



Antimicrobial Activity and Phytochemical Analysis of Solvent Extraction of *Citrus Limon* Peels

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ABSTRACT

Lemons make up the bulk of citrus fruits, and they're frequently employed in the juice business. These enterprises generate a lot of garbage because these peels contain a wide range of bioactive components, they may be used to create a variety of value-added products that help to reduce pollution. This study aims to determine the antibacterial activity and phytochemical analyses of *Citrus limon* peels extracted with a solvent. The antibacterial activity of *Citrus limon* peels was tested against Gram-positive bacteria like *Staphylococcus aureus* and *Enterococcus faecalis*, as well as Gram-negative like *Salmonella typhi*, utilizing different solvents including acetone, ethanol, ethyl acetate, and petroleum ether. To determine whether specific bio-reactive chemicals are present or absent in solvent extraction, a phytochemical analysis was performed. Antimicrobial tests such as agar well diffusion assay, the minimum inhibitory concentration (MIC), and the minimum bacterial concentration were performed, and the results revealed that the ethanol extract of *Citrus limon* peel was more effective than peel extracts prepared with other solvents. Essentially digesting chemical and organic waste, enzyme bio cleaner is a type of natural cleaning product that includes certain numbers and types of bacteria, as well as enzymes and microbial nutrients. The primary objective of the research is to create a natural cleaning agent from citrus fruit utilizing lemon.

Keywords: Solvent extraction, Fermentation, Minimum bactericidal concentration (MBC), Minimum inhibitory concentration (MIC), Phytochemicals

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INTRODUCTION

Lemons make up the bulk of citrus fruits, and they're frequently employed in the juice business. It is one of the most significant commercial fruits cultivated on all continents with a global output of 102.64 million tons (Patsalou *et al.*, 2017). These enterprises generate a lot of garbage, which mostly consists of lemon peels. Because these peels contain a wide range of bioactive components, they may be used to create value-added products that help to reduce pollution. Peels contribute the most to this waste with 50-60% (Jimenez *et al.*, 2020).

Citrus peels are high in flavonoids, flavones glycosides, phenols, essential oils, and organic acids which are uncommon in other plants, according to studies (Kenedi *et al.*, 2021; Mitsagga *et al.*, 2021). These chemicals are not only crucial for human health and the environment, but they also have a wide range of economic uses in the food and pharmaceutical sectors (Harfouch *et al.*, 2019; Kryukova *et al.*, 2021). Other active terpenes as well as aldehydes, esters, and alcohols contribute to the overall antimicrobial effects of the essential oils

(Samarakoon *et al.*, 2012). Citrus fruit has been used in traditional Asian medicine for thousands of years to treat gastrointestinal, bronchial, and asthmatic illnesses (Rafiq *et al.*, 2018; Bottalico *et al.*, 2020).

The most important fruits in the Citrus genus are lemon (*Citrus limonium*), lime (*Citrus aurantifolia*), grapefruit (*Citrus vitis*), tangerine or mandarin (*Citrus reticulata*) and sweet orange (*Citrus sinensis*) (Samarakoon *et al.*, 2012). Flavedo or epicarp (colored peripheral surface) and albedo or mesocarp (white soft inner layer) are the two types of citrus peels (Muliarta & Darmawan, 2021). This research aimed to concentrate on minimizing the waste in the fruit juice manufacturing business. The combined efforts of waste reduction throughout the manufacturing process and product recovery significantly lower the waste and improve the environmental profile of the juice processing business. By analyzing the 3 chemical contents and calculating the yield percentage of crude phytochemicals, the study analyses the antimicrobial activity and fundamental scientific foundation for the usage of citrus peels (Henderson *et al.*, 2018).

fruit solutions are an example of a natural cleaning product. Natural cleaning solutions are less expensive and damaging to the environment. Cleaning supplies are frequently utilized in daily life, whether it be for household chores, laundry, or other industrial uses. Since many of these products contain

substances made of petrochemicals, most conventional cleaning solutions employ chemicals that are relatively harmful to human health and the environment. Garbage enzymes are an organic substance made by simply fermenting fresh vegetable and fruit wastes with water, brown sugar, and specialized yeast and bacteria (Satari & Karimi, 2018).

MATERIALS AND METHODS

Materials

Acetone, Ethanol, Ethyl acetate, Petroleum ether
 Nutrient agar: Peptone - 5.00g/L; Sodium chloride - 5.00g/L;
 Meat extract - 1.50g/L; Yeast extract - 1.50g/L; Agar - 15.00g/L; pH (at 25°C) - 7.4±0.2
 Nutrient broth: Peptone - 5.00g/L; Sodium chloride - 5.00g/L;
 Meat extract - 1.50g/L; Yeast extract - 1.50g/L; pH (at 25°C) - 7.4±0.2

Microorganism selection

Extractions of *Staphylococcus aureus*; *Salmonella typhi* and *Enterococcus faecalis* were used for antibacterial testing as Gram-positive and Gram-negative bacteria, respectively. The pure cultures of *Staphylococcus aureus*; *Salmonella typhi* and *Enterococcus faecalis* are taken from the master plate and then subcultures into nutrient broth by inoculation technique. Overnight cultures of bacteria were prepared on nutrient broth.

Microbiological media and agar plate preparation

28 grams of nutrient agar was liquefied in one liter of distilled water. A small amount of agar-agar was added to it. The mixture was stirred to dissolve all the components. The mixture was autoclaved for 15 mins at 15 lbs pressure. The nutrient agar was cooled after autoclaving. Once the media is cooled, it is poured onto the Petri plates and allowed to solidify.

Collection of plant extracts

The peel of the plant used in the is *Citrus limon* (common name: Lemon). The peels were obtained from local juice shops. The peels were washed with distilled water to remove dust. They were then shade dried at a temperature of 32-35°C for 5 days. The dried peels were ground and made to powder. The powder was stored in a closed container.

Preparation of extracts

25 grams of dried and powdered orange peel was extracted using 100 ml of each solvent (acetone, ethanol, ethyl acetate, and petroleum ether). In a conical flask, the peel powder and solvents were placed and thoroughly mixed using a shaking machine for 48 hrs. at 150 rpm (except Petroleum ether- 24 hrs). The extracts were then filtered using the Whatman filter paper. The filtrate obtained was then dried using the open-dish evaporation method and the dried extract obtained was placed in small vials and stored in the refrigerator at 4 °C (El-Desoukey et al., 2018).

Estimation of percentage yield

The given formula was used to calculate the percentage yield of the extract that was obtained using different solvents (Giwa et al., 2018).

Percentage yield (%)

$$= \frac{\text{Weight of the extract recovered}}{\text{Weight of dry powder}} \times 100 \quad (1)$$

Antimicrobial activity/assay

Agar well diffusion assay

The extracts agar well diffusion assay was conducted to determine the antimicrobial assay. Two Gram-positive bacteria (*Staphylococcus aureus* and *Enterococcus faecalis*) and one Gram-negative bacterium (*Salmonella typhi*) were used to test for antimicrobial activity. Petri plates used for this assay were autoclaved and all the steps were carried inside the laminar airflow chamber. Nutrient agar was used as a nutrient medium for assay. Bacteria was poured and spread on the solidified nutrient agar and wells of 6 mm diameter were punched on the agar. 100 µL of 100 mg/ml of test samples were transferred to the labeled wells. The test samples were allowed to diffuse through the media and the plates were incubated in the upright position for 24 hrs at 37 °C. 1 mg/ml of ciprofloxacin was used as positive control and 25% Dimethyl sulfoxide (DMSO) was used as a negative control. The diameter of the zone of inhibition around the wells was measured to evaluate the antimicrobial assay.

Determination of minimum inhibitory concentration (MIC)

The final extraction concentration with no apparent microbial growth is known as minimum inhibitory concentration (MIC) (Guo et al., 2018). A sterile 96-well microtiter plate was labeled. To all the wells, a nutrient broth of 100 µL was added. Serial dilutions of 6.25 mg/ml, 12.5 mg/ml, 25 mg/ml, and 50 mg/ml of test samples were prepared with a micropipette. 100 µL of the test sample was added to each well in ascending order and tips were discarded after each use. Finally, 25 µL of each bacterial suspension was added to every well. The plate was wrapped loosely with parafilm to avoid contamination and dehydration of bacteria. Added positive control with vegetative broth and test organisms and negative control with the nutrient broth was added. The plate was then kept in the incubator for 24 hrs at 37 °C. After 24 hrs the microtiter plate was read using a microtiter plate reader and the MIC of the extract is recorded.

Determination of minimum bactericidal concentration (MBC)

MBC was determined by taking a loopful of broth from the wells with no evident signs of bacterial growth. The broth was streaked onto the sterile nutrient agar plates by streaking. The plates were then incubated for 24 hrs at 37 °C. The concentration in which no visible growth of bacteria was seen was taken as the minimum bactericidal concentration.

Phytochemical analysis (Qualitative analysis)

• Test for alkaloids

2 ml of filtrate was mixed with 2 ml of distilled water and a continuous shaker. The presence of alkaloids was indicated by the formation of a 1 cm layer of foam.

• Test for amino acids

A few drops of Ninhydrin reagent were added to 2 ml of filtrate. The presence of amino acids was indicated by the appearance of purple color.

- *Test for flavonoids*

2 ml of 2N sodium hydroxide was mixed with 2 ml of filtrate. The presence of flavonoids was indicated by the appearance of yellow color.

- *Test for steroids*

2 ml of filtrate was mixed with an equal volume of chloroform and a few drops of conc. Sulfuric acid. The presence of steroids is indicated by the formation of a brown ring.

- *Test for tannins*

2 ml of filtrate was mixed with a few drops of 0.1% ferric chloride. The presence of tannins was indicated by the formation of blue-black or brownish-green coloration.

RESULTS AND DISCUSSION

The solvent extract of the lemon peel using various solvents produced different outcomes in each of the tests conducted in this study. The percentage yield of the recovered extract was significantly varied when different solvents were used. The percentage yield of extracts obtained from various solvents is shown in **Figure 1**. The greatest percentage yield was ethanol (5.4 %), followed by acetone extract (4.3 %) and ethyl acetate extract (2.3 %) petroleum ether (1.4 %). The petroleum ether extract had the lowest percentage yield (1.4%). The variation in yield between various solvents explains the solubility of distinct plant components in various solvents. Studies conducted by Eldesukoy *et al.*, (2018) showed that the percentage yield of ethanol extract from *Citrus limon* peels was greater than that of other citrus fruits such as *Citrus limetta*, *Citrus aurantifolia*, *Citrus reticulata*, and *Citrus maxima*.

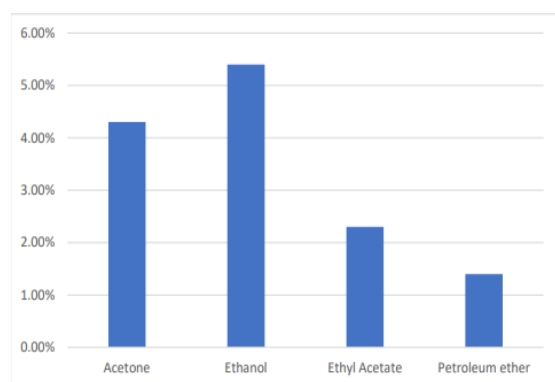


Figure 1. The percentage yield of *Citrus limon* peel extract

The color of the extract was brownish orange. Citrus peel extracts show considerable antibacterial activity against all of the species tested (**Table 1**). Because of its high yield and antibacterial action, ethyl acetate is a good solvent for extracting antibacterial compounds. Because of the enhanced production, a higher antibacterial agent is linked to a higher concentration of certain phytochemicals. *Citrus limon* ethyl acetate extract had the maximum zone of inhibition (16mm) against *S. aureus* and *S. typhi* (10mm), followed by *S. aureus* (13mm). Petroleum ether and ethanol both have antimicrobial properties. Petroleum ether has reduced antibacterial activity when compared to other solvents. This reveals that the solvents can extract antibiotic chemicals that are potentially dangerous to bacterial strains. As a result, different extracts

may contain different antibacterial agents with different modes of action, or bacteria may develop a specialized metabolism to resist or adapt to their activity (Giwa *et al.*, 2018). When compared to extracts from other solvents, ethanol extract contains more phytochemicals (alkaloids, tannins, flavonoids, steroids), which may have boosted bacterial activity. The antibacterial effects seen in this investigation might be attributable to the phytochemical group's synergistic action (Guo *et al.*, 2018).

Table 1. Zone of inhibition of Citrus limon peel extract for various bacterial strains (Well concentration = 100mg/ml).

Bacteria	Zone of Inhibition			
	Acetone	Ethanol	Ethyl acetate	Petroleum ether
<i>E. faecalis</i>	-	14	13	13
<i>S. aureus</i>	13	15	16	12
<i>S. typhi</i>	9	9	10	-

The zone of inhibition obtained for ethanol, acetone, and ethyl acetate extract of *Citrus limon* peel against *S. aureus* bacteria is 9mm, 10mm, and 7mm respectively (Mubarak *et al.*, 2020). In comparison to earlier research, the test organisms and solvents utilized in this investigation showed the following inhibitory zone: *E. faecalis* (acetone extract 0mm, ethanol extract 14mm, ethyl acetate extract 13mm, petroleum ether extract 13mm); *S. typhi* (acetone extract 9mm, ethanol extract 9mm, ethyl acetate extract 10mm, petroleum ether extract 0mm); *S. aureus* (ethanol 21 15mm, acetone 13mm, ethyl acetate, 16 mm, and petroleum ether against bacteria are 12mm). Ciprofloxacin, the positive control had a larger inhibitory zone.

When compared to Gram-positive bacteria, Gram-negative bacteria were less susceptible to the solvent extraction of the peels. The insensitivity of diverse test organisms to the investigated solvent extracts was attributed to variations in the content and structure of Gram-positive and Gram-negative bacteria's cell walls (Shakya *et al.*, 2019). Gram-negative bacteria are less susceptible to antibacterial agents because they have an outer membrane that inhibits hydrophobic chemicals from diffusing through the lipopolysaccharide coating (Kumar *et al.*, 2011). The antibacterial activity of extracts obtained using several solvents indicated that not all phytochemicals with antimicrobial activity are miscible in one solvent (Oikeh *et al.*, 2020).

The MIC and MBC of several solvent extracts of *Citrus limon* are shown in (**Tables 2 and 3**). The extracts were shown to have significant antibacterial activity. The broth dilution technique was used to perform MIC. The broth approach, which is carried out in microtiter trays, has the advantage of requiring less effort for a larger number of duplicates and allowing for the use of very small amounts of test material and growth media. The MIC and MBC data also reveal that ethyl acetate extracts are more effective than extracts from other solvents. The following are the MIC values for different solvent extracts against various bacteria: *S. aureus* (acetone extract- 13 mg/ml, ethanol extract- 15 mg/ml, ethyl acetate extract- 16 mg/ml, petroleum ether extract- 12mg/ml); *S. typhi* (acetone extract- 9 mg/ml, ethanol extract- 9 mg/ml, ethyl acetate extract- 10 mg/ml, petroleum ether extract- 0mg/ml); *E. faecalis* (acetone

extract- 0 mg/ml, ethanol extract- 14mg/ml, ethyl acetate extract- 13 mg/ml, petroleum ether extract- 13mg/ml).MBC values if various solvent extract against different bacteria is as follows: *E. faecalis* (acetone extract- 50mg/ml, ethanol extract- 50mg/ml, ethyl acetate extract100mg/ml, petroleum ether extract- 0mg/ml); *S. aureus* (acetone extract- 50mg/ml, ethanol extract- 75mg/ml, ethyl acetate- 1mg/ml, petroleum ether extract- 0mg/ml); *S. typhi* ((acetone extract- 1mg/ml, ethanol extract- 75mg/ml, ethyl acetate extract- 50mg/ml, petroleum ether extract- 0mg/ml). Less activity at low extract concentrations might imply that the active ingredient concentrations in the extracts are insufficient to have any antibacterial action (Abdella et al., 2019). To battle infections caused by *E. faecalis*, *S. typhi*, and *S. aureus*, ethyl acetate extract of the peel may be chosen over-extract from other solvents (Teneva et al., 2019).

Table 2. MIC value of *Citrus limon* peel extract for various bacterial strains

Bacteria	Extract of Citrus limon peel (mg/ml)			
	Acetone	Ethanol	Ethyl acetate	Petroleum ether
<i>E. faecalis</i>	-	14	13	13
<i>S. aureus</i>	13	15	16	12
<i>S. typhi</i>	9	9	10	-

*Well concentration at 100mg/ml

Table 3. MBC values of *Citrus limon* peel extract for various bacterial strains

Bacteria	Extract of Citrus limon peel (mg/ml)			
	Acetone	Ethanol	Ethyl acetate	Petroleum ether
<i>E. faecalis</i>	50	50	100	-
<i>S. aureus</i>	50	75	1	-
<i>S. typhi</i>	1	75	50	-

A phytochemical study revealed the presence of numerous components in lemon peels. The presence of different phytochemicals such as tannins, saponins, essential oils, flavonoids, and 22 phenolic compounds in lemon peel is connected to its antibacterial effect (Hsouna et al., 2017; Gorski et al., 2022). The phytochemical analysis findings are shown in (Table 4). Extracts from various solvents included phytochemicals of diverse types. All extracts included significant amounts of alkaloids, steroids, flavonoids, amino acids, and tannins (Musa & Hafiz, 2019). All solvents were able to dissolve alkaloids, steroids, flavonoids, amino acids, and tannins in this study. In the extracts of several solvents, amino acids were absent (Egbonu & Osuji, 2016).

Table 4. Phytochemical analysis (qualitative analysis) of *Citrus limon* peel extracts

Phytochemicals	Solvents			
	Acetone	Ethanol	Ethyl acetate	Petroleum ether
Alkaloids	+	+	+	+
Amino acids	-	-	-	-
Flavonoids	+	+	+	-
Steroids	+	-	-	+

Tannins	+	+	+	+
- indicates the absence of phytochemical; + indicates the presence of phytochemical				

The polarity of the chemical and the solvent might explain the presence and absence of distinct components in the extracts. Tannins, steroids, flavonoids, and alkaloids are secondary active metabolites found in plants that contribute to lemon peel's antibacterial activity (Rehab et al., 2018; Nawaz et al., 2020). *Citrus limon* peel contains flavonoids and tannins, indicating that the peel has antioxidant effects. Tannins are also said to have antibacterial properties (Mostafa & Essaway, 2021).

CONCLUSION

Fruit waste recycling is one of the most important strategies for repurposing it in several innovative ways, resulting in new products and meeting crucial demands in human, animal, and plant nutrition, as well as the pharmaceutical industry. *Citrus limon* peel extracts made with various solvents were tested for antibacterial activity and phytochemical content against test organisms. Although the kind and number of active components in each extract are not immediately apparent, they are encouraging; nonetheless, further research with pure compounds is required before a firm judgment can be made about the bioactive molecules that contribute to antimicrobial activity. However, further research is needed to understand how the bioactive component confers antimicrobial properties to the orange peel extract and how these extracts might be used to treat pathogenic bacteria like *S. typhi*. Four different fermentation samples namely T1, T2, T3, and T4 were prepared. Results obtained from PH and sugar analysis showed that T2 and T4 were more effective bio cleaners.

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REFERENCES

- Abdalla, M. H., Gabra, F. A., Danial, A. W., Abdel-Wahab, A. M. (2019). Enhancement of biohydrogen production from sustainable orange peel wastes using *Enterobacter* species isolated from domestic wastewater. *International Journal of Energy Resources*, 43(1), 391-404. doi:10.1002/er.4273
- Ben Hsouna, A., Ben Halima, N., Smaoui, S., & Hamdi, N. (2017). Citrus lemon essential oil: Chemical composition, antioxidant and antimicrobial activities with its preservative effect against *Listeria monocytogenes* inoculated in minced beef meat. *Lipids in Health and Disease*, 16(1), 1-11. doi:10.1186/s12944-017-0487-5

- Bottalico, L., Castellaneta, F., & Charitos, I. A. (2020). From hydrotherapy to the discovery of the gut microbiota: the historical gastrointestinal health concept. *Pharmacophore*, 11(2), 82-90.
- Egbuonu, A. C. C., & Osuji, C. A. (2016). Proximate compositions and antibacterial activity of Citrus sinensis (sweet orange) peel and seed extracts. *European Journal of Medicinal Plants*, 12(3), 1-7. doi:10.9734/EJMP/2016/24122
- El-Desoukey, R. M., Saleh, A. S. B., & Alhowamil, H. F. (2018). The phytochemical and antimicrobial effect of Citrus sinensis (Orange) peel powder extracts on some animal pathogens as eco-friendly. *EC Microbiology*, 14(6), 312-318.
- Giwa, S. O., Muhammad, M., & Giwa, A. (2018). Utilizing orange peels for essential oil production. *Journal of Engineering and Applied Sciences*, 13(1), 17-27.
- Górski, M., Niedźwiadek, J., & Magryś, A. (2022). Antibacterial activity of curcumin—a natural phenylpropanoid dimer from the rhizomes of Curcuma longa L. and its synergy with antibiotics. *Annals of Agricultural and Environmental Medicine*, 29(3), 394-400. doi:10.26444/aaem/148393
- Guo, J. J., Gao, Z. P., Xia, J. L., Ritenour, M. A., Li, G. Y., & Shan, Y. (2018). Comparative analysis of chemical composition, antimicrobial and antioxidant activity of citrus essential oils from the main cultivated varieties in China. *LWT - Food Science and Technology*, 97, 825-839. doi:10.1016/j.lwt.2018.07.060
- Harfouch, R. M., Janoudi, H., Muhammad, W., Hammami, A., & Chouman, F. (2019). In Vitro Antibacterial Activity of Citrus limon Peel Extracts against Several Bacterial Strains. *Journal of Chemical and Pharmaceutical Research*, 11(7), 48-51. doi:10.13140/RG.2.2.20224.15361
- Henderson, A. H., Fachrial, E., & Lister, I. N. E. (2018). Antimicrobial activity of lemon (Citrus limon) peel extract against Escherichia coli. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)*, 39(1), 268-273. https://asrjetsjournal.org/index.php/American_Scientific_Journal/article/view/3805
- Jiménez-Castro, M. P., Buller, L. S., Sganzerla, W. G., & Forster-Carneiro, T. (2020). Bioenergy production from orange industrial waste: a case study. *Biofuels, Bioproducts and Biorefining*, 14(6), 1239-1253. doi:10.1002/bbb.2128
- Kanedi, M., Busman, H., Sutyarso, S., Farisi, S., & Mumtazah, D. F. (2021). Essential oil extracted from plant tuber of nutgrass "Cyperus rotundus" effectively decreased sperm quality of mice. *Journal of Advanced Pharmacy Education & Research*, 11(2), 66-70.
- Kryukova, E. M., Khetagurova, V. S., Ilyin, V. A., Chizhikova, V. V., & Kosoplechev, A. V. (2021). Forming students' environmental culture: modern educational approaches and technologies. *Journal of Advanced Pharmacy Education & Research*, 11(2), 113-118.
- Kumar, K. A., Narayani, M., Subanthini, A., & Jayakumar, M. (2011). Antimicrobial activity and phytochemical analysis of citrus fruit peels-utilization of fruit waste. *International Journal of Engineering Science and Technology*, 3(6), 5414-5421.
- Mitsagga, C., Petrotos, K., & Giavasis, I. (2021). Antimicrobial Properties of Lyophilized Extracts of Olive Fruit, Pomegranate and Orange Peel Extracts against Foodborne Pathogenic and Spoilage Bacteria and Fungi In Vitro and in Food Matrices. *Molecules*, 26(22), 7038. doi:10.3390%2Fmolecules26227038
- Mostafa, R. M., & Essawy, H. S. (2021). Screening and Quantification of Bioactive Compounds and Antimicrobial Activities of Fresh Juice, Methanolic Peel and Pulp Extract of Citrus sinensis L.(Sweet Orange). *Egyptian Academic Journal of Biological Sciences, G. Microbiology*, 13(2), 1-10. doi:10.21608/eajbsg.2021.189671
- Mubarok, I., Shiella, A., Putri, N., Ayu, C., Kirana, C., Ririanty, M. (2020). Orange peel and java sugar as an alternative to natural disinfectant in COVID-19 prevention efforts in the tobacco farming area, coastal area, Jember. In *International Conference on Agromedicine and Tropical Diseases*, 3(1), 10-15. doi:10.19184/icatd.v3i1.24081
- Muliarta, I. N., & Darmawan, I. K. (2021). Processing Household Organic Waste into Eco-Enzyme as an Effort to Realize Zero Waste. *Agriwar Journal*, 1(1), 6-11. doi:10.22225/aj.1.1.2021.6-11
- Musa, D. D., Sangodele, F., & Hafiz, S. S. (2019). Phytochemical analysis and antibacterial activity of orange (Citrus sinensis) peel. *FUDMA Journal of Sciences*, 3(1), 375-380. <https://fjs.fudutsinma.edu.ng/index.php/fjs/article/view/1467>
- Nawaz, H., Shad, M. A., Rehman, N., Andaleeb, H., & Ullah, N. (2020). Effect of solvent polarity on extraction yield and antioxidant properties of phytochemicals from bean (Phaseolus vulgaris) seeds. *Brazilian Journal of Pharmaceutical Sciences*, 56, e17129. doi:10.1590/s2175-97902019000417129
- Oikeh, E. I., Oviasogie, F. E., & Omoregie, E. S. (2020). Quantitative phytochemical analysis and antimicrobial activities of fresh and dry ethanol extracts of Citrus sinensis (L.) Osbeck (sweet Orange) peels. *Clinical Phytoscience*, 6(1), 1-6. doi:10.1186/s40816-020-00193-w
- Patsalou, M., Menikea, K. K., Makri, E., Vasquez, M. I., Drouza, C., & Koutinas, M. (2017). Development of a citrus peel-based biorefinery strategy for the production of succinic acid. *Journal of Cleaner Production*, 166, 706-716. doi:10.1016/j.jclepro.2017.08.039
- Rafiq, S., Kaul, R., Sofi, S. A., Bashir, N., Nazir, F., & Nayik, G. A. (2018). Citrus peel as a source of functional ingredient: A review. *Journal of the Saudi Society of Agricultural Sciences*, 17(4), 351-358. doi:10.1016/j.jssas.2016.07.006
- Rehab, M. A. E., Sowair, S. A., & Ahlam, A. A. (2018). The phytochemical and antimicrobial effect of Mallus domestica (apple) dried peel powder extracts on some animal pathogens as eco-friendly. *International Journal of Veterinary Science*, 7(2), 88-92. <http://www.ijvets.com/pdf-files/Volume-7-no-2-2018/88-92.pdf>
- Samarakoon, K., Senevirathne, M., Lee, W. W., Kim, Y. T., Kim, J. I., Oh, M. C., & Jeon, Y. J. (2012). Antibacterial effect of

- citrus press-cakes dried by high speed and far-infrared radiation drying methods. *Nutrition Research and Practice*, 6(3), 187-194. doi:10.4162%2Fnrp.2012.6.3.187
- Satari, B., & Karimi, K. (2018). Citrus processing wastes: Environmental impacts, recent advances, and future perspectives in total valorization. *Resources, Conservation and Recycling*, 129, 153-167. doi:10.1016/j.resconrec.2017.10.032
- Shakya, A., Luitel, B., Kumari, P., Devkota, R., Dahal, P. R., & Chaudhary, R. (2019). Comparative study of antibacterial activity of juice and peel extract of citrus fruits. *Tribhuvan University Journal of Microbiology*, 6, 82-88. doi:10.3126/tujm.v6i0.26589
- Teneva, D., Denkova-Kostova, R., Goranov, B., Hristova-Ivanova, Y., Slavchev, A., Denkova, Z., & Kostov, G. (2019). Chemical composition, antioxidant activity and antimicrobial activity of essential oil from Citrus aurantium L zest against some pathogenic microorganisms. *Zeitschrift für Naturforschung C*, 74(5-6), 105-111. doi:10.1515/znc-2018-0062