

Review Article

Production of Citric acid from Fruit Waste by using *Aspergillus niger*

Meskerem Eflu*

Industrial Biotechnology Directorate, Food and Nutrition Research Team, Addis Ababa, Ethiopia

Abstract

Citric acid is one of the most important organic acids used in the food, pharmaceutical, and cosmetic industries. Its conventional production methods often rely on costly sugar-based substrates, creating economic and environmental challenges. This study focuses on the sustainable production of citric acid from fruit waste using *Aspergillus niger* as a microbial producer. Fruit wastes such as orange, pineapple, and banana peels are rich in fermentable sugars and nutrients, making them suitable and low-cost substrates for fermentation. The objective of this work is to develop a sustainable and cost-effective process for citric acid production that contributes to waste reduction and resource efficiency.

Aspergillus niger was isolated and characterized from soil samples and used for fermentation under optimized conditions, including controlled pH, temperature, aeration, and nutrient concentration. Optimization of these parameters significantly influenced the yield and quality of citric acid. The approach also promotes an eco-friendly process by minimizing waste and environmental pollution while supporting circular economy principles. The results demonstrate that fruit waste can effectively replace commercial substrates for citric acid production without compromising quality, offering both environmental and economic benefits.

In conclusion, utilizing fruit waste for citric acid fermentation with *A. niger* provides a promising strategy for sustainable industrial biotechnology, aligning with global efforts toward green production and waste valorization.

Introduction

Biotechnology is an interdisciplinary field that is largely oriented towards the industrial applications of microorganisms for the conversion of waste to useful products. The number of substances excreted by microorganisms is endless. They are classified as simple compounds (eg, lower alcohols, acids, etc.) and complex compounds (eg, natural products and celluloses) or as preliminary products and compounds evolving from secondary metabolism. Several fermentation procedures are used for the large-scale production of organic chemicals and high-energy fuels from renewable sources.

Citric acid can be produced by fermentation technology using various moulds, yeasts, and bacteria. Most of them, however, are not able to produce commercially acceptable yields [1]. Citric acid is a weak acid that occurs in nature. The term "citric acid" comes from the Latin word "citrus," which means any of a group of plants that produce juicy fruits with a slightly sour taste. Citric acid can come from natural sources (eg, lemon, lime, and orange) or synthetic sources (eg, chemical reaction and microbial fermentation) [2].

A large number of microorganisms, including bacteria and fungi such as *Arthrobacter paraffini*, *Bacillus licheniformis*, and *Corynebacterium spp.*, *Aspergillus niger*, *A. aculeatus*, *A. carbonarius*, *A. awamori*, *A. foetidus*, *A. fonsecaeus*, *C. oleophila*, *C. guilliermondii*, *C. citroformans*, *Hansenula anamola*, and *Yarrowia lipolytica*, have been used for citric acid production. Although Most of them are unable to produce commercially acceptable yields because citric acid is a metabolite of energy metabolism, and its accumulation only grows in appreciable amounts under conditions of drastic imbalances. The *Aspergillus niger* is widely used for commercial production of citric acid, because it produces more citric acid per unit of time [3,4].

Aspergillus niger is superior to other microorganisms for the commercial synthesis of citric acid because of its better production yield. It is easy to handle, can ferment various cheap raw materials, and delivers high yields. As such, strains of this microorganism can be improved to create industrial strains for use in commercial production, and mutagenesis and strain selection have been carried out for such improvement.

More Information

*Corresponding author: Meskerem Eflu, Industrial Biotechnology Directorate, Food and Nutrition Research Team, Addis Ababa, Ethiopia, Email: meskielfu@gmail.com

Submitted: October 29, 2025

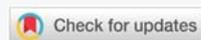
Accepted: March 05, 2026

Published: March 06, 2026

Citation: Eflu M. Production of Citric acid from Fruit Waste by using *Aspergillus niger*. Arch Biotechnol Biomed. 2026; 10(1): 009-012. Available from: <https://dx.doi.org/10.29328/journal.abb.1001048>

Copyright license: © 2026 Eflu M. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Keywords: Citric acid production; *Aspergillus niger*; Industrial biotechnology; Fermentation; Waste valorization; Circular bioeconomy; Fermentation; Microorganisms



Different mutagens, including radiation, such as ultraviolet, X-rays, and gamma-rays, and chemicals, such as ethyl methane sulphonate and diethyl sulphonate, have been used to induce the mutation of *A. niger* [2,5].

The citric acid (2-hydroxy-propane 1, 2, 3-tricarboxylic acid) derives its name from the Latin word citrus, the fruit of the citrus tree, which resembles a lemon. Citric acid is a tricarboxylic acid with a molecular weight of 210.14 Da. With an estimated annual production of about 10, 00000 tons, citric acid is one of the fermentation products with the highest level of production worldwide. A considerable amount of citric acid is required in several industrial processes [6].

Citric acid is a water-soluble, specialty organic acid that exists as a white, crystalline powder and exhibits a significant buffering capacity in water. The global citric acid market in 2023 is projected increase to \$3.2 billion. It is estimated that over a million tons of citric acid are produced globally every year. Citric acid has been designated as Safe by the World Health Organization [7].

Citric acid (CA) is an organic acid that is generally found in a variety of fruits such as limes, lemons, oranges, pineapples, and grapefruits. It is a natural ingredient that aids in detoxification, maintaining energy levels, and supporting healthy digestion and kidney function. It has a slightly tart and refreshing flavor and is employed for balancing the sweetness in soft drinks, juices, and other beverages. Citric acid is used in the food and beverage (F&B) industry due to its antioxidant properties to preserve the food or as an acidifier to enhance the flavors and aromas of fruit juices, ice cream, and marmalades. In the pharmaceutical industry, it is used as an antioxidant to preserve vitamins, effervescent, pH corrector, blood preservative, iron citrate tablets as a source of iron for the body, ointments and cosmetic preparations, and so forth. In the chemical industry, it is used as a foaming agent for softening and treating textiles. In metallurgy, certain metals are utilized in the form of citrate. Because of less eutrophic effect, CA is used in the detergent industry as a phosphate substitute [2,3].

Citric acid has a wide range of applications as a versatile and secure alimentary addition across a variety of commercial sectors, including the chemical, pharmaceutical, cosmetic, and food industries. To fulfill the escalating demand for citric acid, there is an urgent need for production methods that are both affordable and environmentally friendly. It will take some time to fully comprehend the mechanics and characteristics of citric acid, and it must be generated in ways that ensure its sustainability, abundance, and excellent quality. The citric acid production from the West also highlights the potential of biotechnology to turn west in to wealth while addressing environmental and economic challenges .

This review aimed to introduce citric acid production from

fruit waste using *Aspergillus niger*, leveraging an eco-friendly and cost-effective biotechnological process that converts agricultural residues into a valuable industrial product while promoting waste reduction and sustainability with the following scope, purpus and importance of the review.

Scope of the review

This review focuses on exploring citric acid production using *Aspergillus niger* and fruit waste as a substrate. It covers the biological and biochemical aspects of *A. niger*, the types of fruit waste suitable for fermentation, and the optimization of production parameters such as pH, temperature, aeration, and nutrient concentration. The review also discusses advances in fermentation technology, downstream processing, and sustainability approaches in industrial-scale citric acid production. Combining findings from past and current studies, it provides a comprehensive understanding of how waste materials can be transformed into valuable bioproducts.

Purpose of the review

The main purpose of this review is to analyze, summarize, and evaluate existing research on the sustainable production of citric acid from fruit waste using *Aspergillus niger*. It aims to identify effective strategies for improving yield, reducing production costs, and minimizing environmental impact. Furthermore, the review serves as a scientific basis for developing a sustainable and cost-effective process that contributes to waste management, industrial resource efficiency, and eco-friendly biotechnological applications.

Importance of the review

Citric acid is one of the most widely used organic acids in the food, pharmaceutical, and cosmetic industries. However, conventional production processes often rely on expensive substrates, leading to higher costs and environmental concerns. Utilizing fruit waste as a fermentation substrate provides a dual benefit—waste reduction and value addition to agricultural by-products. This review is therefore important because it:

- Promotes sustainable and circular economy practices by converting waste into valuable industrial products.
- Enhances the cost-effectiveness of production through the use of low-cost raw materials.
- Supports environmental conservation by minimizing waste disposal problems.
- Contributes to the development of green biotechnology and eco-friendly industrial processes.

Literature review

Application of citric acid in different industries

Industries	Applications	Reference
Food	Enhancing the activity of antioxidant preservatives (citrate powerful chelating agent for trace metal ions)	Ewelina Ksi azek, 2024, [8]
Beverage	Acidulant and pH stabilizer	
Flavoring agent	The sharp, acidic taste of citric acid can help mask the unpleasant, medicinal taste of pharmaceuticals.	
Environmental remediation	A chelating agent sequesters heavy metals, including radioactive isotopes, easing the removal of hydrophobic organic compounds	YING-YING GU, et al. 2013, [9]
pharmaceuticals	Citrate chelates calcium, reducing the tendency for blood to clot	Sotoyama M, et al. 2017 [10], Yıldız S, et al. 2018 [11],
	It is used as an anticoagulant, effervescent in combination with bicarbonates or carbonates, a flavoring agent, and a stabilizer. It imparts the desired sour taste, which helps mask medicinal flavors.	
Dairy products	Sodium citrate is used in cream production to stabilize casein, prevent the formation of creams during hot milk beverage production, and act as an emulsifier to stabilize the water and oil phases in cheese production. Aqueous solutions of citric acid are used for milkstone removal from equipment.	Fiume M, et al. 2012 [12]
Meat products	It acts as a chelating agent, helping maintain the natural color and prevent discoloration of preserved meats; acts as an antioxidant and synergist for antibacterial agents. Sodium citrate is used in slaughterhouses to prevent the coagulation or clotting of fresh blood.	Singh Dhillon, et al. 2011 [13]
Water purification	Solutions of citric acid are used to remove iron, calcium, and other cations that damage cellulose acetate membranes used in reverse osmosis systems.	Majumder S; Nath, et al. 2013 [14]
Biomedical engineering	Utilized as a copolymer in nanomaterials to encapsulate biologically active compounds	Naeini AT, et al. 2010 [15]
Electroplating	It is used as a chelating agent to control the metal deposition rate on substrates.	Soccol Carlos, R. et al. 2006 [16]
Metallurgical industry	Cleans the steam boiler from metal oxides and purifies iron and copper oxides used in nuclear reactor welding	
Textile industry	It is used for pH regulation, as a buffer, and as a chelating agent in the dyeing process.	
Sea food	Prevents discoloration and the development of unwanted odors by chelating metals	Dziezak JD, 2003 [17]
oils	Used in the deodorization and hydrogenation of oil to chelate metal ions, catalyze the rancidity of fats, interrupt the formation of peroxides and other oxidation products in the auto-oxidation of oils.	Soccol Carlos R, et al. 2006 [16]
Detergent and cosmetics	It is added to hair care products, cosmetics, and detergents for pH regulation and used as a stabilizer, buffering agent, and chelating agent to prevent discoloration.	Shalaev EY, et al. 2002 [18], Fiume M, et al. 2012 [12],
candies	Acts as an acidulant. Provides tartness. Minimizes sucrose inversion. Produces dark color in hard candies. Prevents crystallization of sucrose	Carlos R, et al. 2006 [16]
fertilizer	Forms chelate with Fe, Cu, Mg, and Zn, used for soil correction, increase phosphorus availability to plants, are employed to remove lead from contaminated soils, and are used for copper chelation in algacides for water reservoirs.	Paleckiene R, et al. 2005 [19]

Global market

One estimate places the global citric acid market at around USD 3.78 billion in 2022, with a projected size of USD 5.17 billion by 2030 (CAGR ~4.0 %). Another study reports a market value of about USD 3.65 billion in 2023, expected to reach USD 5.12 billion by 2032 (CAGR ~3.82 %). In terms of volumes, the market was estimated at ~ 3.0 million tonnes in 2024, with a forecast of ~3.7 million tonnes by 2033 (CAGR ~2.5 %). A somewhat lower alternate estimate states ~USD 4.18 billion in 2023, reaching ~USD 6.71 billion by 2033 (CAGR ~4.6 %).

Discussion

Citric acid production using *Aspergillus niger* has proven to be one of the most efficient microbial fermentation processes in industrial biotechnology. Traditional methods rely heavily on refined sugar-based substrates such as sucrose or glucose, which increase production costs and compete with food resources. The use of fruit waste as an alternative substrate offers an economical and eco-friendly solution by converting low-cost agricultural residues into high-value products. Studies have demonstrated that fruit wastes such as orange peels, pineapple residues, banana peels, and mango pulp contain sufficient carbohydrates, minerals, and nutrients to support *A. niger* growth and citric acid biosynthesis.

The performance of *A. niger* in citric acid fermentation depends on multiple factors, including pH, aeration, temperature, sugar concentration, nitrogen limitation, and trace elements. Optimizing these parameters significantly

enhances citric acid yield. Various researchers have reported that pH values around 2–3, temperatures of 28 °C – 32 °C, and high sugar content favor acid accumulation, while nitrogen limitation stimulates citric acid synthesis by diverting carbon flux from biomass formation to organic acid production. Furthermore, the use of solid-state fermentation (SSF) and submerged fermentation (SmF) systems has shown promising results, with SSF being particularly attractive for fruit waste utilization due to reduced energy and water requirements.

Besides yield improvement, the development of this process contributes to environmental sustainability. Converting fruit residues into citric acid helps in waste reduction, decreases environmental pollution, and supports circular economy practices. Additionally, advancements in strain improvement, immobilized cell systems, and genetic engineering of *A. niger* are expanding the scope of industrial-scale production with enhanced productivity and reduced costs [20-28].

Conclusion

The production of citric acid from fruit waste using *Aspergillus niger* represents a sustainable, cost-effective, and environmentally friendly alternative to traditional processes. Fruit wastes provide an abundant and renewable source of carbon, while *A. niger* serves as an efficient microbial producer capable of high yield under optimized fermentation conditions. This approach not only adds economic value to agricultural by-products but also aligns with global efforts toward waste valorization, green biotechnology, and industrial resource efficiency.

Future research should focus on optimizing fermentation parameters for different fruit waste types, improving strain performance through molecular and metabolic engineering, and scaling up the process for industrial application. Overall, integrating biotechnological innovation with waste management strategies can ensure the sustainable production of citric acid and contribute to a cleaner and more circular bioeconomy.

References

- Joshi S. An overview of citric acid production and purification. *World J Pharm Life Sci.* 2023. Available from: <https://doi.org/10.56716/4/4232>
- Lende SV, Karemore H, Umekar MJ. Review of the production of citric acid by fermentation technology. *GSC Biol Pharm Sci.* 2021;17(3):31-40. Available from: <https://doi.org/10.30574/gscbps.2021.17.3.0313>
- Behera BC, Mishra R, Mohapatra S. Microbial citric acid: production, properties, application, and future perspectives. *Food Front.* 2021;2:62-76. Available from: <https://doi.org/10.1002/fft2.66>
- Chauhan V, Hajoori M. Production of citric acid: a microbial perspective. *Int J Creat Res Thoughts.* 2022. Available from: <https://ijcrt.org/papers/IJCRT2208263.pdf>
- Farooq U, Anjum FM, Zahoor T, Sajjad-ur-Rahman S, Hayat Z, Akram K, et al. Citric acid production from sugarcane molasses by *Aspergillus niger* under different fermentation conditions and substrate levels. *Int J Agric Appl Sci.* 2013;5(1). Available from: https://www.researchgate.net/profile/Umar-Farooq-35/publication/259284765_CITRIC_ACID_PRODUCTION_FROM_SUGARCANE_MOLASSES_BY_ASPIERGILLUS_NIGER_UNDER_DIFFERENT_FERMENTATION_CONDITIONS_AND_SUBSTRATE_LEVELS/links/00b4952ab328c0ab7200000/CITRIC-ACID-PRODUCTION-FROM-SUGARCANE-MOLASSES-BY-ASPIERGILLUS-NIGER-UNDER-DIFFERENT-FERMENTATION-CONDITIONS-AND-SUBSTRATE-LEVELS.pdf
- Satheeshkumar S, Sivagurunathan P, Muthulakshmi K, Uma C. Utilization of fruit waste for the production of citric acid by using *Aspergillus niger*. *J Drug Deliv Ther.* 2019;9(4-A):9-14. Available from: <https://jddtonline.info/index.php/jddt/article/view/3487>
- West TP. Citric acid production by *Aspergillus niger* using solid-state fermentation of agricultural processing coproducts. *Appl Biosci.* 2023;2:1-13. Available from: <https://doi.org/10.3390/applbiosci2010001>
- Książek E. Citric acid: properties, microbial production, and applications in industries. *Molecules.* 2024;29(22). Available from: <https://doi.org/10.3390/molecules29010022>
- Gu YY, Yeung AT, Tsang DCW, Fu RB. Applications of citric acid industrial wastewater and phosphonates for soil remediation: effects on temporal change of cadmium distribution. *Soil Sediment Contam.* 2013;22:876-889. Available from: <https://ui.adsabs.harvard.edu/abs/2013SSCIJ.22..876G/abstract>
- Sotoyama M, Uchida S, Tanaka S, Hakamata A, Odagiri K, Inui N, et al. Citric acid suppresses the bitter taste of olopatadine hydrochloride orally disintegrating tablets. *Biol Pharm Bull.* 2017;40:451-457. Available from: <https://doi.org/10.1248/bpb.b16-00828>
- Yıldız S, Aytakin E, Yavuz B, Bozdağ Pehlivan S, Vural İ, Ünlü N. Development and evaluation of orally disintegrating tablets comprising taste-masked mirtazapine granules. *Pharm Dev Technol.* 2018;23:488-495. Available from: <https://doi.org/10.1080/10837450.2017.1315670>
- Fiume M, Heldreth B, Bergfeld WF, Belsito DV, Hill RA, Klaassen CD, et al. Safety assessment of citric acid, inorganic citrate salts, and alkyl citrate esters as used in cosmetics. 2012. Available from: <https://doi.org/10.1177/1091581814526891>
- Singh Dhillon G, Kaur Brar S, Verma M, Tyagi RD. Recent advances in citric acid bio-production and recovery. *Food Bioprocess Technol.* 2011;4:505-529. Available from: <https://link.springer.com/article/10.1007/s11947-010-0399-0>
- Majumder S, Nath B, Sarkar S, Islam SM, Bundschuh J, Chatterjee D, Hidalgo M. Application of natural citric acid sources and their role on arsenic removal from drinking water: a green chemistry approach. *J Hazard Mater.* 2013;262:1167-1175. Available from: <https://doi.org/10.1016/j.jhazmat.2012.09.007>
- Naeini AT, Adeli M, Vossoughi M, Sobhani Z, Atyabi F, Safinya CR. Poly(citric acid)-block-poly(ethylene glycol) copolymers—new biocompatible hybrid materials for nanomedicine. *Nanomedicine.* 2010;6:556-562.
- Soccol CR, Vandenberghe LPS, Rodrigues C, Pandey A. New perspectives for citric acid production and application. *Food Technology and Biotechnology.* 2006. Available from: https://www.researchgate.net/publication/228338285_New_Perspectives_for_Citric_Acid_Production_and_Application
- Dziezak JD. *Encyclopedia of food sciences and nutrition.* San Diego (CA): Academic Press; 2003.
- Shalaev EY, Johnson-Elton TD, Chang L, Pikal MJ. Thermophysical properties of pharmaceutically compatible buffers at sub-zero temperatures: Implications for freeze-drying. *Pharmaceutical Research.* 2002;19:195-201.
- Paleckiene R, Sviklas A, Sliksiene R. Reaction of urea with citric acid. *Russian Journal of Applied Chemistry.* 2005;78:1651-1655.
- Bastos RG, Ribeiro HC. Citric acid production by the solid-state cultivation consortium of *Aspergillus niger* and *Trichoderma reesei* from sugarcane bagasse. *The Open Biotechnology Journal.* 2020;14(1):32-41. Available from: <http://dx.doi.org/10.2174/1874070702010410032>
- Cano y Postigo LO, Jacobo-Velázquez DA, Guajardo-Flores D, García-Amezquita LE, García-Cayuela T. Solid-state fermentation for enhancing the nutraceutical content of agrifood byproducts: Recent advances and its industrial feasibility. *Food Bioscience.* 2021;41:100926. Available from: <https://doi.org/10.1016/j.fbio.2021.100926>
- Chandraker D, Sao S, Deshmukh YK, Verma L, Sahu PK. Isolation of *Aspergillus niger* from *Allium cepa* bulb and production of citric acid from it. *International Journal of Pharma and Bio Sciences.* 2014. Available from: <https://ijpbs.net/abstract.php?article=MzA2OA==>
- Iqbal J, Haq IU, Javed MM, Hameed U, Khan AM, Parveen N, et al. Isolation of *Aspergillus niger* strains from soil and their screening and optimization for enhanced citric acid production using cane molasses as a carbon source. *Journal of Applied Environmental and Biological Sciences.* 2015. Available from: https://www.researchgate.net/publication/274378838_Isolation_of_Aspergillus_niger_Strains_from_Soil_and_their_Screening_and_Optimization_for_Enhanced_Citric_Acid_Production_using_Cane_Molasses_as_Carbon_Source
- Luo H, Wang Y, Zhang H, Lin W, Wu G. Citric acid production using a biological electro dialysis with a bipolar membrane. *Journal of Membrane Science.* 2017;523:122-128. Available from: <https://doi.org/10.1016/j.memsci.2016.09.063>
- Majumder L, Khalil I, Munshi MK, Alam K, Rashid HO, Begum R, et al. Citric acid production by *Aspergillus niger* using molasses and pumpkin as substrates. *European Journal of Biological Sciences.* n.d.;2(1). Available from: https://www.researchgate.net/publication/260064529_Citric_acid_production_by_Aspergillus_niger_using_molasses_and_pumpkin_as_substrates
- Martin SM. Citric acid production by submerged fermentation. *Industrial & Engineering Chemistry.* 1957;49(8):1231-1232. Available from: <https://doi.org/10.1021/IE50572A022>
- Patel G, Patil MD, Soni S, Chisti Y, Banerjee UC. Production of mycophenolic acid by *Penicillium brevicompactum* using solid-state fermentation. *Applied Biochemistry and Biotechnology.* 2016;182(1):97-109. Available from: <https://doi.org/10.1007/s12010-016-2313-3>
- Torrado AM, Cortés S, Salgado JM, Max B, Rodríguez N, Bibbins BP, et al. Citric acid production from orange peel wastes by solid-state fermentation. *Brazilian Journal of Microbiology.* 2011;42(1):394-409. Available from: <https://doi.org/10.1590/S1517-83822011000100049>