P- ISSN 1991-8941 E-ISSN 2706-6703 Journal of University of Anbar for Pure Science (JUAPS) Open Access
2024,(18), (02):130 – 138

Green Chemistry of Lemon Peels, Extracting Components for Sustainability: A Review

Zeyad Fadhil[1], Huda Ghazi Naser[2], Amer Adnan Hasan[2], Rasha Saad Jwad[3], Sohad A. Alshareef[4], Srikanth Kommanaboyina[5], Mohammed H. Al-Mashhadani[6*]

[1]College of Pharmacy, University of Thi-Qar, Dhi Qar, Iraq
[2]Department of Applied Pathological Analysis, College of Science, Al-Nahrain University, P. O. Box: 64021, Baghdad, Iraq
[3]Department of Medical Physics, College of Science, Al-Nahrain University, P. O. Box: 64021, Baghdad, Iraq
[4]Department of Chemistry, Faculty of Science, University of Tabuk, Tabuk 71491, Saudi Arabia
[5]Sai Life Sciences, Unit‐ II, Plot No. DS‐ 7, ICICI Knowledge Park, Turkaplly Village, Hyderabad, Telangana 500078, India
[6*]Department of Chemistry, College of Science, Al-Nahrain University, P. O. Box: 64021, Baghdad, Iraq

ARTICLE INFO

Received: 29 / 03 /2024
Accepted: 30/ 06 /2024
Available online: 26/ 12 /2024

10.37652/juaps.2024.148332.1226

Keywords:
Sustainable chemistry, recycling strategies, limonene, cellulose, lignin, bio-based materials, eco-friendly products.

ABSTRACT

This work investigated the unrealized promise of the environmentally friendly and sustainable chemistry of lemon peels. Lemon peel's chemical makeup, which includes limonene, citric acid, flavonoids, cellulose, and lignin, provides a wide range of chemicals with uses in many sectors. Extraction methods are based on the principles of green chemistry, which ensures environmental and economic safety. Numerous separation techniques, including fractional distillation, highlight the selectivity needed to isolate certain substances. The study will also address the practical use of lemon peel chemistry through recycling, which includes biological transformation and chemical transformation, in addition to its use in treatment, food, packaging, and other fields. Opportunities for innovation, collective action, recycling economy projects, and legislative assistance can help overcome challenges including waste volume and economic feasibility. Recycling lemon peel components is an excellent sustainable way to obtain environmentally friendly biomaterials. This integration helps promote a more renewable and sustainable way of consuming natural resources. In addition to addressing waste management issues, the chemistry of lemon peel provides evidence that natural resources can be used to create a sustainable and environmentally friendly future.

Introduction

Over 100 million tons of various citrus fruits are utilized annually to produce juice; 40%–50% of this volume is regarded as waste citrus peel. These by-products are an excellent source of bioactive substances including pectin, antioxidants, and phenolic compounds that have several functional advantages for human health. Additionally, they contain flavonoids, which offer numerous biological benefits, including anti-inflammatory, anti-tumor, and antibacterial activities, as well as a protective effect against certain illnesses; for instance, they can help prevent coronary heart disease. Citrus species comprise four main types of flavonoids: narirutin, hesperidin, naringin, and eriocarpin. The potent antioxidant properties of bioactive chemicals may be extremely beneficial to human health [1–3].

*Corresponding author at : Department of Chemistry, College of Science, Al-Nahrain University, P. O. Box: 64021, Baghdad, Iraq
ORCID: https://orcid.org/0000-0002-1950-7587 ,
Tel: +964 7719042893
Email: mohammed.mashhadani@nahrainuniv.edu.iq;

One of the key medicinal plants in the Rutaceae family is the lemon. Lemon is primarily grown for its alkaloids, which have been shown to have anticancer properties. Crude extracts of the fruit's leaves, stem, root, and blossom have antibacterial properties against clinically important bacterial strains. Citrus flavonoids display numerous biological properties, including antiviral, antidiabetic, antibacterial, and antifungal activities. Flavonoids can modify enzyme activity, restrict cell growth, and serve as direct antioxidants and free radical scavengers. They appear to provide a protective role in plants against diseases such as bacteria, fungus, and viruses that invade them. Plants often contain flavonoids in glycosylated forms, with their bioavailability significantly influenced by the sugar moiety [4]. This paper presents the current status of lemon peel recycling and chemistry, addresses issues encountered, and highlights areas for innovation [5]. By contemplating future possibilities, we hope to encourage research and progress in this field by anticipating new directions and uses. This analysis concludes by emphasizing the value of lemon peel as a source of sustainable solutions and advocating for its integration and application within the broad field of green chemistry. Figure 1 illustrates the recycling of lemon peel via extraction and separation of bioactive materials, such as limonene, citrus, pectin, polyphenol, flavonoids, vitamins, and essential oils. This review aims to present a comprehensive overview of the scientific methods for recycling lemon peel materials. This involves studying the chemistry of lemon peel compounds, isolating them, and applying them in various contexts.

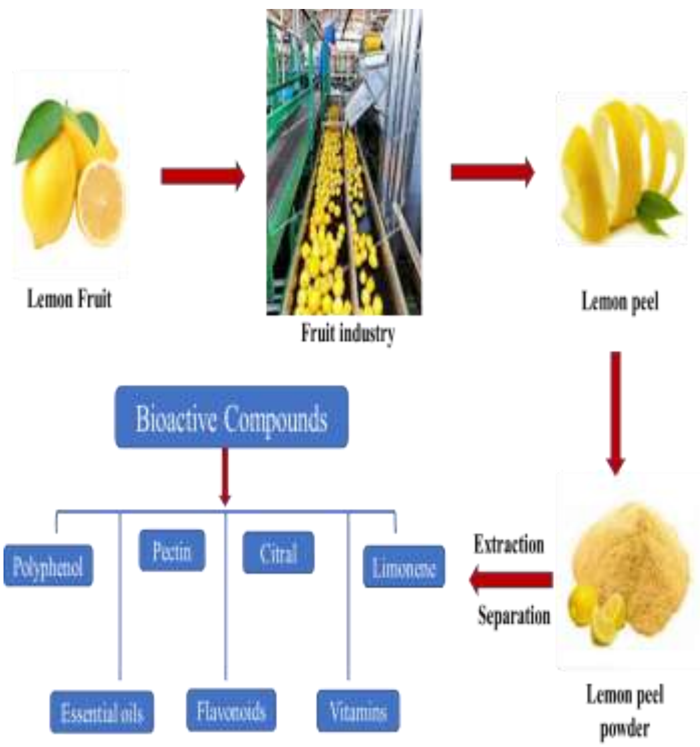

Figure 1: Process of lemon peel recycling.

Chemical composition of lemon peel

Lemon peels were utilized as a local example of the utilization of trash as a raw material to create value-added products in a unique design. This involved changing the process for steam distillation to extract essential oil from plant samples, which was initially included in the course curriculum. The experiment was completely redesigned based on the traditional steam distillation system. It was further improved and evaluated before being implemented in the experimental class. The original glassware system was modified to maximize green extraction and demonstrate the reasons, means, and contexts for incorporating novel sustainability-related elements into chemical procedures [6, 7]. Another important ingredient in lemon peel, citric acid, is responsible for the characteristically sour flavor of citrus fruits. In the food and beverage business, this organic acid is frequently used as a flavor enhancer and acidity regulator. Citric acid is used in many industrial operations, such as those in the pharmaceutical and cosmetic industries, alongside its culinary uses. Citrus peel contains large concentrations of phenolic chemicals called flavonoids, which are primarily useful as nutraceuticals because of their antioxidant properties. The primary class of flavonoids found in citrus fruits is called flavanones. These may be further divided into glycoside and aglycone flavanones based on the presence or absence of a glycoside group in their structure. The plant's cultivation location has a significant impact on the flavonoid content of orange peel. Naringin, hesperidin, and neohesperidin have been shown to be the most prevalent glycoside flavanones in citrus peel, but the concentration of aglycone flavanones is lower than that of glycosides [8]. Fiber-containing substances found in lemon peel include cellulose and lignin. One complex carbohydrate polymer that helps maintain the structural integrity of plant cell walls is cellulose. Although cellulose extraction from lemon peel is well recognized for its use in the paper and textile sectors, it also has potential applications in bio-based composites and sustainable packaging materials [9, 10]. Citrus fruits are the most productive in terms of overall output and financial value. Following the United States and Brazil, India is the third-largest citrus fruit producer in the world. Over 115 million TPA of citrus fruits are produced worldwide. The number of citrus fruits used to produce juice is about 30 million tons. About half of the wet fruit mass is made up of leftover biomass from the juice industry, which is often fed to animals. However, leftover citrus fruit may be used as feedstock to produce ethanol. Citrus peel contains the soluble carbohydrates glucose, fructose, and sucrose. The polysaccharides found in the cell walls of all citrus peels include pectin, cellulose, and hemicellulose. The carbohydrates found in the cell walls of all citrus peels include pectin, cellulose, hemicellulose. Galacturonic acid, galacturonic acid, and arabinose make up the majority of the various parts of pectin and hemicelluloses. Figure 2 shows the structure of these polysaccharides and the value-added citrus peel products [11, 12]. The compounds isolated from lemon peel are polyphenols, which serve as excellent antioxidant and free radical scavengers. Therefore, polyphenols may be used or investigated as anticancer drugs.

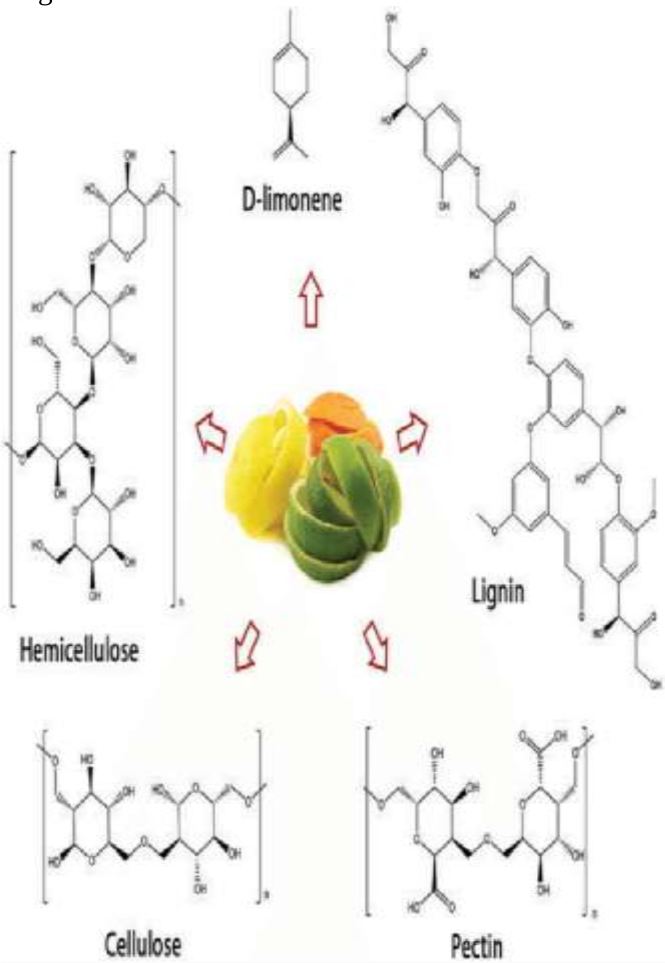

Figure 2: Important chemicals isolated from lemon peel waste [12].

Extraction Techniques

Numerous extraction methods have been used to extract organic chemical compounds from lemon peel [13, 14]. Using organic solvents such as hexane or ethanol to extract them from lemon peel through solvent extraction is a flexible approach that may be adjusted to separate a wide range of constituents, such as terpenes and flavonoids. Although efficient, great care must be taken to reduce any negative effects on the environment, and eco-friendly solvents and extraction conditions should be carefully chosen [15]. The design of the steam distillation apparatus used in the general chemistry experimental course is shown in Figure 3. Steam extraction methods include (a) the conventional method, (b) the Clevenger type method, and (c) a newly suggested innovative approach. Lemon peels are represented by orange squares; water is represented by blue liquid; lemon essential oil is represented by light yellow liquid; and yellow aqueous extract is represented by deep yellow liquid in the Erlenmeyer flask in (c) [6].

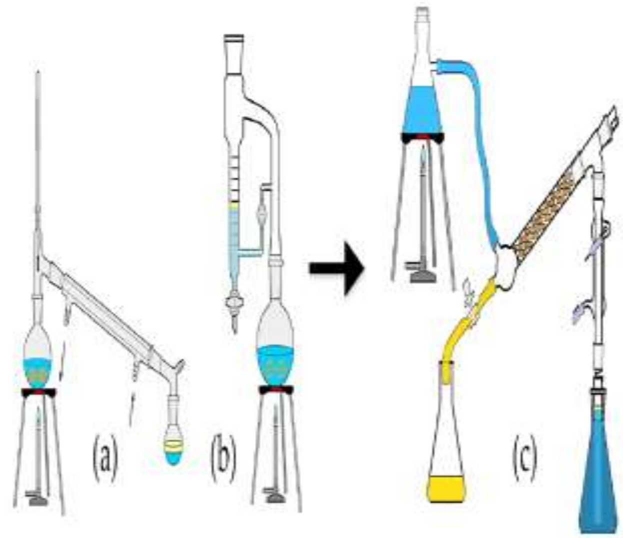

Figure 3: Techniques to extract organic compounds from lemon peel [6].

After separation, isopropyl alcohol is used to filter, concentrate, and precipitate the pectin extract. While pectin is cleaned and subsequently dried, alcohol is recovered by distillation. A large portion of the polymer's "hairy" regions are eliminated during the extraction of pectin, leaving mostly the "smooth" portions of galacturonic acid with a few neutral sugar units attached or in the main linear chain. Pectin yields are typically about 3% of peel weight. After processing a single lemon (200 g) into 100 g of wet peel and 13 g of dry peel, 3 g of pectin is usually extracted, and 10 g of depectinized peel is fed to cattle (Figure 4) [16, 17]. There are trade-offs in terms of efficiency, selectivity, and environmental effects with every extraction method. The particular substances sought and the planned use of the recovered components determine which extraction process is best. The source material and the extraction parameters affect the extracted pectin's chemical properties. The final product is described (pectin for food application is a polymer containing at least 65% galacturonic acid units) and divided into two categories: high- and low-methoxyl pectin (LM and HM, respectively) with degrees of esterification (DEs) of less than 50% and more than 50%, respectively, before it is shipped. The extraction of several valuable components from lemon peel is depicted in Figure 4 [17].

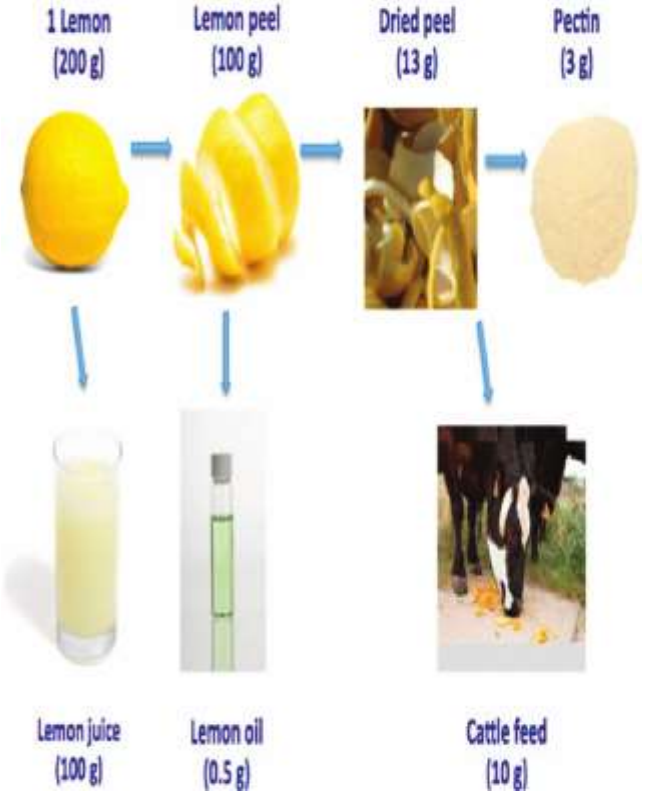

Figure 4: Extraction of main raw materials from lemon peel [17].

Green chemistry principles in lemon peel extraction

Since ancient times, food and natural items have been extracted as a vital source of components for uses in nutrition, aesthetics, and spirituality. With a history spanning over 4,000 years, the Pharaonic civilization was the first to employ solid–liquid extraction and exploit plant life for the production of materials, colors, and scents. Certain sesquiterpenes found in incense extracts, which are frequently used in religious ceremonies, have been found in mummy bandages. Significant discoveries in this area were also made by the Greek and Roman civilizations, who established the foundation for distillation with the invention of the "ambix," which is utilized in extraction and distillation. Distillation and extraction gained significant importance throughout the Islamic era. The process' overall sustainability is enhanced by this emphasis on energy efficiency [18, 19]. In green chemistry, worker safety and end-user safety are of utmost importance. The employment of non-toxic solvents and safety precautions for all personnel participating in the extraction process are given first priority in extraction techniques for components of lemon peel. This commitment to safety includes the management and disposal of extracted materials. When feasible, green chemistry promotes the use of renewable feedstocks. As a byproduct of the citrus industry, lemon peel offers an easily available and sustainable means of extracting important components. Using this resource complies with the idea of using sustainable raw materials in the extraction process [20]. The principles of green chemistry encourage creativity and ongoing process development. Scholars are urged to explore innovative extraction techniques, alternative solvents, and advanced technology to augment the overall sustainability of lemon peel extraction. Over time, the industry will shift toward ecologically friendly methods because of this dedication to innovation [21, 22]. Researchers and practitioners contribute to the development of sustainable and ecologically friendly approaches by utilizing these green chemistry principles in lemon peel extraction, facilitating an environmentally conscious utilization of this natural resource.

Separation of thiol molecules from lemon peel

Unlocking the many uses of lemon peel extracts' chemical components requires the effective separation of their distinct components. A variety of separation techniques are used, each designed to separate certain chemicals. Lemons are a popular citrus fruit that are farmed and utilized in many different ways all over the world. This sour-tasting fruit's primary ingredients have been precisely measured and identified. Further study is required to fully comprehend the trace volatile chemicals that are responsible for the fruit's overall scent. Lisbon lemons were used in this investigation; they were bought from a Californian grove and extracted using a liquid–liquid method. To isolate, concentrate, and improve unknown substances, we applied multidimensional gas chromatography–mass spectrometry and fractionation. Furthermore, by using aroma extract dilution analysis, these techniques were used to assign flavor dilution factors with great accuracy. Lemons have yielded the initial identification of a wide range of chemicals, including many unique sulfur-containing structures and branching aliphatic aldehydes [23, 24]. Chromatography provides remarkable accuracy in the separation and quantification of individual components. Methods such as gas chromatography (GC) and high-performance liquid chromatography (HPLC) fall under this category. Sulfur molecules, which are seldom present in citrus peels, are known to have a major impact on the fruit's scent profile and were discovered to be aroma-active in this specific investigation on lemons. The identification, synthesis, and organoleptic characteristics of these new volatile sulfur compounds are covered in this work. The target chemicals' properties and the required purity for later usage determine which approach is best. Figure 5 shows the identification of various thiol-compounds isolated from lemon peel [25, 26].

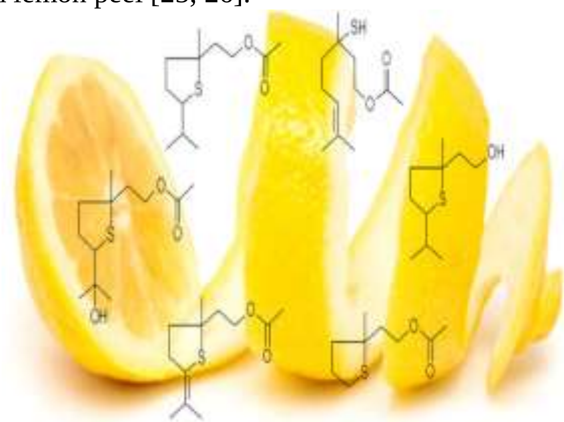

Figure 5: Various isolated thiol molecules from lemon peel [26].

Recycling strategies

After the constituents of lemon peel extracts are isolated, efficient recycling techniques must be utilized to optimize the long-term use of these precious substances. Different recycling strategies are used, and how they are used depends on the components that are being removed. One of the most well-known uses and one of the biggest markets for pectin is in traditional high-sugar jams. Pectin is utilized to reduce lipoprotein levels and make antidiarrheal products. Higher than 60% soluble solids, typical jams are the sole applications for high methoxyl pectins. At present, reduced sugar jams with soluble solid content of 30%–55%, or even less, are allowed in several nations. A vast variety of jams, toppings, and fillings are produced by jam makers for use in the bakery and other sectors. Pectin functions as a naturally occurring preventative agent for toxic cation poisoning. Pectin hydrogel has been used in controlled release matrix tablet formulations and tablet formulations as a binding agent [27, 28]. Chemical conversion is the process of changing the extracted components into other compounds or derivatives, such as in the process of separating pectin from the peels of two distinct citrus fruits, orange and lemon. Analyzing the extracted pectin will reveal its solubility in cold and hot water, as well as in solutions of sugar, organic acid, and alkali (NaOH). It will also reveal the pectin's color, equivalent weight, methoxyl content, ash content, moisture content, and percentage yield. Finally, comparing the properties of two distinct pectins will reveal which is better suited for industrial uses as shown in Figure 6 [29, 30].

Figure 6: Recycling of lemon peel [28]

Applications for extracted components are found throughout several sectors. Terpenes such as limonene, which is extracted from lemon peel, have various applications in the food and cosmetic industries. It can be used as a green solvent in cleaning products or as an additive for flavor and fragrance [31]. Some elements may be added back into agricultural systems as fertilizers or soil amendments, such as organic acids and nutrients [32]. Citric acid and other organic acids derived from lemon peel can help improve soil fertility and structure. These recycling techniques demonstrate how lemon peel ingredients may be used to support sustainable behaviors in a variety of contexts. By completing the circle in the use of resources derived from lemon peels, putting these strategies into practice not only minimizes waste but also advances the circular economy. The particular composition of the extracted components and the intended end-use applications determine the recycling approach to be used. Figure 7 shows the utilization of citrus fruits' by-products [33].

Figure 7: Recycling process to utilization of citrus fruits' by-products [33].

Case Studies and Applications

Case studies and real-world implementations highlight the usefulness and adaptability of recycled lemon peel components across a range of sectors. These illustrations highlight how lemon peel chemistry may support environmentally friendly solutions. These are a few notable examples and case studies. A significant component of lemon peel, limonene, is used in aromatherapy and the fragrance business. Recycled limonene has the potential to take the place of synthetic counterparts in the formulation of natural fragrances, which would help make the fragrance industry more environmentally friendly and sustainable [34]. In the food and beverage sector, citric acid isolated from lemon peel is essential. Case studies show how recycled citric acid may be added to food goods to improve flavor and act as a natural preservative [35] that satisfies customer demand for clean-label and sustainably produced ingredients, which is in line with this application. One potentially useful resource for the creation of biodegradable packaging materials is cellulose derived from lemon peels. Case studies highlight the creation of environmentally friendly packaging options that support the circular economy by lowering dependency on non-renewable resources [36]. Quercetin and hesperidin, two flavonoids isolated from lemon peel, have anti-inflammatory and antioxidant characteristics. These substances have been investigated for use in pharmaceuticals; case studies demonstrate how they may be used to create dietary supplements and natural cures [37]. The extraction of lignin from lemon peel can be used to produce bioenergy. Case studies show how procedures like pyrolysis and anaerobic digestion may turn citrus waste including lemon peels into biofuels. Waste management and the generation of renewable energy are both covered by this application [38]. Given that limonene and other terpenes naturally degrease surfaces, they may be used in eco-friendly cleaning solutions. F. M. Barbosa et al., "Green Extraction of Limonene from Citrus Residues and Its Application in Natural Cleaning Products" [39] provided sustainable alternatives to traditional cleaning agents through case studies that demonstrate the creation of green cleaning solutions utilizing recycled limonene. These case studies highlight the various uses of components made from lemon peel and demonstrate how they may influence sustainable business practices in a variety of sectors. In addition to improving the environment, recycling and reusing these parts can open up business prospects in the growing market for environmentally friendly and sustainable goods.

Conclusion

In summary, this review discusses novel extraction methods and their role in promoting sustainable components in lemon peel. These treatments, such as microwave, ultrasonic, and pulsed electronic methods, utilize or generate low amounts of solvent, energy, and risks. This review has supplied the required theoretical framework along with particular details regarding the mechanics, applications, and environmental effects of green extraction techniques. This review focused on the strategies and showcased them as successful case studies for industrial and research settings. The recycling of lemon peel components is set to significantly influence consumer preferences for eco-friendly options and the adoption of circular economy ideas by firms. Incorporating lemon peel chemistry across many industries addresses issues related to waste management and promotes a sustainable and regenerative approach to resource usage. Lemon peel chemistry demonstrates that harnessing nature's resources can lead to a sustainable and environmentally friendly future through collaborative efforts.

Acknowledgments:

We would like to thank Al-Nahrain University and University of Thi-Qar for their support during this work.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Fidalgo, A., Ciriminna, R., Carnaroglio, D., Tamburino, A., Cravotto, G., Grillo, G., ... & Pagliaro, M. (2016). Eco-friendly extraction of pectin and essential oils from orange and lemon

peels. *ACS Sustainable Chemistry & Engineering*, *4*(4), 2243-2251. https://doi.org/10.1021/acssuschemeng.5b01716

[2] Hilali, S., Fabiano-Tixier, A. S., Ruiz, K., Hejjaj, A., Ait Nouh, F., Idlimam, A., ... & Chemat, F. (2019). Green extraction of essential oils, polyphenols, and pectins from orange peel employing solar energy: Toward a zero-waste biorefinery. *ACS Sustainable Chemistry & Engineering*, *7*(13), 11815-11822. https://doi.org/10.1021/acssuschemeng.9b02281

[3] Banerjee, J., Vijayaraghavan, R., Arora, A., MacFarlane, D. R., & Patti, A. F. (2016). Lemon juice based extraction of pectin from mango peels: waste to wealth by sustainable approaches. *ACS Sustainable Chemistry & Engineering*, *4*(11), 5915-5920. https://doi.org/10.1021/acssuschemeng.6b01342

[4] Imeneo, V., Romeo, R., De Bruno, A., & Piscopo, A. (2022). Green-sustainable extraction techniques for the recovery of antioxidant compounds from "citrus Limon" by-products. *Journal of Environmental Science and Health, Part B*, *57*(3), 220-232. https://doi.org/10.1080/03601234.2022.2046993

[5] Magalhães, D., Vilas-Boas, A. A., Teixeira, P., & Pintado, M. (2023). Functional ingredients and additives from lemon by-products and their applications in food preservation: A review. *Foods*, *12*(5), 1095. https://doi.org/10.3390/foods12051095

[6] Zuin, V. G., Segatto, M. L., Zandonai, D. P., Grosseli, G. M., Stahl, A., Zanotti, K., & Andrade, R. S. (2019). Integrating Green and Sustainable Chemistry into Undergraduate Teaching Laboratories: closing and assessing the loop on the basis of a citrus biorefinery approach for the biocircular economy in Brazil. *Journal of Chemical Education*, *96*(12), 2975-2983. https://doi.org/10.1021/acs.jchemed.9b00286

[7] Ciriminna, R., Fidalgo, A., Delisi, R., Carnaroglio, D., Grillo, G., Cravotto, G., ... & Pagliaro, M. (2017). High-quality essential oils extracted by an eco-friendly process from different citrus fruits and fruit regions. *ACS Sustainable Chemistry & Engineering*, *5*(6), 5578-5587. https://doi.org/10.1021/acssuschemeng.7b01046

[8] 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. https://doi.org/10.1016/j.resconrec.2017.10.032

[9] Auta, M., Musa, U., Tsado, D. G., Faruq, A. A., Isah, A. G., Raji, S., & Nwanisobi, C. (2018). Optimization of citrus peels D-limonene extraction using solvent-free microwave green technology. *Chemical Engineering Communications*, *205*(6), 789-796. https://doi.org/10.1080/00986445.2017.1419206

[10] Teigiserova, D. A., Tiruta-Barna, L., Ahmadi, A., Hamelin, L., & Thomsen, M. (2021). A step closer to circular bioeconomy for citrus peel waste: A review of yields and technologies for sustainable management of essential oils. *Journal of Environmental Management*, *280*, 111832. https://doi.org/10.1016/j.jenvman.2020.111832

[11] Rehan, M., Abdel-Wahed, N. A., Farouk, A., & El-Zawahry, M. M. (2018). Extraction of valuable compounds from orange peel waste for advanced functionalization of cellulosic surfaces. *ACS Sustainable Chemistry & Engineering*, *6*(5), 5911-5928. https://doi.org/10.1021/acssuschemeng.7b04302

[12] John, I., Muthukumar, K., & Arunagiri, A. (2017). A review on the potential of citrus waste for D-Limonene, pectin, and bioethanol production. *International Journal of Green Energy*, *14*(7), 599-612. https://doi.org/10.1080/15435075.2017.1307753

[13] Zuin, V. G., Ramin, L. Z., Segatto, M. L., Stahl, A. M., Zanotti, K., Forim, M. R., ... & Fernandes, J. B. (2021). To separate or not to separate: what is necessary and enough for a green and sustainable extraction of bioactive compounds from Brazilian citrus waste. *Pure and Applied Chemistry*, *93*(1), 13-27. https://doi.org/10.1515/pac-2020-0706

[14] Putnik, P., Bursać Kovačević, D., Režek Jambrak, A., Barba, F. J., Cravotto, G., Binello, A., ... & Shpigelman, A. (2017). Innovative "green" and novel strategies for the extraction of bioactive added value compounds from citrus wastes—A review. *Molecules*, *22*(5), 680. https://doi.org/10.3390/molecules22050680

[15] Šafranko, S., Ćorković, I., Jerković, I., Jakovljević, M., Aladić, K., Šubarić, D., & Jokić, S. (2021). Green extraction techniques for obtaining bioactive compounds from mandarin peel (Citrus unshiu var. Kuno): Phytochemical analysis and process optimization. *Foods*, *10*(5), 1043. https://doi.org/10.3390/foods10051043

[16] Yadav, V., Sarker, A., Yadav, A., Miftah, A. O., Bilal, M., & Iqbal, H. M. (2022). Integrated biorefinery approach to valorize citrus waste: A sustainable solution for resource recovery and

environmental management. *Chemosphere*, *293*, 133459. https://doi.org/10.1016/j.chemosphere.2021.133459

[17] Ciriminna, R., Chavarría- Hernández, N., Inés Rodríguez Hernández, A., & Pagliaro, M. (2015). Pectin: A new perspective from the biorefinery standpoint. *Biofuels, Bioproducts and Biorefining*, *9*(4), 368-377. https://doi.org/10.1002/bbb.1551

[18] Zuin, V. G., & Ramin, L. Z. (2018). Green and sustainable separation of natural products from agro-industrial waste: Challenges, potentialities, and perspectives on emerging approaches. *Chemistry and Chemical Technologies in Waste Valorization*, 229-282. https://doi.org/10.1007/s41061-017-0182-z

[19] Chemat, F., Vian, M. A., Fabiano-Tixier, A. S., Nutrizio, M., Jambrak, A. R., Munekata, P. E., ... & Cravotto, G. (2020). A review of sustainable and intensified techniques for extraction of food and natural products. *Green Chemistry*, *22*(8), 2325-2353. https://doi.org/10.1039/C9GC03878G

[20] Ozturk, B., Winterburn, J., & Gonzalez-Miquel, M. (2019). Orange peel waste valorisation through limonene extraction using bio-based solvents. *Biochemical Engineering Journal*, *151*, 107298. https://doi.org/10.1016/j.bej.2019.107298

[21] Sharma, K., Mahato, N., Cho, M. H., & Lee, Y. R. (2017). Converting citrus wastes into value-added products: Economic and environmently friendly approaches. *Nutrition*, *34*, 29-46. https://doi.org/10.1016/j.nut.2016.09.006

[22] Chatzimitakos, T., Athanasiadis, V., Kotsou, K., Bozinou, E., & Lalas, S. I. (2023). Response Surface Optimization for the Enhancement of the Extraction of Bioactive Compounds from Citrus Limon Peel. *Antioxidants*, *12*(8), 1605. https://doi.org/10.3390/antiox12081605

[23] Gök, A., İsmail Kirbaşlar, Ş., & Gülay Kirbaşlar, F. (2015). Comparison of lemon oil composition after using different extraction methods. *Journal of essential oil research*, *27*(1), 17-22. https://doi.org/10.1080/10412905.2014.982872

[24] Dao, T. P., Tran, N. Q., & Tran, T. T. (2022). Assessing the kinetic model on extraction of essential oil and chemical composition from lemon peels (Citrus aurantifolia) by hydro-distillation process. *Materials Today: Proceedings*, *51*, 172-177. https://doi.org/10.1016/j.matpr.2021.05.069

[25] Mhgub, I. M., Hefnawy, H. T., Gomaa, A. M., & Badr, H. A. (2018). Chemical composition, antioxidant activity and structure of pectin and extracts from lemon and orange peels. *Zagazig Journal of Agricultural Research*, *45*(4), 1395-1404. https://doi.org/10.21608/zjar.2018.48589

[26] Cannon, R. J., Kazimierski, A., Curto, N. L., Li, J., Trinnaman, L., Janczuk, A. J., ... & Chen, M. Z. (2015). Identification, synthesis, and characterization of novel sulfur-containing volatile compounds from the in-depth analysis of lisbon lemon peels (Citrus limon L. Burm. f. cv. Lisbon). *Journal of agricultural and food chemistry*, *63*(7), 1915-1931. https://doi.org/10.1021/jf505177r

[27] Gómez-Mejía, E., Rosales-Conrado, N., León-González, M. E., & Madrid, Y. (2019). Citrus peels waste as a source of value-added compounds: Extraction and quantification of bioactive polyphenols. *Food Chemistry*, *295*, 289-299. https://doi.org/10.1016/j.foodchem.2019.05.136

[28] Bagde, P. P., Dhenge, S., & Bhivgade, S. (2017). Extraction of pectin from orange peel and lemon peel. *International Journal of Engineering Technology Science and Research*, *4*(3), 1-7.

[29] Martínez-Abad, A., Ramos, M., Hamzaoui, M., Kohnen, S., Jiménez, A., & Garrigós, M. C. (2020). Optimisation of sequential microwave-assisted extraction of essential oil and pigment from lemon peels waste. *Foods*, *9*(10), 1493. https://doi.org/10.3390/foods9101493

[30] Wang, J., Zhai, Y., Ou, M., Bian, Y., Tang, C., Zhang, W., ... & Li, G. (2021). Protective effect of lemon peel extract on oxidative stress in H9c2 rat heart cell injury. *Drug Design, Development and Therapy*, 2047-2058. https://doi.org/10.2147/DDDT.S304624

[31] Ledesma-Escobar, C. A., Priego-Capote, F., & de Castro, M. D. L. (2016). Effect of sample pretreatment on the extraction of lemon (Citrus limon) components. *Talanta*, *153*, 386-391. https://doi.org/10.1016/j.talanta.2016.03.024

[32] Sharif Nasirian, V., Shahidi, S. A., Tahermansouri, H., & Chekin, F. (2021). Application of graphene oxide in the adsorption and extraction of bioactive compounds from lemon peel. *Food science & nutrition*, *9*(7), 3852-3862. https://doi.org/10.1002/fsn3.2363

[33] Suri, S., Singh, A., & Nema, P. K. (2022). Current applications of citrus fruit processing waste: A scientific outlook. *Applied Food Research*, *2*(1), 100050. https://doi.org/10.1016/j.afres.2022.100050

[34] Chaves, J. O., Sanches, V. L., Viganó, J., de Souza Mesquita, L. M., de Souza, M. C., da Silva, L. C., ... & Rostagno, M. A. (2022). Integration of pressurized liquid extraction and in-line solid-phase extraction to simultaneously extract and concentrate phenolic compounds from lemon peel (Citrus limon

L.). *Food Research International*, *157*, 111252. https://doi.org/10.1016/j.foodres.2022.111252

[35] Salvo, A., Bruno, M., La Torre, G. L., Vadalà, R., Mottese, A. F., Saija, E., ... & Dugo, G. (2016). Interdonato lemon from Nizza di Sicilia (Italy): chemical composition of hexane extract of lemon peel and histochemical investigation. *Natural Product Research*, *30*(13), 1517-1525. https://doi.org/10.1080/14786419.2015.1115999

[36] Ali, J., Das, B., & Saikia, T. R. I. D. E. E. P. (2017). Antimicrobial activity of lemon peel (Citrus limon) extract. *International Journal of Current Pharmaceutical Research*, *9*(4), 79-82. https://doi.org/10.1016/j.jksus.2019.02.013

[37] Saleem, M., & Saeed, M. T. (2020). Potential application of waste fruit peels (orange, yellow lemon and banana) as wide range natural antimicrobial agent. *Journal of King Saud University-Science*, *32*(1), 805-810.

[38] Jagannath, A., & Biradar, R. (2019). Comparative evaluation of soxhlet and ultrasonics on the structural morphology and extraction of bioactive compounds of lemon (Citrus limon L.) peel. *Journal of Food Chemistry and Nanotechnology*, *5*(3), 56-64. https://doi.org/10.17756/jfcn.2019-072

[39] Lu, Q., Huang, N., Peng, Y., Zhu, C., & Pan, S. (2019). Peel oils from three Citrus species: Volatile constituents, antioxidant activities and related contributions of individual components. *Journal of food science and technology*, *56*, 4492-4502. https://doi.org/10.1007/s13197-019-03937-w.

الكيمياء الخضراء لقشور الليمون، استخلاص مكونات الاستدامة: نظرة عامة

زياد فاضل 1، هدى غازي ناصر 2، عامر عدنان حسن 2، رشا سعد جواد 3، سهاد الشريف 4، سريكانث كومانابوينا 5، محمد حسين المشهداني 6*

[1] كلية الصيدلة، جامعة ذي قار، ذي قار، العراق ، [2]قسم التحليلات المرضية التطبيقية، كلية العلوم، جامعة النهرين، ص.ب: 64021، بغداد، العراق، [3] قسم الفيزياء الطبية، كلية العلوم، جامعة النهرين، ص.ب: 64021، بغداد، العراق

[4] قسم الكيمياء، كلية العلوم، جامعة تبوك، تبوك 71491، المملكة العربية السعودية ، [5]ساي لعلوم الحياة، الوحدة الثانية، القطعة رقم **DS-7**، حديقة المعرفة**ICICI** ، قرية توركابلي، حيدر أباد، تيلانجانا 500078، الهند ، [6] قسم الكيمياء، كلية العلوم، جامعة النهرين، ص.ب: 64021، بغداد، العراق

*البريد الإلكتروني للمؤلف **mohammed.mashhadani@nahrainuniv.edu.iq**

الخلاصة:

يبحث هذا المقال الشامل في الكيمياء المستدامة بيئيًا لقشور الليمون. يوفر التركيب الكيميائي لقشر الليمون، والذي يتضمن الليمونين وحمض الستريك والفلافونويد والسليلوز واللجنين، مجموعة واسعة من المواد الكيميائية ذات الاستخدامات في العديد من القطاعات. وتعتمد طرق الاستخلاص على مبادئ الكيمياء الخضراء. التي تضمن السلامة البيئية والاقتصادية. حيث هنالك العديد من تقنيات فصل المكونات، مثل التقطير التجزيئي التي تسلط الضوء على الانتقائية اللازمة لعزل المواد المرغوبة. كذلك ستتناول الدراسة الاستخدام العملي لكيمياء قشر الليمون من خلال إعادة التدوير التي تشمل التحول البيولوجي، والتحويل الكيميائي. اضافة الى استخدامها في العلاج، والأغذية، والتعبئة والتغليف، وغيرها من المجالات. تساعد فرص الابتكار والعمل الجماعي ومشاريع الاقتصاد لاعادة التدوير والمساعدة التشريعية على التغلب على العقبات بما في ذلك حجم النفايات والجدوى الاقتصادية. إعادة تدوير مكونات قشر الليمون تعتبر طريق مستدامة ممتازة للحصول على المواد الحيوية الصديقة للبيئة. ويساعد هذا التكامل على تعزيز طريقة أكثر تجديدًا واستدامة لاستهلاك الموارد الطبيعية. بالإضافة إلى معالجة قضايا إدارة النفايات. توفر كيمياء قشر الليمون دليلاً على إمكانية استخدام الموارد الطبيعية لخلق مستقبل أكثر استدامة وأكثر خضرة.

الكلمات المفتاحية: الكيمياء المستدامة، استراتيجيات إعادة التدوير، الليمونين، السليلوز، اللجنين، المواد الحيوية، المنتجات الصديقة للبيئة.