial Activity of *Mg-Ga* Alloys. *Acta Biomaterialia*, **185**; 85–97
Zhao, D., Y. Ma, W. Wang, and Q. Xiang (2023). Antibac-

terial Activity and Mechanism of *Cinnamon* Essential Oil Nanoemulsion Against *Pseudomonas deceptionensis* CM2. *Heliyon*, **9**(9); e19582

Zheng, H., Y. Chen, J. Yang, P. Hao, L. Ren, and H. Zhou (2023). Bicomponent Hydrogels Assisted Templating Synthesis of Hierarchically Porous *ZIF-8* for Efficient Antibacterial Applications. *Journal of Molecular Structure*, **1277**; 134824

Zhou, M., B. Zhang, T. Wang, P. Xiao, L. Cheng, and R. Tang (2024). Synergistic Antibacterial Effect of Quaternary Ammonium Salt Functionalized Metal-Organic Framework. *Materials Advances*, **5**(17); 7035–7039

Zhu, Z., M. Yu, R. Ren, H. Wang, and B. Kong (2024). Thymol Incorporation within *Chitosan*/Polyethylene Oxide Nanofibers by Concurrent Coaxial Electrospinning and In-Situ Crosslinking from Core-Out for Active Antibacterial Packaging. *Carbohydrate Polymers*, **323**(September 2023); 121381

Zhuang, D., R. Li, M. Zhang, S. Wang, H. N. Ahmad, and J. Zhu (2024). Photodynamic-Responsive Gelatin-Based Coating with High Utilization *Curcumin* Loaded Bilayer Nanoencapsulation: A Promising Environmental Food Packaging. *International Journal of Biological Macromolecules*, **256**(P2); 128476

Zilani, M. N. H., M. A. Islam, P. Biswas, M. Anisuzzman, H. Hossain, J. A. Shilpi, M. N. Hasan, and M. G. Hossain (2021). Metabolite Profiling, Anti-Inflammatory, Analgesic Potentials of Edible Herb *Colocasia gigantea* and Molecular Docking Study Against COX-II Enzyme. *Journal of Ethnopharmacology*, **281**(April); 114577

