



# Phytochemical and pharmacological activities of *Solanum surattense* Burm. f.–A review

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## ABSTRACT

Medicinal plants are unique in having the ability to produce diverse chemical compounds with remarkable biological activities. Investigations of medicinal plants resulted in the discovery of a large number of bioactive compounds with excellent therapeutic properties. *Solanum surattense*, a perennial wild growing medicinal herb, is widely used in the traditional medicine. Exhaustive literature availability reveals the presence of phytochemical compounds from different plant parts like roots, stem, leaves, fruits, and seeds reported to possess a wide range of pharmacological activities like hepatoprotective, cardioprotective, antiasthmatic and mosquito repellents properties. Intensive investigation on phytochemical constituents resulted in isolation of alkaloid and steroidal compounds solasonoie, solamargine, campesterol, and diosgenin. Evaluation of therapeutic activity of isolated compounds proved as potent ones with reference to the standard. Current literature on the pharmacological activity of *S. surattense* confirms the scientific validation of folklore claims and its traditional use to cure various ailments. Present review is undertaken to summarize all the available information on pharmacological activities, which provide a baseline support for further exploration of its unexplored therapeutic effects like immunomodulation, antipiles activity, antianaphylactic activity, and sexual behavior claimed by folklore.

## INTRODUCTION

Plants have been used as a potential source of medicine, due to an enormous diversity of bioactive compounds. Many of the plants used in the traditional medicine to alleviate the common ailments and to promote a healthy life. World Health Organization mentioned that 80% of world population are dependent on the traditional medicine (Sen and Chakraborty, 2016). India possesses well-versed knowledge of the traditional medicine and its practice since from the ancient past. The continuity of the traditional medicinal practice still today, owing to its cure and effective restoration potential. Bioactive compounds from the plant sources have always been of great significance to develop novel therapeutic drugs. In recent years, increased attention toward the

use of herbal drugs has been observed throughout the world. The resurgence in usage of herbal medicine accelerates the research on pharmacological activities of plants used in the traditional medicine.

*Solanum surattense* (Solanaceae) is a perennial wild growing medicinal herb used as a traditional and folklore medicine. Ancient Indian text *Materia medica* mentioned the use of *S. surattense* leaves to cure a wide range of ailments. *Solanum surattense* usually called as Indians nightshade (English), Nelamulaka (Telugu), and Kantakari (Sanskrit). It is a distributed in Australia, Ceylon, India, Malaysia, Polynesia, and Southeast Asia (Parmar *et al.*, 2010; 2017). Commonly found as wild growing plant along the roadsides and dry wastelands. Phytochemical profile of *S. surattense* reported the presence of alkaloids, flavonoids, phenols, and steroids. Clinical studies on antiasthmatic and curing dental inflammation revealed the effective therapeutic potential of *S. surattense*. Exploration of various pharmacological effects from *S. surattense* emphasized

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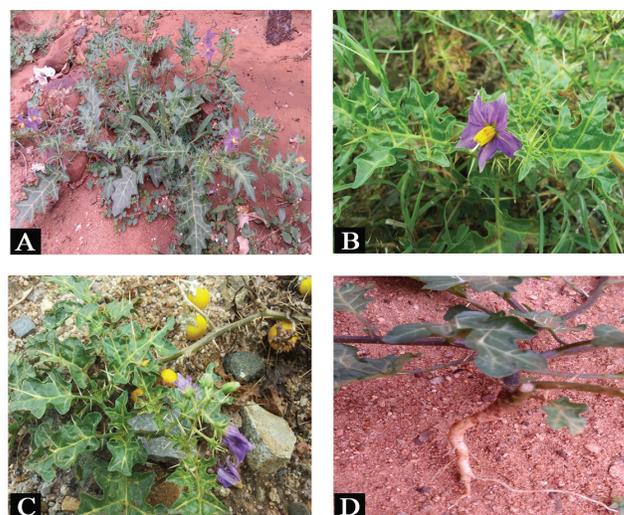
the possible use of bioactive compounds to develop novel therapeutic drugs. It's a promising approach in search and development of the modern medicine, based on traditional medicinal knowledge. Present review, aimed to provide deep insights on its wide range of pharmacological activities and clinical studies of *S. surattense* reported from previous studies (Nithya *et al.*, 2018). It also provides the scope to uncover the unexplored potentialities like immunomodulation, antipiles activity, antianaphylactic activity, and sexual behaviour claimed by folklore.

## METHODOLOGY

*Solanum surattense* synonyms were confirmed through the plant data available site ([www.theplantlist.org](http://www.theplantlist.org)). To present this review, we follow the methodology of collecting enormous data from the most authenticated and scientifically sound sources such as Google Scholar (<http://scholar.google.com>), data bases include PubMed (<http://www.ncbi.nlm.nih.gov/pubmed>), Scopus (<https://www.scopus.com>), Research Gate (<https://www.researchgate.net>), Science Direct (<https://www.sciencedirect.com>), SciFinder (<http://www.libnet.ulg.ac.be/en/eresources/scifinder-scholar>), and Web of knowledge for the search terms: folklore medicine, ethnomedicinal, phytochemistry, and pharmacological activities of *Solanum surattense* and its synonyms also. The literature related to species distribution, synonyms, morphological characters, ethnomedicinal, phytochemistry, clinical study, pharmacological activities, and toxicity of *S. surattense* was included. The phytochemical data were arranged according to category of constituents shown in Figure 2A and B. The selected phytochemical compound structures downloaded from consulting open chemistry database PubChem (<http://pubchem.ncbi.nlm.nih.gov/search/#collection=compounds>), and redrawn through the freeware version of the software ChemSketch.

## Morphological Description of *Solanum surattense*

*Solanum surattense* is prickly, diffused perennial herb, about 1.2-m tall usually with woody base. Stem profusely branched, somewhat zig zag, the young branches clothed with dense satellite and tomentose hairs, prickles compressed straight, glabrous, and shiny, often 1–3 cm long, leaves ovate–elliptic, deeply lobed, base attenuate, veins and margins with spines. Flowers bluish-pink in extra-axillary racemes. Calyx lobes 5, free, abovate, prickly acuminate. Corolla broadly ovate–triangular, lobes 5 acute. Stamens 5. Fruit-Berry, globose, green with white stripes, yellow when ripe, seeds circular, numerous, and smooth (Singh and Singh, 2010). Its taxonomy and nomenclature are as follows: Plant name: *S. surattense*; Kingdom: Plantae; Division: Magnoliophyta; Class: Magnoliopsida; Order: Solanales; Family: Solanaceae; Genus: Solanum. Synonyms Latin: *Solanum surattense* Burm. f Syn; *Solanum xanthocarpum* Schrad. & H. Wendl., *Solanum virginianum* L., *Solanum mairei* H. Levy. The vernacular names in different regional languages in India are as follows: Telugu: Nelamulaka, Vakudu; Sanskrit: Kantakari, Nidightika; Hindi: Katari; Tamil: Kankan, kattiri; Kanada: Nelagulla; Oriya: Bhejibegun and Ankranti. The habitat of plant represented in Figure 1.



**Figure 1.** *Solanum surattense*: (A) habitat, (B) flowering, (C) matured plant with ripened fruits, and (D) root system.

## Ethno medicinal usage

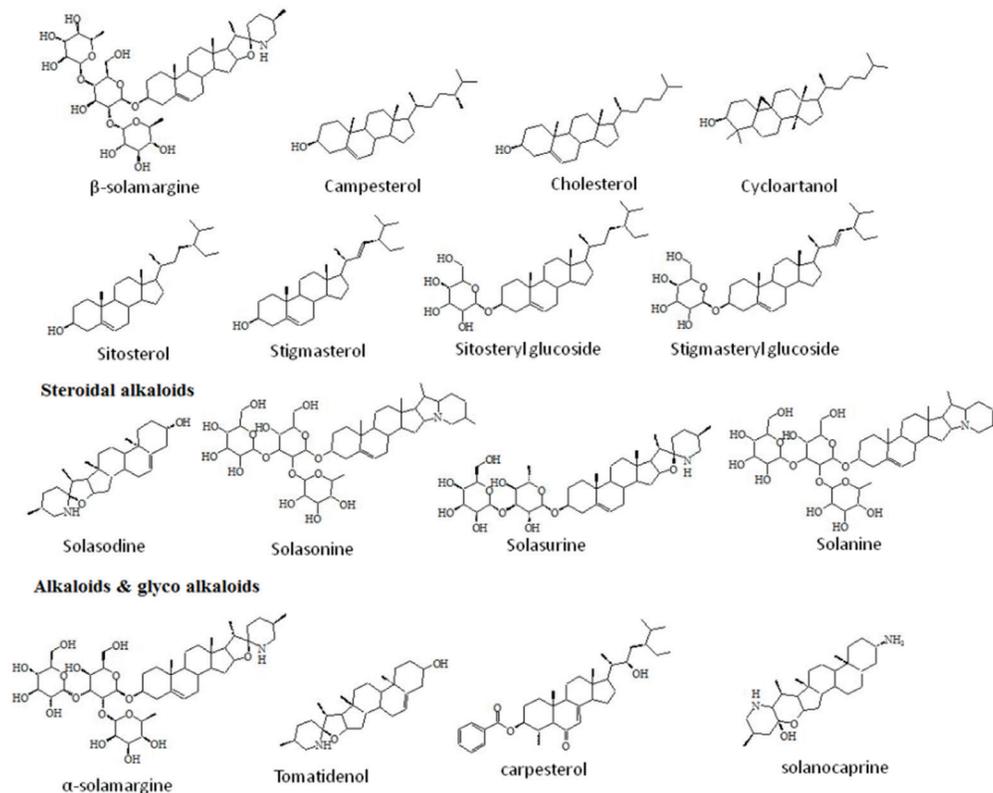
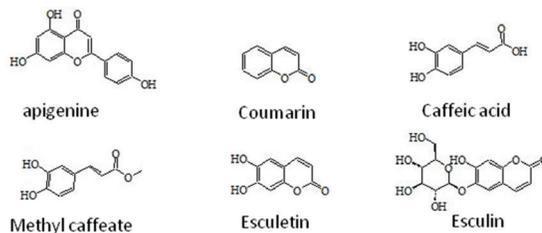
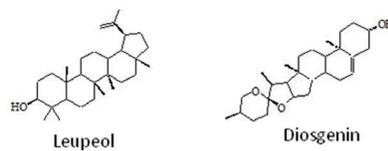
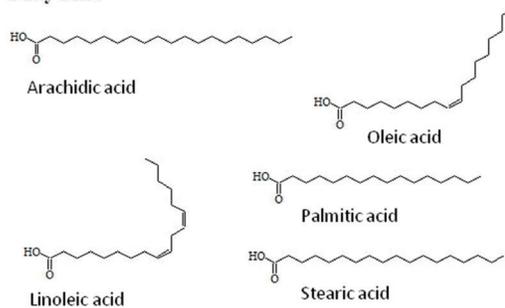
Roots of *S. surattense* are one of the important constituent of Ayurvedic preparation dashmularishta, used as a tonic for lactating mothers (Sharma *et al.*, 2010). Kondh tribes of Dhenkanal district of Orissa, India are using the hot aqueous extract of the matured fruits as a traditional medicine for the treatment of diabetes mellitus (Parmar *et al.*, 2010). Fruits used as a folk medicine to treat inflammatory problems as well as a throat infection by the local people of Manipur, India. Entire plant used for treating leprosy, dropsy, and cough by the folklore (Madhavi *et al.*, 2014). Mukunda tribes of Rajasthan, India used the root paste for the treatment of hernia (Pandey *et al.*, 2018). Root poultice used to treat the piles are practicing as a traditional medicine in many villages of South India. Seeds along with mustard oil fumigation used as an excellent remedy for the treatment of dental caries, teeth pain, and pus formation and associated swelling of gums (Panday, 2004). Stem, flowers, and fruits are used for relief in burning sensation in feet (Pingale, 2013). Seeds also used as a remedy for cough and asthma (Rahman *et al.*, 2003).

## Phytochemical profile

Roots of *S. surattense* are reported to possess Alkaloids, Flavonoids, Triterpenoids, Tannins, Saponins, Glycosides, and steroids (Ghildiyal and Joshi, 2014; Sahle and Okbatinsae, 2017).

### Phytochemistry

Initially, the *S. surattense* fruits was investigated by the Saiyed and Kanga (1936), and they were used for the isolation of bioactive compounds such as glycoalkaloid (solanosine), steroidal compound (carpenterol) and steroidal alkaloids (caffeic acid, coumarins, and triterpenoids). The fruits of *S. surattense* possess steroidal alkaloids like solanocarpine, solamorgine, and solanocarpidine (Jayakumar and Murugan, 2016). The other effective bioactive compounds which include polyphenol (caffeic acid), coumarins (esculentin and aesculin), steroids (carpenterol, carpenterol, daucosterol, stigmasterol, cycloortanol and cholesterol),

**A Steroids****B Flavanoids, Phenolics & Comarins****Triterpenoids & Sapogenin****Fatty acids**

**Figure 2.** (A) Steroids, steroidal alkaloids, alkaloids, and glycoalkaloids phytochemical compounds structures isolated from *Solanum surattense*. (B) Flavanoids, phenolics, coumarins, triterpanoids, sapogenin, and fatty acids isolated compound structures from *S. surattense*.

triterpinins and sapogenin (lupeol and diosgenine) have also been reported (Khanam and Sultana, 2012; Singh and Singh, 2010).

Berries of *Solanum surattense* contain high concentration of an alkaloid solosodine, which is shown the variation in its content in the range of 1.1%–4.6% (Singh and Singh, 2010). Berries collected in autumn (September–October) yielded the alkaloids solasonine and solamorgine. However, the fruits collected in summer (May–June) yielded another alkaloid solasonine (Parmar *et al.*, 2010).

Heble (1971) reported the presence of  $\beta$ -sitosterol and diosgenin from callus tissues of *S. surattense*. Yield of  $\beta$ -sitosterol and the diosgenin from callus tissues was much higher than that of naturally grown plant. Further investigation on the fruit extract of *S. surattense* showed the presence of steroidal and alkaloid compounds—cyclocartanol, cycloartinol, sitosterol, stigmaterol, campsterol, sitosteryl glucoside, solamargine, and  $\beta$ -solamargine. Dry seeds yielded greenish yellow oil rich in fatty acids—linoleic acid, oleic acid, palmitic, steric and arachidonic acid (Heble *et al.*, 1971). Structures of some phytoactive compounds from *S. surattense* are shown in Figure 2A and B.

### Pharmacology of *Solanum surattense*

*Solanum surattense* have the several pharmacological activities, proved by scientific observations of experimental works. The bark, leaves, roots and fruits extensively used in traditional medicine due to the presence of several phytoconstituents like alkaloids, terpenoids, saponins, steroids and flavonoids. Scientific evaluations of isolated bio-compounds have ethnomedicinal and novel pharmacological effects (Figure 3).

#### Antibacterial activity

Many studies have been carried out with the aim of highlighting the capacities of plant extracts to prevent the growth of the bacterial organisms. Leaf extract of *S. surattense* exert the remarkable effect on bacterial strains. Sheeba (2010) reported a significant antibacterial effect of ethanol extracts of *S. surattense* leaf against eight bacterial strains, *Staphylococcus aureus* (11.23 mm), *Streptococcus* (9.22 mm), *Bacillus subtilis* (16.25 mm), *Escherichia coli* (14.19 mm), *Pseudomonas aeruginosa* (4.16 mm), *Salmonella typhi* (1.16 mm) *Vibrio cholera* (10.17 mm). No effect observed with *Shigella dysenteriae* (Sheeba, 2010). Fruits extracts of *S. surattense* exhibited potential effect in preventing the following bacterial strains, Minimum and maximum zones of inhibition observed with *Micrococcus luteus* (3.6, 12.7 mm) *S. aureus* (3.9, 14.0 mm) *E. coli* (8.6, 17.8 mm), *S. typhi* (6.5, 15.7 mm), *M. varians* (7.4, 10.3 mm) *Pasteurella multiformis* (12.5, 20 mm) *V. cholera* (0 mm) (Abbas *et al.*, 2014). Antibacterial efficiency of plant extracts was similar to the efficiency of standard drug ampicillin. Previous studies have reported that the antibacterial activity of *S. xanthocarpum* leaves against the five bacterial stains such as *P. aeruginosa*, *S. typhi*, *S. aureus*, *E. coli*, and *Corynebacterium diphtheriae* (Nithya *et al.*, 2018). Among the solvent extracts, ethyl acetate extracts exhibit moderate and broad spectrum activity against *P. aeruginosa* ( $8 \pm 1.2$  mm) and *S. aureus* ( $7 \pm 1.0$  mm), respectively, and does not show inhibitory activity for *S. typhi*. Other solvent extractions, such as chloroform, hexane and acetone exhibited that the very least antibacterial activity against the *S. aureus*, *P. aeruginosa*, and *C. diphtheriae*.

#### Antifungal activity

*Solanum surattense* extract are evaluated for antifungal effectiveness and a wide range of zone of inhibition has been evidenced against many of the fungal stains such as *Trichoderma viride*, *Aspergillus niger*, *A. flavus*, and *A. Fumigatas*.

Singh *et al.* (2007) reported antifungal efficiency of isolated steroidal glycosides (carpestroal) on *T. viride* and *A. niger*. *Trichoderma viride* exhibited the highest susceptibility and showed the highest growth inhibition antifungal effect of plant extracts were similar to that of standard drug amphotericin-B. In comparison with the fruit extracts, it is less than the effect of standard drug because of the low dose of antifungal components.

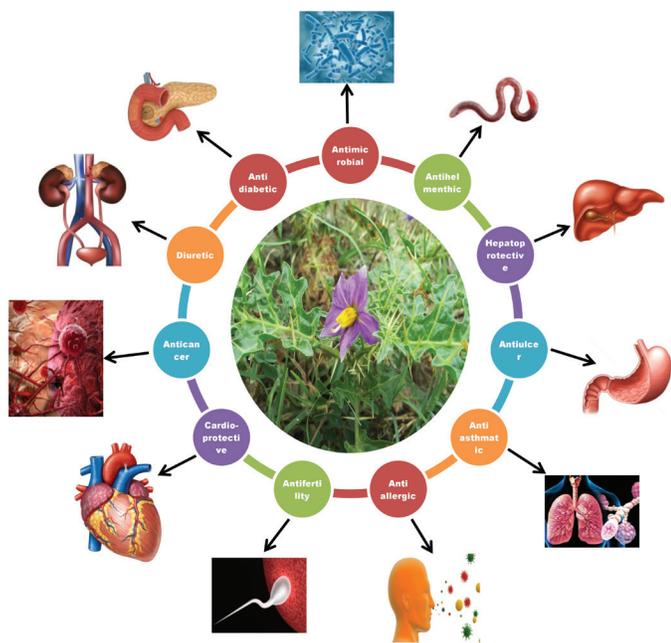
#### Antioxidant activity

Antioxidants are capable of damaging the reactive oxygen species (ROS), that cause oxidative damage. Free radicals react with the bio molecules like DNA, proteins lipids and produce the toxic effects. So far, a large number of plants reported to possess anti-oxidant potential due to rich phytochemical constituents like phenols and Flavonoids. Yadav *et al.* (2014) reported the total phenolic and flavonoid content from leaf [25.91 gallic acid equivalent (GAE)/mg b.w] [17.7 Quercitien (QE)], stem (5.879 GAE/mg b.w) (3.129 QE), and fruit (4.975 GAE/mg b.w) (5.208 QE) phenol quantity expressed as GAE and flavonoid content as Quercitien. The leaf contains high quantity of phenols and flavonoid than the stem and fruits. Muruhan *et al.* (2013) evaluated the ROS scavenging efficiency of *S. surattense* leaf extracts against 2,2-diphenylpicrylhydrazyl scavenging activity, revealed that the plant extract exhibited remarkable antioxidant activity at all test doses in a dose-dependent manner. Fruit extracts also reported to possess appreciable amount of radical scavenging activity (about 80%) at the lowest test conc. (250  $\mu$ g/ml). No enhanced activity was observed at increased test dose conc. 500 and 1,000  $\mu$ g/ml, due to saturation effect (Rehman Shah *et al.*, 2013). Similar findings also noticed from anti-oxidant studies of *S. surattense* fruit extracts (Kumar and Pandey, 2014).

Poongothai *et al.* (2014) reported that *S. surattense* leaf extracts enhanced the level of anti-oxidant enzymes catalase (CAT), superoxide dismutase (SOD), and glutathione (GSH) peroxidase in alloxan-induced animal models. Plant extracts increased the anti-oxidants to normal level and the efficiency was similar to standard drug glibenclamide. Remarkable anti-oxidant potentiality of *S. surattense* leaf extracts might be attributed to the presence of phenolic and flavonoids compounds in high quantity (Poongothai *et al.*, 2014). All these findings confirm *S. surattense* to be an ideal choice to pursue the further exploration in developing the effective natural anti-oxidants.

#### Mosquito larvicidal effect

Mosquito larval diseases such as malaria, dengue, filariasis, yellow fever, and Japanese encephalitis are prevalent in the tropical countries. The concentration of large number of mosquito vector species in the tropical region increases the risk to affect from the above diseases. The control of mosquito born disease such as malaria is becoming increasingly difficult, because of development of resistance in mosquitoes made the vector control strategy ineffective. Application of chemical and synthetic larvicides to control the larval vectors resulted in the



**Figure 3.** Graphical representation of pharmacological activities reports in *S. surattense*.

development of insecticide resistance and adversely affects the environment by contaminating the soil, air and soil due to their hazardous and persistence properties. Environmental degradation, bio magnification, and increased resistance in mosquitoes for dichloro diphenyl trichloroethane are a well-known fact. Most efficient approach is to control the mosquito vectors during the stage of larval development. Nature has given the plants, which destroys the mosquitoes during larval stage. Bansal *et al.* (2009) reported the larvicidal efficiency of *S. surattense* fruit extracts against four vector species such as *Anopheles culifaci*, *Anopheles stephensi*, *Aedes aegypti*, and *Culex quinquefasciatus*. *Anopheles* sps are the important vectors of malaria, whereas *A. aegypti* cause dengue and *Culex* cause filariasis. *Anopheles culifaci* showed more susceptibility, followed by *A. Stephensi*, *A. Aegypti*, and *C. quinquefasciatus*. Among the extracts of different parts like whole fruit, seeds, and fruit without seeds, seed extracts exhibited potential larvicidal efficiently followed by whole fruit and the least by fruits without seeds (Bansal *et al.*, 2009). Mohan *et al.* (2005) reported that, along with the fruits, the roots of *S. surattense* also effective against larvae of *A. Stephensi* and *Culex* sps. Subsequent studies carried out by Mohan *et al.* (2007) synergistic effect of *S. surattense* root extract and synthetic pyrethroid cypermethin in 1:1 ratio exhibited the highest mosquito larvicidal efficiency than the other test ratios 1:2 and 1:4. Previous study with root extract of *S. surattense* confirmed the mosquito larvicidal property and its efficiency further enhanced by the cypermethrin due to synergism. Similar studies carried out by Bansal *et al.* (2015) reported that the synergetic efficiency of the *S. surattense* and *Withania somnifera* against the larval vectors of three mosquito vector species like *A. stephensi*, *A. aegypti*, *C. quinquefasciatus*. Among the three, *A. stephensi* was more susceptible to the test ratio 1:3 Ws: Ss. Individual extracts, *S. surattense* had shown more effectiveness

as compared with the *W. somnifera* with all three vector species. The larvicidal efficiency was higher with increased in proportion of *S. surattense* and get decreased with increase in proportion of *W. somnifera* extract (Bansal *et al.*, 2015). Leaf extract of *S. surattense* also reported to possess larvicidal efficiency against *C. Quinquefasciatus* (Mahesh Kumar *et al.*, 2012). Hence, from the above findings, it was clear that *S. surattense* possess individual and synergetic mosquito larvicidal efficiency. These studies considered to be of great importance in notifying the potential larvicidal compounds from the natural source.

#### Antimalarial activity

Emergence of malaria in many parts of world due to the development of resistance of vectors. Availability of the antimalarial drugs also associated with some side effects because of its synthetic chemical nature. This necessitates searching the safe and effective antimalarial drugs alternative to the existing ones (Antony and Parija, 2016). Traditional medicinal knowledge yields the anti-malarial drugs like quinine and artemesin and their efficiency to control the malaria, stimulated many researchers to find the similar potential anti-malarial drug from the plant sources (Pulice *et al.*, 2016). Ramazani *et al.* (2010) reported that *S. surattense* possess anti-malarial activity. *Solanum surattense* extract exhibited antiplasmodial activity with an  $IC_{50} = 50 \mu\text{g/ml}$  on K1 strain (*Plasmodium falciparum* resistant),  $IC_{50} = 40.88 \mu\text{g/ml}$  on chloroquine-sensitive strain (Chloroquine-sensitive). Recently, Kaushik *et al.* (2015) reported that the antiplasmodial activity of *S. surattense* aerial part extraction (ethyl acetate) against the *P. falciparum*. Accordingly, the  $IC_{50}$  of *P. falciparum* 3D7 strain was showed  $17 \mu\text{g/ml}$  and Indonesia strain of *P. falciparum* strain showed  $7 (0.41) \mu\text{g/ml}$  values. In addition, the cytotoxicity ( $TC_{50} \mu\text{g/ml}$ ) of *S. surattense* showed  $75 (10.7) \mu\text{g/ml}$  against HeLa cell lines.

#### Anthelmintic activity

Priya *et al.* (2010) evaluated the anthelmintic activity of *S. surattense* whole plant crude aqueous, hydroethanolic, and ethanolic extracts at 25, 50, and 100 mg/ml conc. in distilled water. Piperazine citrate  $10 \mu\text{g/ml}$  used as a reference standard. The study revealed ethanolic plant extracts (100  $\mu\text{g/ml}$  conc.) showed the remarkable anthelmintic property than aqueous and hydroethanolic extracts. Barik *et al.* (2018) noticed similar findings on the anthelmintic efficiency of *S. surattense* fruit ethanolic and aqueous extracts.

#### Anti-asthmatic activity

Asthma, a chronic inflammatory disease affects airway by obstruction, eosinophilia, and bronchial hyper responsiveness (Zanini *et al.*, 2015). Asthma became a global health problem result from a complex interaction between genetic and environmental factors. Use of bronchial dilators and steroidal inhalers, the effectiveness is only limited to mild-to-moderate asthma. However, the use of steroidal related medications has not been right solution because some adverse effects are also associated with that. Literature reveals many plants are reported to have well-defined anti-asthmatic agents and for some agents, the possible anti-asthmatic mechanism was explored. In search of safe and effective medicine from the plants to cure asthma, *S. surattense*

considered as the right choice, because of long usage in Ayurveda and Siddha as effective to cure respiratory disorders (Babu *et al.*, 2009). Anti-asthmatic efficiency studies on *S. surattense* flower extracts revealed that the presence of anti-histamine and mast cell stabilizing efficiency.

### Clinical studies

Shirishadi, a polyherbal drug used to treat asthma, *S. surattense* forms one of the important constituents. Clinical studies on 60 bronchial asthmatic patients resulted that significant improvement in pulmonary expiratory flow rate (PEFR), forced vital capacity (FVC), and forced expiratory volume (FEV). A constant change was observed throughout the follow up, no resume of bronchial constriction. Clinical trials proved that anti-asthmatic potentiality of polyherbal drug for the management of asthma (Divya *et al.*, 2013).

Govindan *et al.* (1999) studied the clinical efficiency of *S. surattense* on bronchial asthma, by the administration of single dose (300 mg) to the patients suffering from mild-to-moderate asthma, resulted that relief from asthmatic symptoms were observed after 1 hour and its effect lasted for about 6–8 hours. Potentiality of the plant extracts was evidenced in values of PEFR, FVC, FEV, and forced expiratory flow confirm the improvement of the pulmonary function. The anti-asthmatic response observed for *S. surattense* is apparently less than compared with that of standard bronchodilator drug Salbutamol and deriphillin. No untoward effects noticed during the study. The low response of the *S. surattense* extracts due to the crude form of drug or less effective dose. Administration of plant extract for 3 days resulted in the progressive improvement in respiratory function of asthmatic individuals. Significant improvement in PEFR and the reduction of other symptoms like cough, breathlessness, and the formation of sputum clearly indicate its potential bronchodilator effect. The effective response exhibited by plant extracts was equivalent to that of standard drug deriphylline, but less than salbutamol. Clinical studies confirm the traditional use of *S. surattense* in bronchial asthma. Accordingly, *S. surattense* has been defined as the ideal candidate for the modern medicine towards asthma.

### Anti-cancer activity/apoptosis

Plants serve as an excellent source of anticancerous drugs. The success of plant-based anti-cancerous drugs like vinblastine, vincristine, podophyllotoxin, and camptothecins... etc. inspires the researchers to continue the search for new anticancerous agents from plants. Anticancerous efficiency of *S. surattense* further widens the pharmacological properties. The anti-cancerous efficiency of *S. surattense* due to the presence of secondary metabolites of Lupeol, apigenin, solamargine and diosgenins. Solamargine, a steroidal alkaloid possess antitumor effect (Burger *et al.*, 2018). Kuok *et al.* (2000), tested the anticancerous property of solamargine (glycoalkaloid) on human hepatoma cells (Hep3 cells). Two hours incubation with a constant concentration of solamargine triggered the apoptosis of maximum number of Hep3 cells. Cells in G<sub>2</sub>/M phases are relatively susceptible to apoptosis mediated by solamargine. The possible mechanism of solamargine-mediated apoptosis is due to up regulation of tumor necrosis factor (TNF) receptor-I and II on Hep3B cells. TNF-I or II specific antibody neutralizes the

cytotoxicity mediated by solamargine strengthened the underlying mechanism of solamargine-mediated apoptosis of He3B cells. Kumar and Pandey (2013) evaluated the anticancerous efficiency of fruit extract of *S. surattense* on human lung cancer cell lines (HOP-62) and leukemic (THP-1) cell lines. Non-polar extracts (hexane, benzene, chloroform, and ethyl acetate) exhibited potent anticancer activity against THP-1 cell lines (85%–90% growth inhibition). Chloroform and benzene fractions accounted for about 70% cytotoxicity against lung cancer cell lines (HOP-62). The anticancer efficiency of *S. surattense* of fruit extracts on THP-1 cell lines established a positive correlation between flavanoid content and percentage of growth inhibition in cell lines. Anticancerous efficiency of *S. surattense* fruit extracts might be attributed to the presence of flavanoids such as apigenin, quercetin, fisetin, and luteolin, which known to be the potent inhibitors of cancer cell proliferation (Kumar and Pandey, 2014). Solamargine and solasodine are cytotoxicity to Hep 2 B cells of 10 µm (Cham, 2017). Diosgenin exhibited apoptosis activity on HCT 116 cell lines (Human colon carcinoma cell lines) (Sethi *et al.*, 2018). The apoptotic efficiency was weak by comparison to the standard drug cisplatin (Bhutani and Paul, 2010). The presence of 2- rhamnose moiety of solamargine and solasonine was essential for apoptosis induction. Solasodine and diosgenin, do not contain carbohydrate moieties, were only weakly cytotoxic. These findings of the study confirm the apoptosis inducing activity and to cause cell death, by the steroidal constituents from *S. surattense*. Thorough systematic investigations required to understand the detailed mechanism of inducing apoptosis and cell death, to develop the potential therapeutic drug to overcome cancer.

### Anti-HIV activity

Kumar and Pandey (2014) reported that the fruit extract of *S. surattense* possess anti-reverse transcriptase (RT) activity. Non-polar extracts (hexane, benzene, chloroform, ethyl acetate, and acetone) and aqueous extracts at dose 0.6 and 6.0 µg/ml are tested to evaluate the anti-RT activity. Results revealed that non-polar extracts showed that dose-dependent inhibitory activity. Benzene and acetone extracts at 0.6 µg/ml conc. exhibited the highest (20%) percentage of RT inhibition, whereas extracts at 6 µg/ml conc., benzene exhibited the highest (25%) percentage of RT inhibition followed by hexane (20%) and chloroform (15%). However, the fruit extracts (non-polar) of *S. surattense* showed lower percentages of RT inhibition with reference to the standard drug Nevirapine.

### Analgesic activity (reducing the tooth pain)

Panday (2004) reported that seed fumes of *S. surattense* used for the treatment of tooth pain and pain from gingival swellings. Trials done on patients suffering from dental caries, pain, and pus formation, 75% of them completely cured after 3–4 hours. Effective results find in patients suffering from dental caries associated with severe swelling and pain. Vijay Amirtharaj *et al.* (2015) reported that, experimental studies on 50 patients suffering from dental problems such as pulpitis, treated with mouth rinse solution (single dose) made from *S. surattense* seed extracts. Test results showed 68% of the patients in the experimental group, got the relief after the treatment. These findings confirm the efficiency of *S. surattense* seeds to cure

certain ailments like dental caries, swellings, and tooth pain and considered to be an alternative and safe medicine to cure the dental problems.

#### *Anti-inflammatory activity*

Inflammation is a complex set of interactions between cells and soluble factors that arise in the tissues in response to the infection, trauma, or injury. Inflammation is one of the major constraints results in human diseases like heart disease and diabetes. The choice of non-steroidal and steroidal drugs has side effects. This necessitates searching safe anti-inflammatory agents from the natural source. Fruits of *S. Surattense* are used as anti-inflammatory agents used in the traditional medicine. Investigation of anti-inflammatory efficiency of *S. surattense* extracts on inhibition of paw edema in animal models revealed that only moderate inhibition was observed (Ramanarayana Reddy *et al.*, 2014). However, the contrary findings observed from the studies of Anwikar and Bhitre (2010) Synergistic anti-inflammatory effect of *S. surattense* was also observed with *Cassia fistula* (1:1 combination), the efficiency was slightly less (75%) than compared with that of the standard drug Diclofenac sodium (81%), but individually it is 66.41% with *S. surattense*. Isolated steroidal compounds from *S. surattense*, stigmasterol, carpesterol, and diosgenin also reported to possess anti-inflammatory activity. Among the three, diosgenin found to possess remarkable anti-inflammatory efficiency.

#### *Antidiabetic activity*

Prevalence of diabetes throughout the world necessitates the in-search of new, effective, and anti-diabetic drugs than the existing ones. Extensive research going on along these lines and reported many plants have to possess a wide range of anti-diabetic compounds, among the reported ones *S. surattense* possess prominent anti-diabetic potentiality equal to the standard drug Glibenclamide. Leaf extracts of *S. surattense* effectively lowered the blood glucose levels and increased the level of insulin (Poongothai *et al.*, 2014; Sridevi *et al.*, 2007). Antidiabetic studies validate the traditional use of *S. surattense* fruits by the folklore as an anti-diabetic agent. Comparative studies in the field and *in vitro* grown *S. surattense* plants for antidiabetic activity. Poongothai *et al.* (2014) noticed that remarkable anti-diabetic efficiency of *in vitro* grown plants compared with the field grown plants. Availability of the rich source of mineral nutrients during culture conditions, rendered the plants rich in phytochemical, resulted in exhibiting high potential. These findings enabled the use of *in vitro* techniques to raise the plants, which provide the source of therapeutic drugs with high potentialities (Poongothai *et al.*, 2014).

$\beta$ -Sitosterol, a phytosterol from *S. surattense* also reported to possess anti-diabetic properties. A study carried out for duration of 21 days in experimental animal models resulted that increased level of serum insulin was observed in  $\beta$ -Sitosterol-treated group than compared with the normal ones. The pancreatic protein content estimation, normal in the treated group (diabetic induced), but enhanced level of pancreatic protein observed in normal ones (Control) in a dose-dependent manner. The level of anti-oxidants lipid peroxide, GSH peroxidase, GSH, SOD, and CAT of pancreatic tissue were significantly increased in

$\beta$ -Sitosterol-treated group. These findings confirm the protective role of *S. surattense* extracts in preventing from the effects of diabetes induced oxidative damage (Gupta *et al.*, 2011a).

#### *Hepatoprotective activity*

Hepatic diseases are one of the most serious and common diseases to the mankind. Pathogenesis of the hepatic diseases, due to the oxidative stress and inflammation. Despite, tremendous advances in the modern medicine, the management of liver disease is still a major challenge. *Solanum surattense* fruits used as a traditional medicine to treat the disorders of the liver. Investigations of hepatic protective nature of *S. surattense* leaf and fruit determined its potentiality as an effective hepatic agent. Hepatotoxicity induced by carbon tetrachloride (CCl<sub>4</sub>) resulted the necrosis of hepatic cells and increased the level of serum marker enzymes [aspartate aminotransferase (AST), alanine aminotransferase (ALT), and alkaline phosphatase level (ALP)]. Administration of the fruit extract at dose 400 mg/kg showed a significant effect on lowering the serum marker enzymes AST (67.71), ALT (75.66), and ALP (54.52). Reduction in the level of serum marker enzymes with plant extracts was similar to the effect of standard drug Silymarin AST (70.31), ALT (77.40), and ALP (59.80) (Gupta *et al.*, 2011b; Jalali Ghassam *et al.*, 2014). Singh *et al.* (2015) noticed the similar findings of *S. surattense* fruit extracts against paracetamol and azithromycin induced hepatic injury. Leaf extracts, at low test dose (100, 200 mg/kg), resulted in a marginal increase of CAT, SOD, and GSH enzymes, whereas a higher dose restored the level of anti-oxidant enzymes. *Solanum surattense* extracts offered the hepatic protection, by reducing the oxidative stress induced by CCl<sub>4</sub>. These findings support the use of *S. surattense* fruits as a traditional medicine.

#### *Antiulcer activity*

Investigations on antiulcer potentiality of *S. surattense* leaf extracts by Bahuguna *et al.* (2008) revealed that alcoholic extracts exhibited significant antiulcer property than other solvent extracts. Plant extract raises the pH (3.10) of gastric contents and lowered the total acidity resulted in decrease of ulcer index. The antiulcer efficiency of *S. surattense* was comparable to the effect of standard antiulcer drug Omeprazole in lowering the acidity. Omeprazole exhibited pronounced effect in decreasing the ulcer index than the plant extracts. The lowered efficiency of plant extracts due to less quantity of anti-ulcer agents in crude form (Bahuguna *et al.*, 2008).

#### *Wound healing activity*

Wounds (Physical injuries) and wound infections are the most common diseases overcome by wound healing. Wound healing restores the disturbed anatomical continuity and normalizes the epithelial integrity of the skin (Gonzalez *et al.*, 2016). Many plants used as a remedy for wound healing, in traditional system of the medicine. Investigations on the wound healing property of various plants led to the discovery of a large number of wound healing agents from plants. Inquisitiveness to develop effective wound healing agents continued to screen many medicinal plants, used in traditional system of medicine. *Solanum surattense* fruit poultice used traditionally for wound healing (Kumar *et al.*, 2010). Dewangan *et al.* (2012) reported the *S. surattense* extract (ethanol

exhibited pronounced wound healing activity than compared with other solvent extracts. Reduction in epithelisation, time, and scar area in test group due to increased hydroxyproline content and high tensile strength, which is an indication of quality of wound healing. The wound healing efficiency of plant extracts was similar and comparable to the efficiency of standard drug Sulphadiazine. This study provides a scientific support on the account of *S. surattense* use as a traditional wound healer. To use *S. surattense*, active principles in modern medicine need further investigation for isolation and to carry out biological tests to confirm the role of specific compounds in wound healing.

#### *Diuretic activity*

Investigations of Ahmed *et al.* (2016) on diuretic and serum electrolyte regulation properties of *S. surattense* fruit extracts revealed that fruit extracts significantly increased the urine output in a dose-dependent manner. The diuretic potentiality of plant extract was slightly less than compared with the efficiency of standard drug furosemide (Ahmed *et al.*, 2016). Fruit extract exhibited the diuretic activity by increasing the osmolality of urine together with excretion of electrolytes, due to the presence of phenolic caffeic acid and methyl caffeates as secondary metabolites (Patel *et al.*, 2012). Regarding the serum electrolytes, fruit extracts reduced the level of sodium, potassium, and calcium whereas serum bicarbonates concentration was increased in a dose-dependent manner. Treatment with fruit extracts result a substantial decrease in blood urea nitrogen and  $\text{Ca}^{2+}$  proved its diuretic potential. Similar findings noticed with leaf extracts by Ramanarayana Reddy *et al.* (2014) strengthen the diuretic efficiency of *S. surattense* extracts.

#### *Anti-hyperlipedemic activity*

Total cholesterol, Triglycerides, Phospholipids, and free fatty acid levels in plasma are the significant biomarkers, to assess the hyper or hypolipidemic. Sridevi *et al.* (2011) carried out the biochemical studies on streptozotocin induced experimental animal models. very low-density lipoprotein cholesterol and low-density lipoprotein cholesterol levels increased and high-density lipoproteins cholesterol levels decreased, reflects the altered lipoprotein profile. Animal models treated with *S. surattense* plant extract normalized the plasma lipid profile than compared with control group (without treatment). The anti-hyperlipedemic potentiality of *S. surattense* was equal to the effect of standard drug Glibenclamide (Sridevi *et al.*, 2011). This study confirms the potential ability of *S. surattense*, as anti-hyperlipedemic agent and provides a scientific rationale for the use of *S. surattense* for the development of effective medicine to combat diabetes and its associated effects on body metabolism.

#### *Analgesic activity*

*Solanum surattense* leaf extracts have the potential capability to use as an analgesic. Studies in experimental animals with plant extract showed an elevated response in the dose-dependent manner. This investigation authenticates the traditional use of *S. surattense* as analgesic and provides the scope to develop natural analgesics from the folklore claims (Huque *et al.*, 2015).

#### *Anti-urolithiatic activity*

Urinary calculi are the most prevalent disorder of the urinary system. Urinary calculi formed from the oxalates of calcium, phosphates, etc. affect the renal function and decreasing the glomerular filtration rate due to obstruction to the flow of urine (Alelign and Petros, 2018). A large number of plants are used to cure urinary calculi, since from ancient times. Ancient literature Ayurveda describes the traditional use of *S. surattense* for the treatment of urolithiasis. Chauhan *et al.* (2009) reported the ethnopharmacological use of *S. surattense* for the treatment of urinary track and kidney stones in Muzaffarnagar, U.P (India). Experimental models treated with ethylene glycol for a period of 28 days resulted, the increase in excretion of  $\text{Ca}^{2+}$ , phosphate, uric acid and a decrease in citrate and magnesium content in urine due to impairment of renal function. Treatment with *S. surattense* extracts improved the renal function by its potential effects like diuretic; anti-oxidant reduced the CaOx crystal formation. The decreased levels of  $\text{Ca}^{2+}$  and uric acid was evidenced in plant extract treated group indicates the improvement of renal function and confirms its antiurolithiatic role. Similar studies with saponins rich fraction of *S. surattense* fruits resulted that, less number of calcium oxalate crystals and their aggregation in plant extract treated group. Plant extract prevents the formation of calcium oxalate crystals as well as their aggregation (Patel *et al.*, 2012). The anti-urolithiatic efficiency was slightly less compared with the standard drug Cystine. This study confirms the traditional use of *S. surattense* fruits for urolithiasis as effective medicine.

#### *Cardio-protective activity*

Myocardial injury results from the prolonged myocardial ischemia with necrosis of myocytes due to interruption of blood supply to an area of heart (Hashmi and Al-Salam, 2015). According to WHO, it is the leading cause of morbidity and mortality throughout the world (Wunsch and Gourbin, 2018). To overcome the myocardial infarction, effective and safe medicine is an immediate concern. Pullaiah *et al.* (2015) studied the cardio protective efficiency of *S. surattense* extracts against Isopropanol induced myocardial injury in animal models. Enhanced level of marker enzymes lactate dehydrogenase (LDH) and creatine kinase-muscle/brain (ck-MB) is observed in plasma of myocardial injured animal models. Isopropanol induced myocardial injury is mediated via the  $\beta$ - adrogenic receptor. Acute  $\beta$ - adrogenic receptor stimulation rapidly generates ROS and also depressed the total anti-oxidant capacity. Treatment with plant extracts showed significant cardio protection in a dose-dependent manner with reference to the standard drug propanol. Potapovich *et al.* (2012) and Witaicenis *et al.* (2013) reported the presence of seven kinds of flavonoids and coumarins like esculentin. Esculentin is particularly well proven anti-inflammatory and anti-oxidant activity, which plays a prominent role in healing of myocardial injury. Elevated levels of serum cardiac markers like LDH and cK-MB are drastically reduced because of the presence of cardio protective agents of *S. surattense*. The cardio protective mechanism of *S. surattense* appears to be through improvement of overall anti-oxidant defense mechanism of cardiac tissue. Increased anti-oxidant defense mechanism was evidenced, in the

level of anti-oxidants like GSH, SOD, and CAT in animal models treated with plant extract.

#### *Antifertility activity*

Antifertility control the population explosion and also provides a plausible solution to the number of problems what the world confronts. Contraceptive methods, most of the choices, are antifertility agents. Contraceptive drugs available are synthetic/chemical and in many cases found the side effects. Hence, there is a need to replace the chemical drugs by the safe herbal drugs. Many plants have been used as antifertility agents in traditional medicine, but a very few of them evaluated scientifically. Among the contraceptives, availability of male infertility agents is meager. Development of male infertility agents considered to be a potential area of the investigation. Research studies on *S. surattense* reported to possess excellent antifertility activity. Administration of fruit extracts at dose 0.5 mg/kg for duration of 60 days to experimental animal models resulted that arresting the process of spermatogenesis. It was also evident that reduced number of primary and secondary spermatocytes and spermatids correlated with arresting of the spermatogenesis. In testis, leading cells were also significantly decreased, confirms the antispermatogenic nature of *S. surattense* fruit (Purohit, 1992).

The *S. surattense* seed extract also reported to possess antifertility efficiency by depleting the oxidative potential of cauda epididymal spermatozoa. Administration of the seed extract at the dose of 10 mg/kg b.w to experimental animal models for a period of 15 days resulted significant decrease in the level of AST, ALT, glutamate dehydrogenase, Citric acid, and Isocitrate dehydrogenase was observed. Sperm motility was also decreased in the animal model group treated with plant extract. Decreased oxidative potential in the cauda epididymal spermatozoa indicates the antifertility effect of *S. surattense* seeds (Thirumalai *et al.*, 2012).

Dixit and Gupta (1982) reported the anti spermatogenic property of solasodine, an alkaloid found in *S. surattense* fruits. Administration of solasodine at 20 mg/kg to experimental animal models for the duration of 30 days resulted that testicular lesions and severe impairment of spermatogenesis. Analysis of biochemical like total protein, sialic acid, and glycogen contents of the testis and epididymis were significantly reduced, whereas the level of testicular cholesterol was increased. Administration of solasodine to castrated dogs, failed to stimulate the epididymal growth. Treatment with solasodine on experimental animals (dogs) affected the male fertility by affecting the androgenesis. Absence of sperms in the cauda epididymis and ductus defens rendered the male infertile. The findings of these investigations confirm the antifertility role of *S. surattense* fruit and seed extracts.

#### *Fertility activity*

The post-menopausal syndrome is characterized by low estrogen levels, leading to sexual dysfunction, vaginal dystrophy, and osteoporosis. *Solanum surattense* is reported to possess fertility activity by promoting conception in females. Studies on postmenopausal ovariectomized animal models by the administration of *S. surattense* extract at doses 200 and 400 mg/kg for duration of 90 days resulted that increased serum estradiol content, vaginal cornification and uterine weight. Fertility effect was similar to the effect of standard drug  $\beta$ -estradiol. At doses

200 mg/kg exhibited the potent estrogenic activity, but at higher doses it induces negative feedback inhibition (Aswar *et al.*, 2014). These findings suggest the potential ability of *S. surattense* in preventing the post-menopausal symptoms associated with estrogen deficiency by promoting the estrogen levels.

#### *Antinociceptive activity*

Rahman *et al.* (2003) studied the antinociceptive activity of *S. surattense* on experimental animal models. Methanol extracts of *S. surattense* significantly suppressed the frequency of acetic acid induced abdominal constrictions in animal models. At dose 500 mg/kg reduced the frequency of worthiness and showed the 73.08% inhibition. *S. surattense* exhibited the antinociceptive efficiency in a dose-dependent manner.

#### *Anti-piles activity*

The Ayurvedic text mentioned that *S. surattense* possess anti piles activity (Pandey *et al.*, 2018). Indian tribe to cure piles since from the ancient past has used a root of *S. surattense*, as a traditional medicine. Still, it is practiced in many regions of India because of its remarkable curative properties. There are no scientific reports until now. Systematic investigation and isolation of bioactive agents, which are effective to cure piles from the crude extracts of *S. surattense* roots, provide the possibility for the development of effective drug than the available ones.

#### **Acute toxicity studies**

Studies on leaf and fruits extracts of *S. surattense* revealed that, plant extracts are non-toxic in nature, even at higher dose 2,000 mg/kg (Gupta *et al.*, 2011; Ahmed *et al.*, 2016; Pingale, 2013). Intake of steroidal glycosides (Solanaceae) led to acute intoxication and severe cases cause death, but no adverse effect of *S. surattense* reported so far (Langkilde *et al.*, 2009).

#### **CONCLUSION AND PERSPECTIVES**

*Solanum surattense* has been used in the traditional Indian medicine (Ayurveda) to cure for various ailments since from the ancient times and also practiced by the folklore. Phytochemical investigation on roots, leaves, and fruits revealed the presence of secondary metabolites like flavanoids, alkaloids, phenols saponins, glycosides, steroids, and triterpenoids. Intensive investigations on phytochemical constituents of *S. surattense* reported the presence of glycoalkolid solasonine, steroidal alkaloids solanocarpine, solasonine, solamargine, carpesterol, and diosgenine. Folklore claims in its traditional usage to cure various ailments propheled to carry out various phamacognostic activities by the phytochemists. Phamacognstic activities like antimicrobial, anihelmenthic, antihyperglycemic, hypolipidemic, cardiovascular protective effect, antiulcer, wound healing, uriolithiatic, and antifertility are extensively investigated by many researchers. Systematic investigation and clinical trials validate the folklore claims and traditional use of *S. surattense* for its versatile therapeutic effects. Extensive survey of literature revealed that number of compounds isolated from this multitherapeutic medicinal plant, but the limitation is only a few of them is studied for its potent biological activity. The present review suggests that current literature on pharmacological activities proved to be a multitherapeutic medicinal plant. Further

exploration of bioactive compounds from *S. surattense* and its validation promises the possibility to exploit and develop novel chemotherapeutic drugs from this natural resource.

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