

REVIEW

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# *Psidium guajava* leaves assisted green synthesis of metallic nanoparticles: a review

Shriniwas P. Patil<sup>1\*</sup>  and Pradip M. Rane<sup>2</sup>

## Abstract

**Background:** Several attempts have been made for green synthesis of metallic nanoparticles, revealing the significance of plant extracts in reducing metal source to nanoparticles and applications in various domains of science.

**Main body:** *Psidium guajava* (guava) is evergreen, edible fruit-bearing plant, belonging to family Myrtaceae. Its leaves are reported to contain several phytochemicals like tannins, glycosides, terpenes, and triterpenes. This article focus on applications of *Psidium guajava* leaves extract in fabrication of nanoparticles of various metals like silver, gold, titanium dioxide, zinc oxide, and copper oxide. In respective research attempts, these metallic nanoparticles were evaluated for one or more applications like anti-microbial activity and/or photocatalytic activity.

**Conclusion:** Use of polar extract of guava leaves indicated involvement of its polar phyto-compounds in reducing the metal source and stabilizing the nanoparticles. In conclusion, it could be noted that metal nanoparticles have better anti-microbial activity and photocatalytic potential over aqueous leaves extract.

**Keywords:** *Psidium guajava*, Phytochemicals, Metal nanoparticles, Anti-microbial potential, Photocatalytic activity

## 1 Background

Considering the wide range of applications of metal nanoparticles, several attempts were made for their synthesis. For this, researchers mainly focus on green route of their synthesis to avoid hazardous chemicals and physical abrasion based on possible accidents involved in chemical and physical methods available for the fabrication of metallic nanoparticles. Green synthesis of metallic nanoparticles includes reduction of metal ion source compound by extract (mainly of polar solvent) of any organ on plant and capping of newly synthesized nanoparticle by phytochemicals present in the extract [1].

*Psidium guajava* (common name—guava) (Fig. 1), a large dicotyledonous shrub or small evergreen tree, belonging to the family Myrtaceae, native to tropical America, is a well-known tree with edible fruits [2]. Almost all parts have history of therapeutic application [3]. This plant grows to full growth in wide range of soil

types [4]. Guava leaves (Fig. 2) are greenish, simple, exstipulate with short petiole, entire margin, ovate or acuminate apex, rounded to sub-acuminate base, and pinnate/reticulate venation. The leaves are 10–12 cm long and 5–7 cm wide.

The present review aimed toward summarizing the materialistic requirements, procedures employed for green synthesis of metal nanoparticles using *P. guajava* leave extract and their different applications. Most of the research articles, I referred for this review were published on well-recognized journals of international databases like, Elsevier-ScienceDirect (<http://www.sciencedirect.com>), Springer (<http://link.springer.com>), MDPI, Innovare Academic Sciences (<https://innovareacademics.in/>), and PubMed (<http://www.ncbi.nlm.nih.gov/pubmed>).

Prior to summarize the data about metallic nanoparticle synthesis, it will be worthy to have a look on phytochemicals reported so far from *P. guajava* leaves and thereby their pharmacological potentials as one of the older applications.

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**Fig. 1** *Psidium guajava* plant in its habitat, with few fruits and flowers

## 2 Main text

### 2.1 Phytochemical prospection of guava leaves

Matsuo et al. firstly isolated (+)-galocatechin from *P. guajava* leaves [5], then Begum et al. isolated triterpenoids guavanoic acid, guavacoumaric acid, asiatic acid, jacoumaric acid, 2 $\alpha$ -hydroxyursolic acid, isoneriuoumaric acid,  $\beta$ -sitosterol-3-O- $\beta$ -D-glucopyranoside, and

ilelatifol D from the leaves of *P. guajava* [6]. They also found  $\alpha$ -pinene,  $\beta$ -pinene, limonene, isopropylalcohol, menthol, terpenyl acetate, caryophyllene, longicyclene, and  $\beta$ -bisabolene as components of essential oil. Glycodises like guavin B, guavin A, isostrictinin, strictinin amritoside or ellagic acid 4-gentiobioside, and pedunculagin were isolated from *P. guajava*.



**Fig. 2** *Psidium guajava* leaves

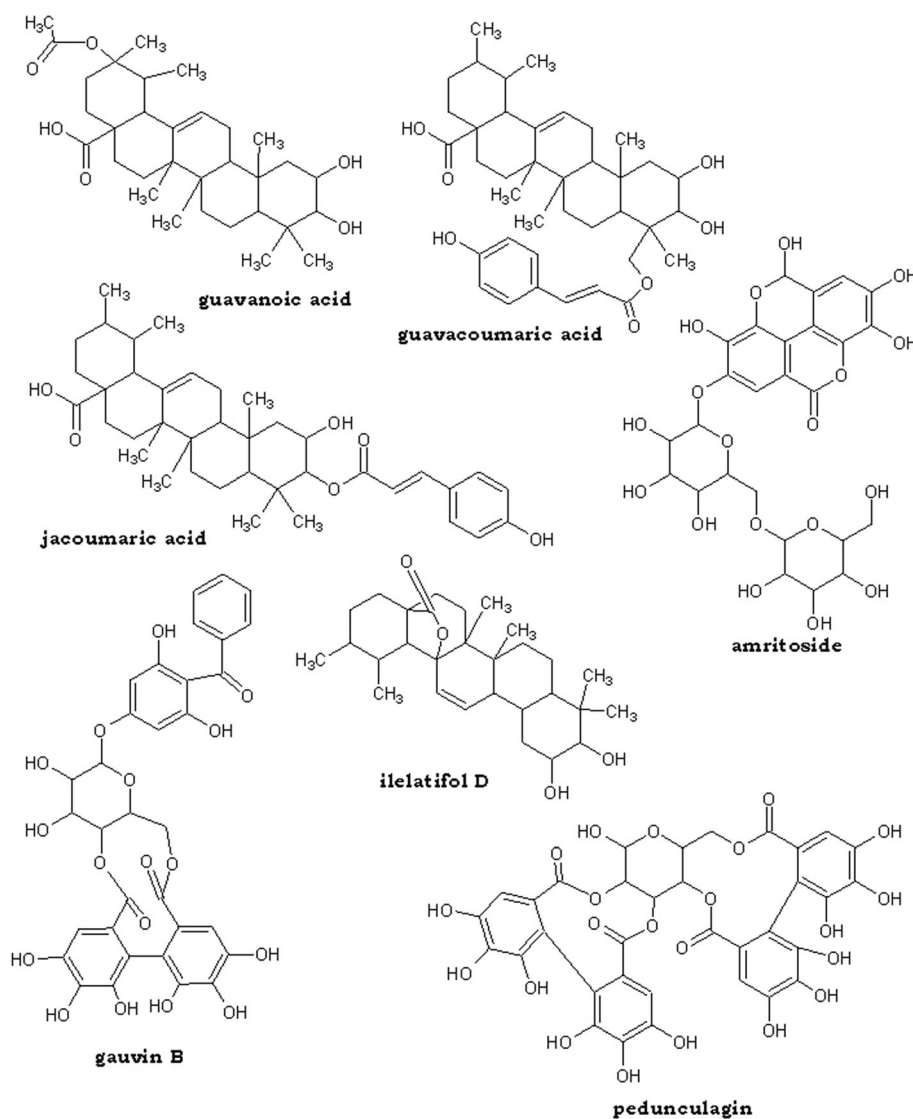
Flavonoids including quercetin and its glycosides have also been isolated from guava leaves (Fig. 3) [7, 8].

## 2.2 Pharmacological activities of guava leaves

Since long back, guava leaves have been used in treatment of various illnesses. However, their pharmacological activities have been proved scientifically in the last few decades. Based on the isolation of phytochemicals from guava leaves, and phytochemical prospection, phyto-compounds present in leaves are supposed to possess relevant biological activity. Pharmacological activity of guava leaves with model used for screening has been mentioned in Table 1.

## 2.3 Metallic nanoparticles green synthesized using guava leaves

Several researchers have successfully attempted the synthesis of metallic nanoparticles using mainly aqueous extract of *P. guajava* leaves. Use of water for extraction reveals the presence of primary and secondary metabolites, mainly of polar nature. Not reported so far, but primary metabolites like mono- and oligo-saccharides, polar proteins may also be present in the extract. However, polar secondary metabolites including glycosides and polyphenolics like flavonoids and tannins (as reported in earlier section) could be responsible for reduction of metal ions to nanoparticles.



**Fig. 3** Phytochemical constituents present in *P. guajava* leaves

**Table 1** Pharmacological activities of *Psidium guajava* leaves

| Pharmacological activity     | Model used in screening  | Reference |
|------------------------------|--|-----------|
| Antibacterial activity       | Broth micro-dilution assay and MIC determination               | [9]       |
| Anti-oxidant activity        | DPPH free radical scavenging assay                             | [10]      |
| Anti-diarrheal effect        | Castor oil-induced diarrhea (COID) model                       |           |
| Anti-diabetic activity       | Alloxan induced diabetic test model                            | [11]      |
|                              | Streptozotocin (STZ)-induced diabetes mellitus mode            | [12]      |
| Anti-hyperlipidemic activity | Lipase inhibition  | [13]      |
| Cardioprotective effects     | Ischemia-reperfusion injury using isolated perfused rat hearts | [14]      |
|                              | Inotropic effect   | [15]      |
|                              | Contractile effect on aortic rings in rat                      | [16]      |
| Hypotensive effect           | Hypertensive Dahl salt-sensitive rats                          | [12]      |
| Anti-proliferative activity  | Methylene blue assay   | [17]      |
| In vivo cytotoxic activity   | Brine shrimp cytotoxicity                                      | [18]      |
| In vitro anticancer assay    | MTT assay  |           |
| Anti-tumor activity          | Potato disk assay  |           |
| Anti-inflammatory potential  | Electrophoretic mobility shift assay                           |           |
| Hepatoprotective activity    | Carbon tetrachloride-induced liver toxicity                    | [19]      |
|                              | Paracetamol-induced liver toxicity                             |           |
|                              | Thioacetamide induced liver toxicity                           |           |
|                              | Ethanol-induced liver toxicity                                 | [20]      |

## 2.4 Gold nanoparticles

Use of *P. guajava* leave extract in fabrication of nanoparticles was initiated by Taha et al. in 2013, by synthesizing gold nanoparticles using  $25 \times 10^{-3}$  M gold (III) chloride hydrate ( $\text{HAuCl}_4 \cdot 3\text{H}_2\text{O}$ ) as a gold ions donor, which were reduced to nanoparticles by aqueous extract (prepared by extracting about 1 g of leave powder with 100 mL of de-ionized water for 24 h). They found few irregular but mostly spherical gold nanoparticles [21].

## 2.5 Titanium dioxide nanoparticles

In 2014, Santhoshkumar et al. attempted green synthesis of titanium oxide nanoparticles using aqueous extract (prepared by extracting about 20 g of leave powder with 250 mL of doubled-distilled water at 60 °C for 15 min) and 0.1 mM  $\text{TiO}(\text{OH})_2$ . They found titanium oxide nanoparticles spherical in shape. Further, they evaluated their antimicrobial activity against *A. hydrophila*, *E. coli*, *P. mirabilis*, *S. aureus*, *P. aeruginosa*, and antioxidant activity using sulfuric acid, sodium phosphate, and ammonium molybdate, DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging models [22].

## 2.6 Silver nanoparticles

So far numerous attempts were made for synthesis of silver nanoparticles using different plant extracts. The main reason lies in their application against variety of microorganisms by one or a combination of more than

one mechanism of anti-microbial activity, apart from different applications in different domains. Considering this wide range of utilities, several times, silver nanoparticles have also been tried to get prepared using *P. guajava* leave extract. Most of these researchers used 1 mM silver nitrate ( $\text{AgNO}_3$ ) as silver ions donor to be reduced by aqueous extract of *P. guajava* leaves, prepared in double-distilled water [23–25]; however, Dama et al. used methanol as solvent for extraction. They found silver nanoparticles in spherical shape and evaluated their anti-microbial efficacy against microbes like *E. coli*, *S. aureus*, and *P. aeruginosa* [26].

## 2.7 Tin oxide nanoparticles

M. Kumar et. al. proved that aqueous extract of *P. guajava* leaves could be utilized in reduction of 2.1 M tin (IV) chloride or stannic chloride ( $\text{SnCl}_4$ ) to spherical-shaped tin oxide nanoparticles. Additionally, researchers studied their photocatalytic activity using dye reactive yellow 186/vinyl disulphone RY 186 [27].

## 2.8 Zero-valent iron nanoparticles

A couple of years ago, Somchaidee et al. fabricated zero-valent iron nanoparticles using *P. guajava* extract prepared by extraction of about 4 g of leaf powder with 100 mL of three solvents, namely, water, ethanol, hydroethanolic solvent at 60 °C for 15 min. These extracts were then separately treated with ferric chloride ( $\text{FeCl}_3$ )



solution, which later formed zero-valent iron nanoparticles. Then, researchers tried their efficiency in photocatalytic degradation of dye methylene blue [28].

## 2.9 Zinc oxide nanoparticles

Last year, Saha et al. explored the use of extract of *P. guajava* leaves prepared by maceration of about 10 g of leaf powder with 100 mL of double distilled water for 24 h, in green synthesis of zinc oxide nanoparticles from zinc oxide donor, 1 M zinc acetate ( $\text{Zn}(\text{CH}_3\text{COO})_2$ ). After characterization, they determined photocatalytic activity (using dye methylene blue) and antimicrobial activity (against *E. coli* and *S. aureus*) of so synthesized zinc oxide nanoparticles [29].

## 2.10 Copper oxide nanoparticles

Recent attempt of *P. guajava* leaves extract use was made in synthesis of copper oxide nanoparticles where about 4 g of copper acetate monohydrate ( $\text{Cu}(\text{CH}_3\text{COO})_2$ ) in 10 mL de-ionized water was used as copper oxide ion donor [30]. Here, reduction and stabilization of copper oxide nanoparticles were achieved by aqueous extract of *P. guajava* leaves prepared by extraction of about 10 g of leaves powder with 100 mL of de-ionized water at 80 °C for 3 h. They found these copper oxide nanoparticles spherical in shape. Further, they determined their efficiency in photocatalytic degradation of dyes Nile blue and RY 160.

## 2.11 Screening of antimicrobial activity of *P. guajava* leaves assisted synthesis of metallic nanoparticles

Most of the metallic nanoparticles synthesized using *P. guajava* leaves have been evaluated for their antimicrobial potential by slightly different methods possessing some common aspects. Generally, for this, selected Gram-positive and Gram-negative bacteria sub-cultured in nutrient broth at 37 °C for 24 h and followed well diffusion assay. Then, a loopful of bacterial culture was swabbed over the solidified Mueller Hinton agar plates and incubated for 37 °C for 24 h. Finally, anti-bacterial

activity is revealed by occurrence of zone of inhibition around the well (Table 2).

## 2.12 Photocatalytic degradation of dyes by *P. guajava* leaves assisted synthesis of metallic nanoparticles

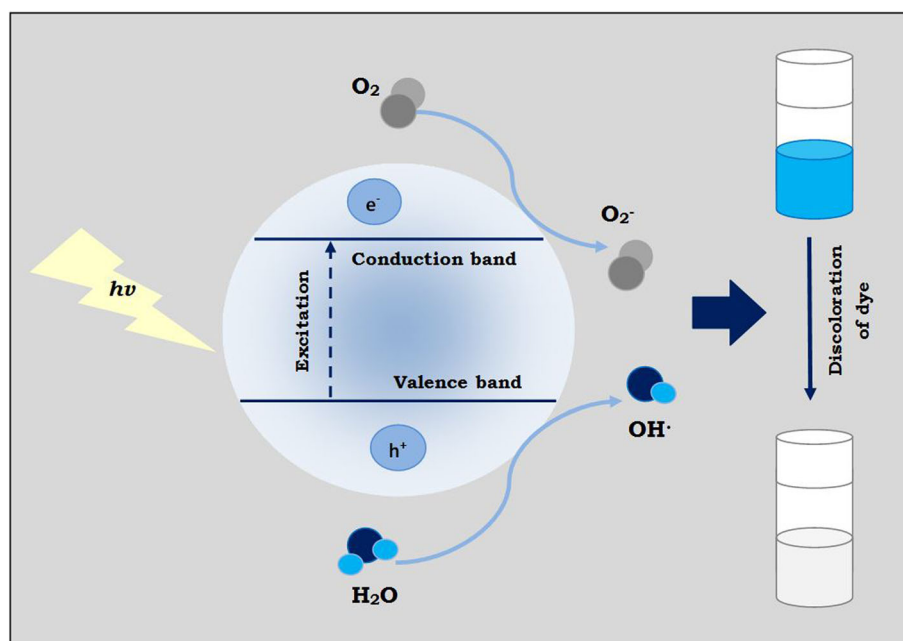
Similar to antimicrobial activity, the potential of most of metallic nanoparticles synthesized using *P. guajava* extract to cause photocatalytic degradation of dyes has also been determined, sharing common mechanism and deferring in dyes used. Photocatalysis is electromagnetic irradiation-induced series of chemical reactions including reduction and oxidation. When photons (in the form of light rays) irradiates the material with energy equal to or higher than its bandgap, electron in the conduction band (CB) jump to the valence band (VB) through the bandgap leaving positive holes. This leads to the formation of reactive oxygen species (ROS), which is the significant outcome of photocatalysis as it affects surrounding thereby used in degradation of dye and pollutants [31] and antibacterial potential [32] (Fig. 4). Here, absorbance of irradiation by material can be enhanced by doping, photosensitization of semiconductor, and use of plasmonic. The common approach of evaluating the photocatalytic efficiency is to compare between the initial concentrations of the unwanted compounds (e.g., dye as pollutant) with the concentration of these compounds after the photocatalytic reactions using the equation:

$$\ln \frac{C_0}{C_t} = kt$$

Tin oxide [27], zero-valent iron oxide [28], zinc oxide [29], and copper oxide [30] nanoparticles, green synthesized using aqueous extract of *Psidium guajava* leaves have been evaluated for their photocatalytic activity using dyes RY160 and RY186, methylene blue, or Nile blue.

**Table 2** Anti-microbial activity (in the form of zone of inhibition) exhibited by *P. guajava* leaves assisted synthesized nanoparticles against selected microbes

| Nanoparticle               | Zone of inhibition (in mm) |                 |                     | Reference |
|----------------------------|----------------------------|-----------------|---------------------|-----------|
|                            | <i>E.coli</i>              | <i>S.aureus</i> | <i>P.aeruginosa</i> |           |
| ZnO-chitosan nanocomposite | 28.6 ± 0.1                 | 30.3 ± 0.2      |                     | [29]      |
| TiO <sub>2</sub>           | 23                         | 25              | 19                  | [22]      |
| Silver                     |                            |                 | 23.3 ± 1.7          | [23]      |
| Silver                     | 11 ± 0.14                  |                 | 8 ± 0.09            | [26]      |
| Silver                     | 9.5                        | 10              | 10.5                | [24]      |
| Silver                     | 12                         | 12              |                     | [25]      |



**Fig. 4** Nanoparticles assisted photocatalysis and discoloration of dye

### 2.13 Future prospects

From this literature survey made for applications of *P. guajava* leaf extracts for the green synthesis of metal and metal oxide nanoparticles, it is clear that due to presence of variety of secondary metabolites which may have pharmacologically beneficial effect, responsible for reduction of donor compound to its corresponding nanoparticles and also for stabilizing them to particular size and shape. So, there are two different fronts at which research could be made: The first one is exploring the new applications of existing nanoparticles synthesized from *P. guajava* leaves. There are few biological aspects, where an active entity has to be penetrated inside the cell. Due to the high penetration ability of nanoparticles, antimicrobial and anti-cancer/anti-proliferative activities of existing as well as nanoparticles of different metals those could be synthesized from *P. guajava* leaves can be tried on different cell lines (other than those studied so far) and different microorganisms (other than those studied so far), respectively. The second approach involves eco-friendly synthesis of new nanoparticles of metals and metal oxides (other than those green synthesized so far) and/or evaluation of their potential in different scientific domains like cadmium sulfide antimicrobial nanoparticles,  $\text{Eu}_3^{3+}$  doped  $\text{Y}_2\text{SiO}_5$  nanophosphors to be used in light-emitting diodes (LEDs), cupric oxide nanoparticles to be used in dye-sensitized solar cells (DSSCs), and cerium oxide nanoparticles as an anti-obesity pharmaceutical formulation.

### 3 Conclusion

Based on this review, it can be concluded that *P. guajava* leaf extracts can be used for green synthesis of metallic nanoparticles having a wide range of applications in various scientific domains, including antimicrobial and photocatalytic activities.

#### Abbreviations

CB: Conduction band; COID: Castor oil-induced diarrhea; DPPH: 2,2-Diphenyl-1-picrylhydrazyl; MDPI: Multidisciplinary Digital Publishing; VB: Valence band; ROS: Reactive oxygen species; RY160 and 186: Reactive yellow 160 and 186; STZ: Streptozotocin

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SPP selected the topic and written manuscript. PMR drew figures and diagrams. All authors read and approved the final manuscript.

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**References**

- Patil SP (2020) *Calotropis gigantea* assisted green synthesis of nanomaterials and their applications: a review. Beni-Suef Univ J Basic Appl Sci 9:14. <https://doi.org/10.1186/s43088-020-0036-6>
- Dakappa SS, Adhikari R, Timilsina SS, Sajjekhan S (2013) A review on the medicinal plant *Psidium guajava* Linn. (Myrtaceae). J Drug Deliv Ther. 3(2): 162–168. <https://doi.org/10.22270/jddt.v3i2.404>
- Nwinyi O, Chinedu SN, Ajani OO (2008) Evaluation of antibacterial activity of *Psidium guajava* and *Gongronema latifolium*. J Med Plants Res. 2(8):189–192
- Jimenez-Escrib A, Rincon M, Pulido R, Saura-Calixto F (2001) Guava fruit (*Psidium guajava* L.) as a new source of antioxidant dietary fiber. J Agric Food Chem. 49(11):5489–5493. <https://doi.org/10.1021/jf010147p>
- Matsuo T, Hanamura N, Shimoi K, Nakamura Y, Tomita I (1994) Identification of (+)-gallochechin as a bio-antimutagenic compound in *Psidium guajava* leaves. Phytochemistry 36(4):1027–1029. [https://doi.org/10.1016/S0031-9422\(00\)90484-9](https://doi.org/10.1016/S0031-9422(00)90484-9)
- Begum S, Siddiqui BS, Hassan SI (2002) Triterpenoids from *Psidium guajava* leaves. Nat Prod Letters 16(3):173–177. <https://doi.org/10.1080/10575630290004251>
- Arima H and Danno G. Isolation of antimicrobial compounds from Guava (*Psidium guajava* L.) and their structural elucidation. Biosci Biotechnol Biochem 2002; 66(8):1727–30. doi: 10.1271/bbb.66.1727
- Abdel WSM, Hifawy MS, El GoharyandM HM. Isak. Study of carbohydrates, lipids, protein, flavonoids, vitamin C and biological activity of *Psidium guajava* L. growing in Egypt. Egypt J Biomed Sci. 2004; 16: 35–52.
- Neviton RS, Diógenes AGC, Michelle SS, Celso VN, Benedito PDF. An evaluation of antibacterial activities of *Psidium guajava* L.). 2005; Brazilian Arch Biol Technol 48 (3): 429–436. doi: <https://doi.org/10.1590/S1516-89132005000300014>
- Suganya T, Fumio I, Siriporn O (2007) Antioxidant active principles isolated from *Psidium guajava* grown in Thailand. Sci Pharm 75:179–193. <https://doi.org/10.3797/scipharm.2007.75.179>
- Mazumdar S, Akter R, Talukdar D (2015) Anti-diabetic and anti-diarrheal effects of ethanolic extract of (L.) Bat. leaves in Wister rats. Asian Pac J Trop Biomed 5(1):10–14
- Ojewole JA (2005) Hypoglycemic and hypotensive effects of *Psidium guajava* Linn. (Myrtaceae) leaf aqueous extract. Methods Findings Exp. Clin Pharm 27(10):689–695. <https://doi.org/10.1358/mf.2005.27.10.948917>
- Tella T, Masola B, Mukaratirwa S (2019) The effect of *Psidium guajava* aqueous leaf extract on liver glycogen enzymes, hormone sensitive lipase and serum lipid profile in diabetic rats. Biomed Pharmacother 109:2441–2446. <https://doi.org/10.1016/j.biopha.2018.11.137>
- Yamashiro S, Noguchi S, Matsuzaki T, Miyagi K, Nakasone J, Sakanashi M et al (2003) Cardioprotective effects of extracts from *Psidium guajava* L. and *Limonium wrightii*, Okinawan medicinal plants, against ischemia reperfusion injury in perfused rat hearts. Pharmacology 67(3):128–135. <https://doi.org/10.1159/000067799>
- Conde Garcia EA, Nascimento VT, Santiago Santos AB (2003) Inotropic effects of extracts of *Psidium guajava* L. (guava) leaves on the Guinea pig atrium. Brazilian J Med Biol Res 36(5):661–668. <https://doi.org/10.1590/S0100-879X2003000500014>
- Olatunji-Bello I, Odusanya AJ, Raji I, Ladipo CO (2007) Contractile effect of the aqueous extract of *Psidium guajava* leaves on aortic rings in rat. Fitoterapia 78(3):241–243. <https://doi.org/10.1016/j.fitote.2006.11.007>
- Sul'ain MD, Zazaliand KE, Ahmad N (2012) Screening on anti-proliferative activity of *Psidium guajava* leaves extract towards selected cancer cell lines. J US China Med Sci 9:30–37
- Ashraf A, Sarfraz RA, Rashid MA, Mahmood A, Shahid M, Noor N (2015) Chemical composition, antioxidant, antitumor, anticancer and cytotoxic effects of *Psidium guajava* leaf extracts. Pharma Biol 54(10):1971–1981. <https://doi.org/10.3109/13880209.2015.1137604>
- Roy CK, Kamath JV, Asad M (2006) Hepatoprotective activity of *Psidium guajava* Linn. leaf extract. Indian J Exp Biol. 44(4):305–311
- Hung-Hui C, Po-Hua W, Diana L, Yun-Chieh P, Ming-Chang W (2011) Hepatoprotective effect of guava (*Psidium guajava* L.) leaf extracts on ethanol-induced injury on Clone 9 rat liver cells. Food Nutr Sci 2:983–988
- Taha A, Shamsuddin M (2013) Biosynthesis of gold nanoparticles using *Psidium guajava* leaf extract. Malaysian J Fundam Appl Sci. 9(3):119–122
- Santhoshkumar T, Rahuman AA, Jayaseelan C, Rajakumar G, Marimuthu S, Kirithi AV, Velayutham K, Thomas J, Venkatesan J, Kim S-K (2014) Green synthesis of titanium dioxide nanoparticles using *Psidium guajava* extract and its antibacterial and antioxidant properties. Asian Pac J Trop Med 7(12):968–976
- Bose D, Chatterjee S (2016) Biogenic synthesis of silver nanoparticles using guava (*Psidium guajava*) leaf extract and its antibacterial activity against *Pseudomonas aeruginosa*. Appl Nanosci 6:895–901. <https://doi.org/10.1007/s13204-015-0496-5>
- Geetha V (2017) Green synthesis of silver nanoparticles from *Psidium guajava* leaves and its antibacterial activity. Int J Bioassays 6. 7(5441):5443. <https://doi.org/10.21746/ijbio.2017.07.003>
- Sharmila C, Ranjith Kumar R, Chandar Shekar B. 2018. *Psidium guajava*: a novel plant in the synthesis of silver nanoparticles for biomedical applications. Asian J Pharm Clin Res, 11(1): 341–345. doi: <https://doi.org/10.22159/ajpcr.2018.v11i1.21999>
- Dama LB, Mane PP, Pathan AV, Chandarkar MS, Sonawane SR, Dama SB, Chavan SR, Chondekar RP, Vinchurkar AS (2016) Green synthesis of silver nanoparticles using leaf extract of *Lawsonia inermis* and *Psidium guajava* and evaluation of their antibacterial activity. Science Res Rep 6(2):89–95
- Kumar M, Mehta A, Mishra A, Singh J, Rawat M, Basu S (2017) Biosynthesis of tin oxide nanoparticles using *Psidium guajava* leave extract for photocatalytic dye degradation under sunlight. <https://doi.org/10.1016/j.matlet.2017.12.074>
- Somchaidee P, Tedsree K (2018) Green synthesis of high dispersion and narrow size distribution of zero-valent iron nanoparticles using guava leaf (*Psidium guajava* L.) extract. Adv Nat Sci Nanosci Nanotechnol. 9. 035006 (9 pp), <https://doi.org/10.1088/2043-6254/aad5d7>
- Saha R, Subramani K, Petchi Muthu Raju SAK, Rangaraj S, Venkatachalam R (2018) *Psidium guajava* leaf extract-mediated synthesis of ZnO nanoparticles under different processing parameters for hydrophobic and antibacterial finishing over cotton fabrics. Progress Organic Coatings 124:80–91. <https://doi.org/10.1016/j.porgcoat.2018.08.004>
- Singh J, Kumar V, Kim K-H, Rawat M (2019) Biogenic synthesis of copper oxide nanoparticles using plant extract and its prodigious potential for photocatalytic degradation of dyes. Environ Res 177:108569. <https://doi.org/10.1016/j.envres.2019.108569>
- Liu M, Zhang D, Chen S, Wen T (2016) Loading Ag nanoparticles on Cd(II) boron imidazolate framework for photocatalysis. J. Solid State Chem. 237: 32–35. <https://doi.org/10.1016/j.jssc.2016.01.016>
- Fakhri A, Naji M (2017) Degradation photocatalysis of tetrodotoxin as a poison by gold doped PdO nanoparticles supported on reduced graphene oxide nanocomposites and evaluation of its antibacterial activity. J Photochem Photobiol B 167:58–63. <https://doi.org/10.1016/j.jphotobiol.2016.12.027>

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