

Exploration of *Polygonum odoratum* as a medicinal plant with promising antimicrobial and antioxidant effects for translational use in conventional medicine: a systematic review

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Abstract

Background Global health authorities have recognized the increasing worldwide integration of traditional complementary medicine. Medicinal plants hold substantial promise that, when properly harnessed, can be effectively integrated into the mainstream conventional medicine. One of such notable example is *Polygonum odoratum*. However, there remains a need to broaden the scientific evidence base for the medicinal use of this plant. The present study was thus carried out to systematically explore the biological activities of *P. odoratum*.

Methods Data were retrieved through a systematic search of four electronic databases: PubMed, Scopus, Google Scholar, and ScienceDirect. The study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The risk of bias was assessed using the revised Cochrane Risk-of-Bias tool (RoB 2) and SYRCLE's risk-of-bias tool for preclinical studies. Given the high degree of heterogeneity observed across studies, meta-analysis was deemed inappropriate. Consequently, descriptive summaries of the included studies are provided.

Results The systematic review identified 34 studies that fulfilled the eligibility criteria. Synthesis of these studies revealed that *P. odoratum* exerts a broad spectrum of biological activities, including antimicrobial, anti-inflammatory, antioxidant activity, and anticancer effects, as well as protective activities against various organ-specific disorders. Overall, the majority of the studies assessed for quality demonstrated a low risk of bias according to both the RoB 2 and SYRCLE tools.

Conclusions The available evidence indicates that *P. odoratum* possesses diverse biological activities, including antimicrobial, antioxidant, anti-inflammatory, anticancer, and organ-protective effects. However, the current body of evidence is derived predominantly from in vitro and animal studies, with only limited clinical data available. Further mechanistic investigations and well-designed clinical trials are warranted before recommendations can be made for its integration into conventional clinical practice.

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Keywords Antimicrobial · Antioxidant · Medicinal compound · Traditional medicine · Secondary metabolite · *Polygonum odoratum*

Abbreviations

A β 42	Amyloid-beta 42
AD	Anti-diabetic
AI	Anti-inflammatory
Akt	Protein kinase B
Akt/mTOR	Protein kinase B/ mammalian target of rapamycin pathway
AM	Antimicrobial
AO	Antioxidant
APA	Acetyl-para-aminophenol
Bax/Bcl-2	Bcl-2-associated X protein/B-cell lymphoma 2
COX-2	Cyclooxygenase-2
EBV	Epstein-Barr virus
EP	Extracellular polysaccharide
G2/M phase	Gap 2 to mitosis phase transition
hFOB	Human fetal osteoblast
HT-29	Human tumor 29
iNOS	Inducible nitric oxide synthase
IL-6	Interleukin-6
LPS	Lipopolysaccharide
MAPK	Mitogen-activated protein kinase
MMP-9	Matrix metalloproteinase-9
mRNA	Messenger ribonucleic acid
MRSA	Methicillin-resistant <i>Staphylococcus aureus</i>
mTOR	Mammalian target of rapamycin
NF- κ B	Nuclear factor kappa B
NO	Nitric oxide
Nrf2	Nuclear factor erythroid 2-related factor 2
PGE ₂	Prostaglandin E ₂
<i>P. odoratum</i>	<i>Polygonum odoratum</i>
PICOS	Population, Intervention, Comparison, Outcomes and Study design
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
RoB 2	Revised Cochrane Risk of Bias tool for randomized trials
STZ	Streptozotocin
SYRCLE	Systematic Review Centre for Laboratory animal Experimentation
TNF- α	Tumor necrosis factor-alpha
VEGF-A	Vascular endothelial growth factor A

Background

The World Health Organization (WHO) recognizes the growing integration of traditional medicine into conventional healthcare systems worldwide [1–3]. Furthermore, traditional medicine remains one of the primary sources of healthcare in developing countries [4–6]. Medicinal plants have been used for centuries as traditional medicine

to promote health and to prevent and treat various diseases [7, 8]. The therapeutic properties of plant-derived natural products are largely attributed to their secondary metabolites, collectively known as phytochemicals or phytonutrients [9, 10].

Traditional medicine, which is rooted in indigenous knowledge and cultural practices, has garnered considerable scientific attention over recent decades due to its therapeutic potential and ongoing advancement [11–13]. *Polygonum odoratum* Lour (*P. odoratum*) is a widely used medicinal plant in traditional systems, valued for both its medicinal and culinary applications. Native to tropical Southeast Asia, the plant is commonly cultivated throughout Southeast Asia [14] and in many parts of South and East Asia.

The characteristics of *P. odoratum* is a perennial plant that typically grows 60–90 cm in height. It features a reddish, erect ascending stems that are branched, and alternate, green slender leaves measuring 6–15 cm long with distinctive dark purple markings at the center [15]. Taxonomically, the plant belongs to the Kingdom Plantae, Order Caryophyllales, Family Polygonaceae, Genus *Polygonum*, and species *odoratum*. It is also known by the synonym *Persicaria odorata* [16, 17].

Polygonum odoratum is widely consumed as a leafy vegetable and serves as a common ingredient in various Southeast Asian, South Asian, and East Asian cuisines. It is frequently used in soups, stews, curries, and salads [18]. In these regions, the plant is valued both as a nutritional local vegetable food and as a culinary herb that imparts a distinctive flavor and aroma to dishes. In addition to its culinary uses, the *P. odoratum* has a long history of traditional medicinal application for the treatment of flatulence, constipation, and inflammation caused by insect bites [19–21].

The longstanding traditional use of *P. odoratum* among native Southeast Asian, South Asian, and East Asian communities has spurred growing scientific interest in elucidating the phytochemical constituents and biological activities underlying its ethnomedicinal applications. However, the existing literature contains only one systematic review on this plant, which focused exclusively on its anticancer activities [22]. To date, no comprehensive systematic review has been conducted to evaluate the overall biological activities of *P. odoratum*. To strengthen the scientific evidence base for the traditional medicinal use of *P. odoratum*, a comprehensive evaluation of its biological activities is warranted. Therefore, the present systematic review aimed to summarize the available preclinical and clinical evidence on the biological activities of *P. odoratum*, evaluate the quality of the existing evidence, identify the proposed mechanisms of action, and highlight key knowledge gaps for future translational research.

Method

Registration and reporting of results

The systematic review was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO). Separate registration was performed for animal studies (ID: CRD42023467047) and human studies (ID: CRD42023477603). The review process was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [23].

Data sources and search strategy

The following electronic databases were systematically searched from database inception until July 2025: PubMed, Scopus, Google Scholar, and ScienceDirect. Search terms included “*Polygonum odoratum*” and “*P. odorata*”. In addition, grey literature and forward citations from included studies and relevant reviews were screened.

Study selection

The search results were imported into Endnote reference management software (version X9) and subsequently uploaded to Covidence systematic review management software (<https://www.covidence.org>) for screening. Covidence automatically removed duplicate records. Two independent reviewers (MM and SKL) then screened the titles and abstracts of all retrieved records, followed by full-text assessment of potentially eligible articles. Studies were included if they used experimental models (in vitro, in vivo, or human) to evaluate the biological activities of *P. odoratum* extracts or its isolated compounds, compared with the defined control group, using any relevant outcome measure. Table 1 summarized the details of the PICOS inclusion criteria applied in the present study. Any discrepancy concerning the study selection was resolved by discussion, and if needed, by adjudication of other reviewers.

Data extraction

Data extraction was performed independently by two reviewers (MM and SKL). Relevant study characteristics were extracted using a standardized Microsoft Excel data extraction form (Supplementary Material 1). The extracted information included author and year of publication, country of study, study aim, type of extract, plant part used, experimental model or condition tested, treatment effects observed, main findings, and proposed mechanisms of action. A third investigator cross-checked all the data extracted for accuracy and completeness.

Risk of bias assessment

Risk of bias was assessed using SYRCLE's risk-of-bias tool [24] for animal studies, and Cochrane Risk-of-Bias (RoB 2) tool [25] for human clinical trial. Both tools evaluate domains of bias based on 10 items; the studies are assessed as either 'high risk', 'unclear risk' or 'low risk' of bias. One reviewer (MM) independently assessed the risk of bias, with all assessments subsequently verified by the other authors. In vitro studies, which constituted the majority of included records, were not subjected to formal risk of bias assessment because validated tools for in vitro experiments are currently limited.

Results

Studies and their characteristics

A total of 588 studies were systematically identified from the electronic databases, and seven through forward citation tracking (details from each in the Covidence generated prisma diagram as supplementary material 2). Four hundred and eighty-seven studies remained after the automatic removal of duplicates by Covidence from the various databases. After subjecting the evidence to eligibility criteria based on titles and abstracts, 364 studies were disqualified and 123 remained. These 123 articles were further screened based on full text in which about 89

Table 1 Inclusion criteria of the study

PICOS component	Inclusion criteria
Population	In vitro model, in vivo model (all species, all sexes), or human population (all ages, all sexes) with experimental testing
Intervention	Treatment involving <i>P. odoratum</i> alone, its synthetic product, or its combination with other agents
Comparison	Untreated control, sham, or placebo
Outcomes	Any outcome associated with biological activity
Studies	Preclinical and clinical studies

studies were discarded and the remaining 34 were included in the systematic synthesis of this review as illustrated in Fig. 1.

The extracted study characteristics are presented in Table 2. The studies characteristics revealed the Asian popularity of the plant, as the majority ($N=26$) of the included studies originated from Thailand, while the remaining were carried out in Malaysia ($N=4$), India ($N=2$), and Bangladesh with Vietnam ($N=1$ each). The leaves of the *P. odoratum* were the most frequently used plant part in the included studies and the ethanolic extract was the most frequently used form of the plant. The included studies consisted predominantly of in vitro studies, followed by animal studies and one clinical study. The plant was found to exert a broad spectrum of effects, including anti-inflammatory and antioxidant activities, anticancer activity, antimicrobial activity, and other activities against organ-specific disorders.

Risk of bias analysis

The majority of the included studies were in vitro studies ($N=27$). Therefore from the remaining 7 studies, six animal studies were assessed for risk of bias using SYRCLE's risk of bias ($N=6$) and one clinical study using the Cochrane risk of bias ($N=1$) tools as shown in Fig. 2. The risk of bias assessment was represented in Fig. 2. It illustrated that within the experimental animal studies, SYRCLE's risk of bias depicted that 66.66% ($N=4$) were of low risk of bias, and 33.33% ($N=2$) as high risk of bias. On the other hand, Cochrane risk of bias that assessed

Fig. 1 PRISMA diagram

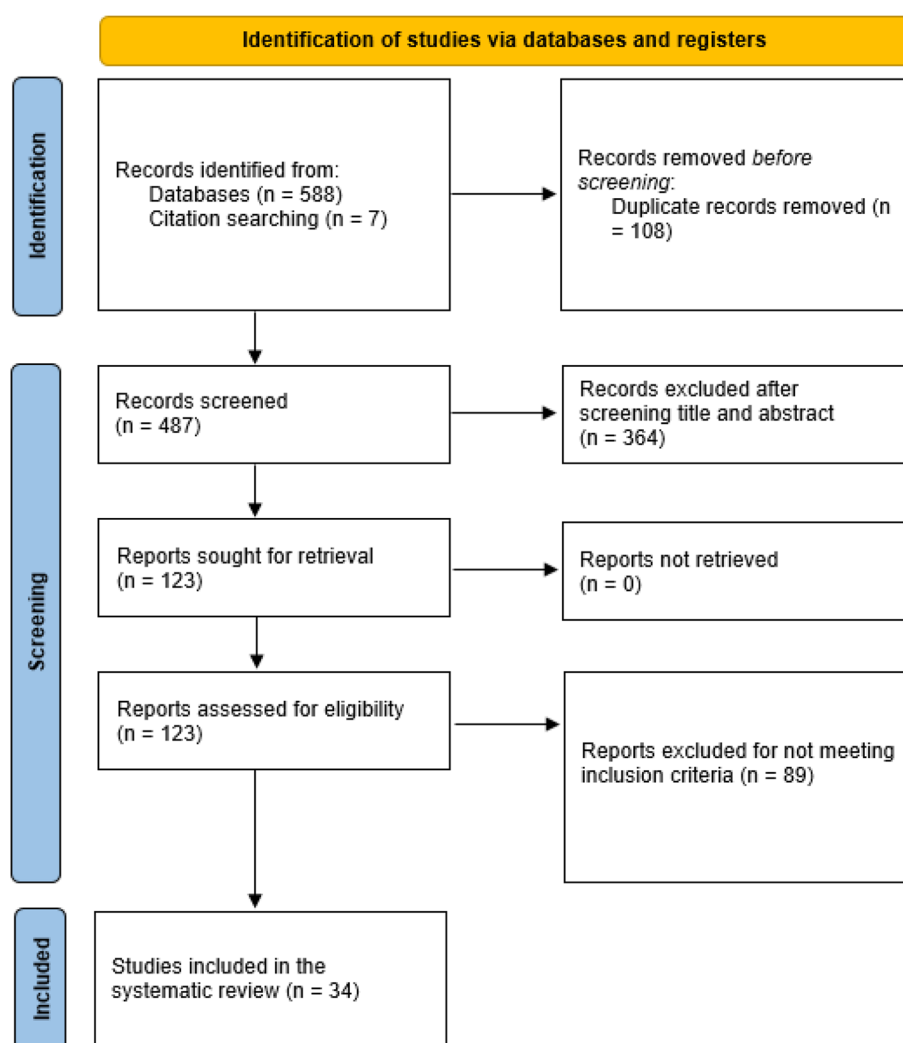


Table 2 Data extracted from included studies

Author	Country of study	Main objective	Part of <i>P. odoratissima</i> used	Type of extract used	Characteristics of cell/animal/patients	Effect produced	Main findings	Rationale identified behind the produced effect
Chansiw et al 2019 [26]	Thailand	To investigate from leaf and extracts of <i>P. odoratissima</i> extracted using 3 different extraction method, the inflammatory and antioxidant activities, as well as total phenolic and flavonoid contents	Leaves, and stem	Three different extracts: 95% methanol, dichloromethane and water	Cell line (RAW 264.7 macrophage cells prompted by lipopolysaccharide for testing inflammation and cell viability), In vitro setting (using 2,2-diphenyl-1-picrylhydrazyl and 2,2'-azino-bis (3-ethyl-6-benzthiazoline-6-sulphonic acid) assays)	Antiinflammatory and antioxidant stress	The dichloromethane leaf extract (DLE) showed superior and powerful potent anti-inflammatory effect, while the methanolic leaf extract (MLE) exhibited best antioxidant activity	The effects observed was attributed to high levels of polyphenols present
Fujita et al. 2015 [27]	Thailand	To test the effect of fresh essential oil prepared from leaves of <i>P. odoratissima</i> on a foodborne bacterium <i>Salmonella enterica</i> serotype <i>Choleraesuis</i> (<i>S. Choleraesuis</i>)	Leaves	Essential oil prepared through steam distillation of the fresh leaves	Cell line culture (various bacterial test strains)	Antimicrobial (against <i>S. Choleraesuis</i>)	Antibacterial activity against <i>S. Choleraesuis</i> was observed to be significant, and GC-MS showed the presence of about 25 volatile compounds in the essential oil	The observed effect was attributed to phytochemicals characterized as anti- <i>Salmonella</i> agents, which were suggested to be effective disinfectant and prevent food contamination
Okonogi et al 2016 [28]	Thailand	To evaluate the effect of crude extract of <i>P. odoratissima</i> on inflammation in vitro, as well as purify and identify the active compounds	Leaves	Ethanol extract	Cell line (macrophage RAW 264.7 cells for testing inflammatory activity)	Antiinflammatory activity	The extract produced significant reduction of IL-6 secretion by both 100% and 50% ethanol extraction	The observed effect was attributed to its core compounds quercetin and scutellarein-7-glucoside
Chansiw et al 2022 [29]	Thailand	To evaluate the using cell line the antiinflammatory effect of <i>P. odoratissima</i> using crude ethanolic extract	Leaves	Ethanol extract	Cell line (RAW264.7 macrophage cells induced by LPS through proinflammatory mediator) and in vitro (<i>TRF</i>)	Antiinflammatory activity	The viability of RAW264.7 cell line was observed to increase with treatment, the production of nitric oxide, prostaglandin E2, and TNF- α decreased from the medium of LPS induced RAW264.7 cell culture, as well as significantly decreased mRNA levels of COX-2, iNOS, TNF- α , and IL-6	The antiinflammatory activity was due to bioactive phenolics including gallic acid, catechin and epicatechin 3-gallate, as well as flavonoids rich in quercetin and coumarin

Table 2 (continued)

Author	Country of study	Main objective	Part of <i>P. odoratissima</i> used	Type of extract used	Characteristics of cell/animal/patients	Effect produced	Main findings	Rationale identified behind the produced effect
Murray et al. 2019 [30]	Thailand	To extract essential oil from fresh leaves of <i>P. odoratissima</i> through steam distillation and investigate its food preservation potential by testing oxidation of L-3,4-dihydroxyphenylalanine (L-DOPA) catalyzed by mushroom tyrosinase	Leaves	Essential oil <i>P. odoratissima</i> derived from the fresh leaves through steam distillation	In vitro setting assays (by UV–VIS spectroscopy and oxygen consumption assays)	Anti-melanogenesis (prevent melanin production) with a vital food science application such as extending the shelf-life of fresh foods and reducing food waste	The 3 compounds abundantly present in the in the essential oil were found to inhibit enzymatic catalyzation L-DOPA, as recognized by UV–VIS spectroscopy and oxygen consumption assays	The effect observed was credited to general 25 compounds identified to be present in the essential oil, with 3 utmost copious being alkanals -dodecanal, decanal and anisaldehyde
Kumar and Chaiyasut 2017 [30]	Thailand	To study the principal testing of antioxidant, astringent, and 5-alpha reductase inhibitory activities of 17 vegetables cultivated in Northern Thailand	Leaf and stem	Ethanol extract (95% ethanolic extract)	In vitro setting assays (antioxidant assay using DPPH, ABTS, FRAP, and hydrogen peroxide scavenging activity. Assay for total tannin and total flavonoid contents)	Anti-oxidative stress	<i>P. odoratissima</i> was found to show the most potent hydrogen peroxide scavenger when compared with other popular 16 vegetables consumed in Northern Thailand	The tannin content of the selected vegetable was implicated for the observed antioxidant effect
Kawwised et al. 2022 [31]	Thailand	To investigate the effects of <i>P. odoratissima</i> leaf extract (POE) on cytotoxicity and oxidative stress status	Leaves	Aqueous extract	Cell line (cell culture media of Raw 264.7 cells use to test cell viability cell induced by low dose ionizing radiation), in vitro setting (antioxidant assay using DPPH and FRAP, and assay for total phenolic compounds)	Antioxidant activity capable of being radioprotector for diagnostic procedures	The results showed that POE displayed a strong antioxidant property with no bit of cytotoxicity	POE was found to compose of 8 vital constituents and the observed effect was attributed to the main active constituents such as gallic acid, ellagic acid, and catechin
Wattana-thorn et al. 2022 [32]	Thailand	To investigate whether purposeful constituents in the combined extract of <i>P. odoratissima</i> and <i>Morus alba</i> can improve cognition in peri- and postmenopausal women	Leaves	Aqueous extract prepared by using the decoction method	Human (perimenopausal and postmenopausal women)	Cognition-enhancing activity	Consumption of product of combined extract of <i>P. odoratissima</i> and <i>M. alba</i> showed memory improvement, as well as repressing the activity of AChE, MAO-A, and MAO-B enzymes	The effect was credited to the polyphenol-richness of the combined supplement
Somporn et al. 2013 [33]	Thailand	To determine antioxidant potential of <i>P. odoratissima</i> extract against acetyl-para-aminophenol (APAP)-induced hepatotoxicity in rats	Whole plant leaves	Ethanol extract	Experimental Sprague–Dawley rats	Hepato-protective activity	Extract pre-treatment resulted in significant decrease of AST, ALT and MDA levels and liver injury	The hepato-protective effect was suggested to be due to the antioxidant properties of the phytochemicals

Table 2 (continued)

Author	Country of study	Main objective	Part of <i>P. odoratum</i> used	Type of extract used	Characteristics of cell/animal/patients	Effect produced	Main findings	Rationale identified behind the produced effect
Jaruchotikamol et al. 2001 [34]	Thailand	To examine the antioxidant activity and hepatoprotective effect of <i>P. odoratum</i> against paracetamol-induced toxicity	Whole plant leaves	Ethanolic extract	Experimental ICR mice	Hepato-protective activity	Extract pre-treatment resulted in significant decrease of plasma level of ALT and LDH	The hepatoprotective effect was due to free radical scavenging activity of the extract
Padumandana and Luecha 2014 [35]	Thailand	To study the efficiency of 20 Thai vegetables on osteoblast cell proliferation	Leaves	Ethanolic extract	Cell line (human fetal osteoblastic hFOB 1.19 cell line)	Anti-osteoporosis	<i>P. odoratum</i> showed the highest percent survival among the selected 20 local vegetables from Thai traditional formulation	Treatment excites osteoblast cell expansion through mechanism suggested to be due to bone resorption inhibiting properties
Nanasombat and Teckchuen 2009 [36]	Thailand	To determine whether some selected Thai vegetables possess activity against microbes, oxidants, and cancer, as well as identify bioactive compounds of the selected vegetables	Leaves	Methanolic extract	Cell line (19 microbial strains culture for testing anti-bacterial activity), in vitro setting (KB epidermal carcinoma, breast adenocarcinoma, MCF-7, and Vero cells from African green monkey kidney fibroblast in 96 well microplates for testing cytotoxicity), in vitro setting (free radical scavenging activity using DPPH for testing antioxidant)	Antimicrobial, antioxidant and anti-cancer activities	Methanolic extract of <i>P. odoratum</i> was among the best 3 extracts that exhibited best antioxidant and antibacterial activities among the 20 species selected Thai local vegetables	Activities observed was attributed to the identified flavonoids found the plant including rutin, catechin, quercetin, kaempferol and isorhamnetin

Table 2 (continued)

Author	Country of study	Main objective	Part of <i>P. odoratu m</i> used	Type of extract used	Characteristics of cell/ animal/pati ents	Effect produced	Main findings	Rationale identified behind the produced effect
Chansiw et al. 2018 [21]	Thailand	To investigate antihemolytic activity of <i>P. odoratu m</i> methanolic extract, as well as its activity against bacteria and cancer cell line	Leaves and stems	Methanolic extract	Cell line (Human promyelocytic leukemia cell line (HL-60) was cultured then used assessed for cellular viability and apoptosis using MTT and flow cytometry respectively, in addition with cell cycle analysis). In vitro setting (2, 2'-Azobis (2-methylpropanamide) dihydrochloride that generate free radicals mediated insult on RBC membrane measured using spectrophotometry for anti-hemolytic activity), In vitro setting (eight bacterial strains tested by broth microdilution protocol to determine minimal inhibitory concentrations for antibacterial activity)	Antihemolytic, antibacterial and cancer inhibiting activities	Antihemolytic activity was observed with treatment of methanolic extract of both leaf and stem, but the leaf extract demonstrated superior activity. The two extracts also demonstrated antibacterial activity, and the leaf extracts also exhibited anticancer activity	The observed effect might be due to high concentrations of phenolic compounds (such as gallic acid, quercetin, apigenin, ellagic acid, ferulic acid, and p-coumaric acid) and flavonoids
Charoen-sak et al. 2009 [37]	Thailand	To evaluate whether 3 different extracts of popular herbs use in northeastern Thailand (<i>Anethum graveolens</i> Linn., <i>Oroxylum indicum</i> Linn. and <i>P. odoratu m</i>) confer inhibition against cell culture of insect pest, <i>Spodoptera litura</i>	Leaves	Hexane, acetone and ethanol extracts	Insect culture (followed by recording percent mortality of the larvae)	Insecticidal activity (against insect pest, <i>S. litura</i>)	Extracts shown to be effective at suppressing the progress of <i>S. litura</i> at larval stage but could not suppress the growth of pupae evolving into the adult	Observed activity was suggested to be due to secondary plant compounds including terpenes, alkaloids, steroids, phenolics and cardiac glycosides

Table 2 (continued)

Author	Country of study	Main objective	Part of <i>P. odoratum</i> used	Type of extract used	Characteristics of cell/animal/patients	Effect produced	Main findings	Rationale identified behind the produced effect
Wattana-thorn et al. 2017 [38]	Thailand	To determine the protecting effect of the combination of mango seed and Vietnamese coriander against diabetes eyes complication of cataract and retinopathy	Aerial part of <i>P. odoratum</i>	50% hydroalcoholic extracts	Wistar rats (streptozotocin (STZ)-induced diabetes model)	Anticataractogenesis and antiretinopathy activity	The combination was found to improve diabetes eyes complication of cataract and retinopathy	The activity observed was suggested to be due to constituent rich content of phenolic compounds, but conceivable fundamental molecular mechanism might occur via the repression of aldose reductase, oxidative stress status, and MAPK signal transduction especially p38MAPK and ERK along with repression of VEGF
Sungkarnmee et al. 2014 [39]	Thailand	To determine the antiosteoporotic effect and its underlying mechanism of the combined extract of <i>M. alba</i> and <i>P. odoratum</i> leaves in ovariectomized rats, an animal model of menopause	Aerial part of <i>P. odoratum</i>	Extracted in boiled water	Wistar rats (ovariectomized as an animal model of menopause)	Antiosteoporotic activity	The combined extract of <i>M. alba</i> and <i>P. odoratum</i> decreased oxidative stress and osteoclast density but increased osteoblast density and cortical thickness	The observed antiosteoporotic activity was suggested to be due to the rich content of quercetin, a most common flavonol
Wattana-thorn et al. 2019 [40]	Thailand	To determine the acute toxicity and renoprotective against diabetic nephropathy of the collective extract of mango seed and aerial parts of <i>P. odoratum</i> in streptozotocin-diabetic rats	Aerial part of <i>P. odoratum</i>	50% hydroalcoholic extract	Wistar rats (streptozotocin (STZ)-induced diabetes model)	Renoprotective activity	The combination extract showed renoprotective against diabetic nephropathy in STZ-diabetic rats	The antioxidants present in the combined extract was implicated
Worathaphoka et al. 2012 [41]	Thailand	To investigate phytochemicals, antioxidant activities and cytotoxic effects of leaf extracts of six selected regional, Thai vegetables on normal human erythrocytes and lymphocytes and some human cancer cell lines	Leaves	70% ethanolic extract	Cell line (MCF7, human breast cancer cell line and HepG2 cell for testing cytotoxicity), in vitro setting (free radical scavenging activity determined by DPPH assay)	Antioxidants and cytotoxic activity	The extracts demonstrated potent antioxidant and cytotoxic activity against cell lines	Phytochemicals qualitatively identified were implicated

Table 2 (continued)

Author	Country of study	Main objective	Part of <i>P. odoratum</i> used	Type of extract used	Characteristics of cell/animal/patients	Effect produced	Main findings	Rationale identified behind the produced effect
Junsathian et al. 2018 [42]	Thailand	To quantify various biological and neuroprotective activities in some varieties of Thai edible plants	Whole plant	Crude aqueous extract	Cell line (A β aggregation in human neuroblastoma cells for testing neuroprotection and prevention of Alzheimer's disease), in vitro setting (free radical DPPH scavenging activity, and ferric reducing antioxidant power activity FRAP for testing antioxidant activity)	Antioxidants and neuroprotective activity	The highest total flavonoid was found in <i>P. odoratum</i> and the extract showed ability to inhibit A β 42 peptide and fibrils	Phytochemicals identified such as tannins, flavonoids, steroids, and terpenoids were implicated
Dedvisitsakul and Waila-lad 2022 [43]	Thailand	To determine the inhibitory effects of plant extracts from some selected indigenous edible plants commonly used in northern Thailand on the carbohydrate hydrolyzing enzymes (α -amylase and α -glucosidase activities), AGEs formation and free radicals	Leaves	95% ethanolic extracts	In vitro setting (α -amylase and α -glucosidase assays for testing anti-diabetic activity)	Anti-diabetic activity	The extract showed inhibition of α -amylase, and α -glucosidase	The phytochemical constituents were implicated for anti-diabetics observed
Duangjai et al. 2020 [44]	Thailand	To evaluate the relaxant effects of <i>P. odoratum</i> extract on isolated rat ileum	Leaves	Aqueous extract	Male Wistar rats (dissected to isolate ileum to for KCl-induced contraction testing)	Smooth muscle relaxants activity	The <i>P. odoratum</i> extract reduced KCl-induced contraction, reduced the contraction by propranolol and L-NAME, as well as attenuated CaCl ₂ -induced contractions	The relaxation effect was attributed to quercetin and/or other flavonoid compounds present in the extract, mediated by the NO and beta-adrenoceptors pathways, and also the blockade of calcium influx
Putthawan et al. 2017 [45]	Thailand	To investigate their cytotoxic and apoptotic abilities of selected Thai plants in colon and liver cancer cell lines	Stem and leaf	80% ethanolic	Cell lines (human colon adenocarcinoma (HT-29) and human hepatocellular carcinoma (HepG2) cells for cytotoxicity test by MTT assay)	Cytotoxic activity (against cancer cells)	The extract demonstrated strong cytotoxic activity	Flavonoids were implicated to be the main phytochemical responsible for anticancer activity in <i>P. odoratum</i>

Table 2 (continued)

Author	Country of study	Main objective	Part of <i>P. odoratu m</i> used	Type of extract used	Characteristics of cell/ animal/pati ents	Effect produced	Main findings	Rationale identified behind the produced effect
Murakami et al. 2000 [46]	Malaysia	To test high potential Southeast Asian plants as a source of effective chemoprotective compounds	Whole plant	Methanolic extract	Cell line (EBV genome-carrying human lymphoblastoid cell for cell viability assessment using EA activation assay)	Anti-tumor activity	The extract demonstrated chemopreventive properties comparable to that of plants from Malaysia and Indonesia	The observed effect was attributed to the bioactive components
Alongshangbam et al. 2014 [15]	India	To investigate the possible antioxidant activity of <i>P. odoratum</i> and to determine bioactive compounds, total phenols and flavonoids of the plant	Aerial part	Ethanollic extract	In vitro setting (total flavonoids estimation, DPPH radical scavenging activity, and HPLC analysis)	Antioxidant activity	The plant was found to possess prominent antioxidant activity and showed the presence various phenolic compounds	The phenolic compounds identified and quantified through HPLC was implicated
Thongdon-A et al. 2012 [47]	Thailand	To compare antioxidant potency and total dietary fiber content of three Thai local vegetables	Aerial part	95% ethanolic extract	In vitro setting (total dietary fiber enzymatic-gravimetric assay, antioxidant assay using DPPH)	Antioxidant activity and high fiber content	<i>P. odoratum</i> showed considerable antioxidant activity and high fiber content	The phytochemicals and dietary fiber content were respectively implicated
Thongdon-A et al. 2013 [48]	Thailand	To evaluate dietary fiber content and oxidative stress status of local vegetables, and explore their possibility for healthy food product development	Aerial part	95% ethanolic extract	In vitro setting (antioxidant capacity determination by photochemiluminescence and fiber content by enzymatic-gravimetric assay)	Antioxidant activity and high fiber content	<i>P. odoratum</i> showed considerable antioxidant activity and high fiber content	The phytochemicals and dietary fiber content were respectively implicated
Devi Khwairakpam et al. 2019 [49]	India	To investigate the anticancer potential of <i>P. odoratum</i>	Leaf and stem	Methanolic extract	Cell line (SAS cells and other human oral squamous cell carcinoma cell line for cell viability test using MTT assay)	Anticancer activity	The extract was found to exert antiproliferative, antimetastatic activities, and induced cell cycle arrest	The phytochemical constituents (flavonoids and quinones) were implicated via downregulation of Akt/mTOR signaling pathway
Kawaree et al. 2006 [50]	Thailand	To investigate the anticancer activity of the oils derived from three different plants	Leaf	Volatile oil formed by hydrodistillation	Cell line (P388 mouse lymphocytic leukemia test for cytotoxicity using trypan blue assay)	Anticancer activity	The volatile oil from <i>P. odoratum</i> showed significant pharmacological effect to anticancer activity	The observed effect was attributed to constituent phytochemicals

Table 2 (continued)

Author	Country of study	Main objective	Part of <i>P. odoratu m</i> used	Type of extract used	Characteristics of cell/ animal/pati ents	Effect produced	Main findings	Rationale identified behind the produced effect
Aminullah et al. 2020 [51]	Malaysia	To investigate the antibacterial activity of silver nanoparticles produced from <i>P. odoratum</i> leaves extract (PO-AgNPs)	Leaf	PO-AgNPs synthesized from aqueous extract	In vitro setting (standard disc diffusion technique and time-kill assay for antibacterial activity)	Anti-bacterial activity	PO-AgNPs was found to produced antibacterial activity against skin-associated pathogenic bacteria such as Methicillin-resistant <i>Staphylococcus aureus</i> (MRSA), <i>S. aureus</i> , <i>S. epidermidis</i> and <i>Pseudomonas aeruginosa</i>	The actual mechanism of PO-AgNPs was recommended as further investigation needed
Abubakar et al. 2015 [52]	Malaysia	To evaluate the effect produced by different standardized leaf-extracts of <i>P. odoratum</i> on antimicrobial pathogens using four strains of bacteria	Leaf	Two extracts: aqueous and aqueous-ethanol extracts	Culture media of four bacterial strains (<i>Escherichia coli</i> ATCC 11229, <i>Enterococcus faecalis</i> ATCC 29212, <i>P. aeruginosa</i> ATCC, and <i>S. aureus</i> ATCC 6538 assessed using disc-diffusion and microplate dilution assays)	Anti-bacterial activity	The extracts showed natural antibacterial by inhibiting the growth of <i>S. aureus</i> , <i>E. faecalis</i> and <i>E. coli</i>	The observed antibacterial effect was attributed to phytochemical components of the plant
Řebíčková et al. 2020 [53]	Vietnam	To determine the essential oils (EOs) composition of herbs most commonly utilized as cuisine/natural medicine and evaluate their antimicrobial efficiency	Leaves and stems	Essential oil of <i>P. odoratum</i> derived by hydrodistillation	Culture media of gram positive and gram-negative bacteria determined for antibacterial using minimum inhibitory concentration (MIC)	Anti-bacterial activity	The outcomes assessed indicated that EOs of both liquid and vapor phases demonstrated activity against bacteria	The anti-bacterial activity was attributed to the abundant compound in <i>P. odoratum</i> essential oil essentially α -humulene
Roy et al. 2024 [54]	Bangladesh	To test antioxidant and antibacterial efficacy of five selected indigenous vegetables typically consumed in local community Bangladesh	Leaves	Methanolic extract	In vitro assessment for antioxidant assay (DPPH; 2,2-diphenyl-1-picrylhydrazyl) and test for antibacterial potency (MIC; minimum inhibitory concentration, MBC; minimum bactericidal concentration, and ZOI; zone of inhibition)	Potent antibacterial and antioxidant effects	A strong potency of <i>P. odoratum</i> leaf extract against both gram-negative gram-positive bacteria was examined	The antibacterial potency was implicated to be due to the polyphenols, flavonoids, and tannin contents of the <i>P. odoratum</i> leaves

Table 2 (continued)

Author	Country of study	Main objective	Part of <i>P. odoratu m</i> used	Type of extract used	Characteristics of cell/ animal/pati ents	Effect produced	Main findings	Rationale identified behind the produced effect
Ardburai et al. 2024 [55]	Thailand	To test seven different local indigenous plants and suitable solvents to extract substances with the capacity to suppress the immature stages of house fly populations	Arial part	Five different extracts: hexane, ethyl acetate, acetone, ethanol, and water	In vitro larvicidal bioassay prepared in the laboratory employing a completely randomized design (CRD) with 37 treatments and 5 replications	Strong ovicidal, larvicidal and pupicidal activity	A significant mortality rate at the egg stage was observed in the acetone and ethanolic extracts of <i>P. odoratum</i>	The pesticidal activity observed was attributed to the organic compounds identified by GC-MS
Shazrin Abidin et al. 2024 [56]	Malaysia	To determine the presence of quercetin (known for potential against COVID-19) in <i>P. odoratum</i> leaves by using High-Performance Liquid Chromatography coupled with Ultraviolet (HPLC-UV)	Leaves	Methanolic extract	In vitro HPLC-UV result accuracy was determined by applying the method to samples containing known amounts of analyte	Potential health benefit include the antiviral effect against COVID-19	A significant amounts of flavonoids (quercetin) was detected in the <i>P. odoratum</i> leaves sample	The potential health benefit was due to the presence of large amount of secondary metabolites (quercetin)

Fig. 2 The risk of bias assessment using SYRCLE's risk of bias tool and the Cochrane risk of bias (ROB 2) tool

Preclinical studies										
Study reference	Random sequence generation	Baseline characteristics	Allocation concealment	Random housing	Blinding of participants and personnel	Blinding of outcome measurement	Random outcome assessment	Incomplete outcome data	Selective reporting	Other bias
Somparn et al 2013	?	+	?	?	-	-	?	+	+	+
Jaruchotikamol et al 2001	-	+	?	?	-	-	?	+	+	+
Wattanathorn et al 2017	?	+	?	+	+	+	?	+	+	+
Sungkamane et al 2014	+	+	?	+	+	+	?	+	+	+
Wattanathorn et al 2019	?	+	?	+	+	+	?	+	+	+
Duangjai et al 2020	?	+	?	+	+	+	?	+	+	+
Clinical study										
Study reference	Random sequence generation	Baseline characteristics	Allocation concealment	Random housing	Blinding of participants and personnel	Blinding of outcome measurement	Random outcome assessment	Incomplete outcome data	Selective reporting	Other bias
Wattanathorn et al 2022	+	+	?	+	+	+	?	+	+	+
High risk of bias Unclear risk of bias Low risk of bias										

the single identified human clinical trial study was judged to have a low risk of bias. The main methodological strength of all the studies judged to have low risk of bias were in three domains; incomplete outcome data, selective reporting, and other bias. While the predominant methodological flaw with the experimental animal study assessed involve blinding, as the studies did not adequately report blinding of participants and personnel and blinding of outcome measurement.

Discussion

The studies included in this review were conducted in Southeast Asia and South Asia. This geographical distribution underscores the regional importance of *P. odoratum* as a traditional medicinal plant. The predominant use of the leaves further aligns with and supports its traditional application in these regions, where the leaves are highly valued. The main biological effects observed are summarized below.

Antimicrobial activity

Antimicrobial activity of *P. odoratum* extracts and their derivatives was demonstrated in several studies. Methanolic leaf extracts of *P. odoratum* were ranked among the three most active extracts when evaluated among 20 Thai vegetables. [36]. Both leaf and stem extracts of *P. odoratum* exhibited strong antibacterial activity [21]. In addition, the leaf aqueous-ethanolic and aqueous extracts demonstrated antibacterial activity by inhibiting the growth of four bacterial strains [52].

Essential oil extracted from the fresh leaves of *P. odoratum* showed significant antibacterial activity against *Salmonella. Choleraesuis* [27] as well as against several Gram-positive and Gram-negative bacteria in culture media [53]. Additionally, silver nanoparticles synthesized from aqueous leaf extract of *P. odoratum* (PO-AgNPs) demonstrated antibacterial activity against skin-associated pathogens, including methicillin-resistant *Staphylococcus aureus* (MRSA), *S. epidermidis*, *S. aureus* and *Pseudomonas aeruginosa* [51].

The antimicrobial properties of *P. odoratum* also extend beyond direct therapeutic effects against bacterial infections. Essential oil obtained through steam distillation of fresh leaves has demonstrated potential in food preservation. It was found to extend the shelf-life of fresh foods and reduce food waste by inhibiting melanogenesis (enzymatic browning) in food products [57]. Leaf extracts of *P. odoratum* effectively inhibited the growth of *Spodoptera litura* (a major insect pest of vegetables) at the larval stage, highlighting the plant's potential as a natural pesticide or insecticide [37].

Collectively, the included studies suggest that the antimicrobial activity of *P. odoratum* is mediated by multiple phytochemicals constituents rather than a single active compound. In addition to α -humulene, flavonoids and phenolic compounds such as quercetin, catechin, and gallic acid have been implicated in the antibacterial effects observed [53, 58]. These phytochemicals are proposed to exert antimicrobial effects through multiple mechanisms, including disruption of bacterial membrane integrity, alteration of membrane permeability, inhibition of biofilm formation, suppression of virulence factors, and induction of oxidative damage within microbial cells. Nevertheless, the precise molecular mechanisms underlying the antimicrobial activity of *P. odoratum* have not been fully elucidated in the included studies. Further detailed mechanistic studies are warranted to validate these proposed modes of action.

Anti-inflammatory and antioxidant activity

The available evidence demonstrates that *P. odoratum* possesses potent antioxidant and anti-inflammatory activities across multiple experimental models. These effects were observed in in vitro studies using RAW 264.7 macrophage cells [26, 29], cultured cell line of macrophage RAW 264.7 [28], and in various oxidative stress assays [15, 30, 47, 48]. All included studies attributed these biological activities primarily to the phytochemical constituents present in the plant.

Several studies further investigated the molecular basis of the anti-inflammatory effects of *P. odoratum*. Ethanol leaf extracts significantly suppressed the production of nitric oxide (NO), prostaglandin E₂ (PGE₂), tumor necrosis factor- α (TNF- α), and interleukin-6 (IL-6). These extracts also downregulated the gene expression of inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2) in lipopolysaccharide (LPS)-stimulated RAW 264.7 macrophages [28, 29]. Collectively, these findings suggest that *P. odoratum* suppresses inflammatory signaling upstream of pro-inflammatory mediator production. Although the precise molecular targets have not been fully elucidated, the observed suppression of these inflammatory mediators is consistent with modulation of the nuclear factor kappa B (NF- κ B) and mitogen-activated protein kinase (MAPK) signaling pathways, which regulate the transcription of numerous inflammatory genes [28, 29]. Nevertheless, direct evidence demonstrating the involvement of these pathways in *P. odoratum* remains limited, and further mechanistic studies are warranted.

The phytochemical components of *P. odoratum* have previously been identified and compiled to include quercitrin, gallic acid, polygonumins A, α -humulene, (+)-catechin, beta-caryophyllene, decanal, scutellarein-7-glucoside, and eupatoriochromene [16]. In another study [22], the phytochemical compounds were assembled to include rutin, ellagic acid, quercetin, gallic acid, ferulic acid, chlorogenic acid, apigenin, p-coumaric acid, kaempferol, luteolin, g-resorcylic acid, catechin, isorhamnetin, sesquiterpenes and derivatives, C10 and C12 aldehydes and alcohols, alkanes family. These findings further demonstrate the rich phytochemical composition of *P. odoratum* especially the polyphenols.

Hyper-inflammation and oxidative stress are involved in the pathogenesis of numerous diseases due to the interaction between the two factors to create a vicious circle under pathologic conditions [58]. The viciousness of these two factors arises from the fact that they are critically involved in early mechanisms of diseases, and

they amplify each other via oxidative stress-inflammatory cycle to perpetuate development and progression of diseases [59]. To best comprehend the strong anti-inflammatory and antioxidant action produced by *P. odoratum*, the extract was tested and found to exhibit the strongest hydrogen peroxide scavenging activity relative to the other 16 Thai vegetables tested [30]. These antioxidant and anti-inflammatory properties may partly explain the popularity of the plant within traditional Thai medicine.

Anticancer activity

Cancer remains one of the leading causes of death in Thailand [60] and the country's most prevalent cancer types are lung, breast, cervical, colorectal, and liver [61]. *P. odoratum* was revealed from the included studies to exert anticancer activities in several cell lines, including cell culture of breast cancer [41], colon adenocarcinoma (HT-29) and hepatocellular carcinoma [45], EBV-induced lymphoblastoid cancer [46], oral squamous cell carcinoma [49], lymphocytic leukemia [50], three cell lines, including epidermal carcinoma, breast adenocarcinoma and kidney fibroblast [36], and promyelocytic leukemia [21].

Although the observed anticancer activities have generally been attributed to the phytochemical constituents of *P. odoratum*, one compound, polygonumin A, has been proposed as a particularly promising candidate for further investigation [62]. Interestingly, the molecular mechanism through which *P. odoratum* exerts anticancer effect was investigated and proposed to involve suppression of protein kinase B (Akt)/mammalian target of rapamycin (mTOR) pathway (Akt/mTOR pathway) [49], a pathway that is conspicuously known to be activated by human cancers [63]. Suppression of this pathway was associated with reduced cellular proliferation, migration, survival, angiogenesis, and decreased expression of downstream proteins involved in tumour progression, including cyclin D1, survivin, VEGF-A, COX-2, and MMP-9 [49]. Due to the critical role of Akt/mTOR pathway signaling in modulating cell growth, survival, motility and metabolism, the inhibitors of this pathway have shown positive effect in clinical cancer trials [64]. Nevertheless, it should be emphasized that these findings for *P. odoratum* are derived primarily from in vitro studies, and therefore should not be interpreted as evidence of clinical efficacy. Additional animal studies and well-designed clinical trials are required to determine whether these molecular effects translate into meaningful therapeutic benefits in humans.

Activities against organ-specific disorders

Several organ-specific disorders have been investigated using *P. odoratum* extracts to test its treatment effects. In the liver, two studies [33, 34] reported for hepatoprotective activity when tested against acetyl-para-aminophenol (APAP)-induced hepatotoxicity in experimental mice and rats, respectively. In the bone, a study investigated the effect treatment using ethanolic leaf extract on human fetal osteoblastic (hFOB 1.19) cell line, treatment demonstrated powerful anti-osteoporosis activity by showing highest percent survival among the selected 20 local vegetables from Thai traditional vegetables [35]. Similarly, a study tested the effect of treatment on bone integrity parameters such as osteoclast/osteoblast density and bone cortical thickness in ovariectomized rats' model of menopause, the treatment resulted in producing anti-osteoporotic activity by decreasing osteoclast density but increasing osteoblast density and cortical thickness [39]. The *P. odoratum* leaf extract demonstrated radioprotective properties for diagnostic procedures [31].

In the brain, the effect of combined extract of *P. odoratum* and *M. alba* was investigated on cognitive function in peri- and postmenopausal women [32]. The result from this study showed that the consumption of the combined supplement conferred cognition-enhancing activity through an improvement in working memory. Neuroprotective activity of the crude extract was also observed through inhibition of A β 42 peptide and fibrils thereby conferring the plant promising action in prevention of Alzheimer's disease [42].

In the pancreas, the anti-diabetic activity of the extract was tested and confirmed through inhibition of α -amylase, and α -glycosidase [43]. The combined extract of mango seed and aerial parts of *P. odoratum* was evaluated in a streptozotocin-induced diabetic rat model of diabetic nephropathy, and the treatment resulted in renoprotective

activity [40]. In a similar way, the combined extract of *Mangifera indica* and *P. odoratum* was tested on cataract and retinopathy in streptozotocin- (STZ-) diabetic rat model, the anti-cataract and anti-retinopathy effects were observed [38]. Moreover, the intestinal smooth muscle activity was evaluated for relaxant effects of *P. odoratum* extract on isolated rat ileum, and the smooth muscle relaxing activity was observed as a result of treatment [44]. Although these findings collectively suggest diverse pharmacological potential, nearly all evidence originates from experimental models. Therefore, the efficacy and safety of *P. odoratum* in humans remain largely unknown.

Phytochemical mechanisms of *P. odoratum*

Plethora of studies reported the phytochemical components of *P. odoratum* to include polysaccharides, flavonoids, steroidal saponins, lectins, alkaloids, lignin, volatile oil, other polyphenols (apart from flavonoids), other steroidal glycosides (apart from saponins), dipeptides, amino acids, and trace mineral elements [65–67]. Nevertheless, the consensus of the studies converge in the significant abundance of polysaccharides, flavonoids, steroidal saponins as the primary active components responsible for the various biological effects that accounts for the medicinal effects of the plant [68–70]. Fig. 3 summarizes the various bioactive monomers of polysaccharides, flavonoids, steroidal saponins isolated from *P. odoratum* with their corresponding biological effects produced.

Several bioactive phytochemical producing downstream biological effects have been identified; their specific molecular mechanism remains an area of active research. The mechanism of antioxidant activity was attributed to the direct radical scavenging effect of the phytochemicals such as flavonoids resulting in attenuation of oxidants without any enzymatic involvement. It was also suggested that an indirect mechanism through upregulating mRNA expression of nuclear factor erythroid 2-related factor 2 (Nrf2) resulting in copious production of endogenous antioxidant enzymes play a key role [71]. The mechanism of anticancer activity of *P. odoratum* implicated multiples of phytochemicals involving diverse but overlapping signaling pathways. But the prevailing evidence involved cell cycle regulation through activation of signaling pathways such as activation of p53 protein via the p38 pathway that lead to G2/M phase arrest. Moreover, induction autophagy or apoptosis via regulation of the Bax/Bcl-2 balance, activation of caspase-3, and inhibition of the Akt-mTOR pathway have all been implicated [72].

The anti-inflammatory mechanism of *P. odoratum* are also derived from its phytochemical components especially the polysaccharide content. The possible involvement of multiple immunomodulatory pathways through modulating the signaling process involve in the expression of inflammatory mediators, such as inducible nitric oxide synthase (iNOS) and NF- κ B pathways have been implicated [73]. The antimicrobial activity of *P. odoratum* was predominantly attributed to its steroidal saponins and anthraquinone derivatives content, with the possible mechanism involving direct inhibition of the microbes as the mainstay mechanism [74].

There are challenges that poses variations in the phytochemical components of *P. odoratum* as reported from the different geographical locations of the studies such as Southeast Asia, China, South Korea, India among others. The difference in phytochemical profiles of *P. odoratum* have been demonstrated in different regions of same province [75]. The differences in active metabolites contents of *P. odoratum* have been found due to seasonal dynamic changes associated with different growth stages [15]. A notable differences in the metabolite composition of *P. odoratum* was implicated due to severe cultivation constraints practices such as continuous cropping obstacles [76].

Future perspective

The current evidence identifies several important research priorities for *P. odoratum* rather than established therapeutic applications. Although the available studies demonstrate promising biological activities, most evidence is derived from in vitro and animal models. Future investigations should therefore focus on elucidating the molecular mechanisms underlying these biological effects, validating efficacy in well-designed animal models, and generating high-quality clinical evidence to support potential translational applications. Multiple interactions

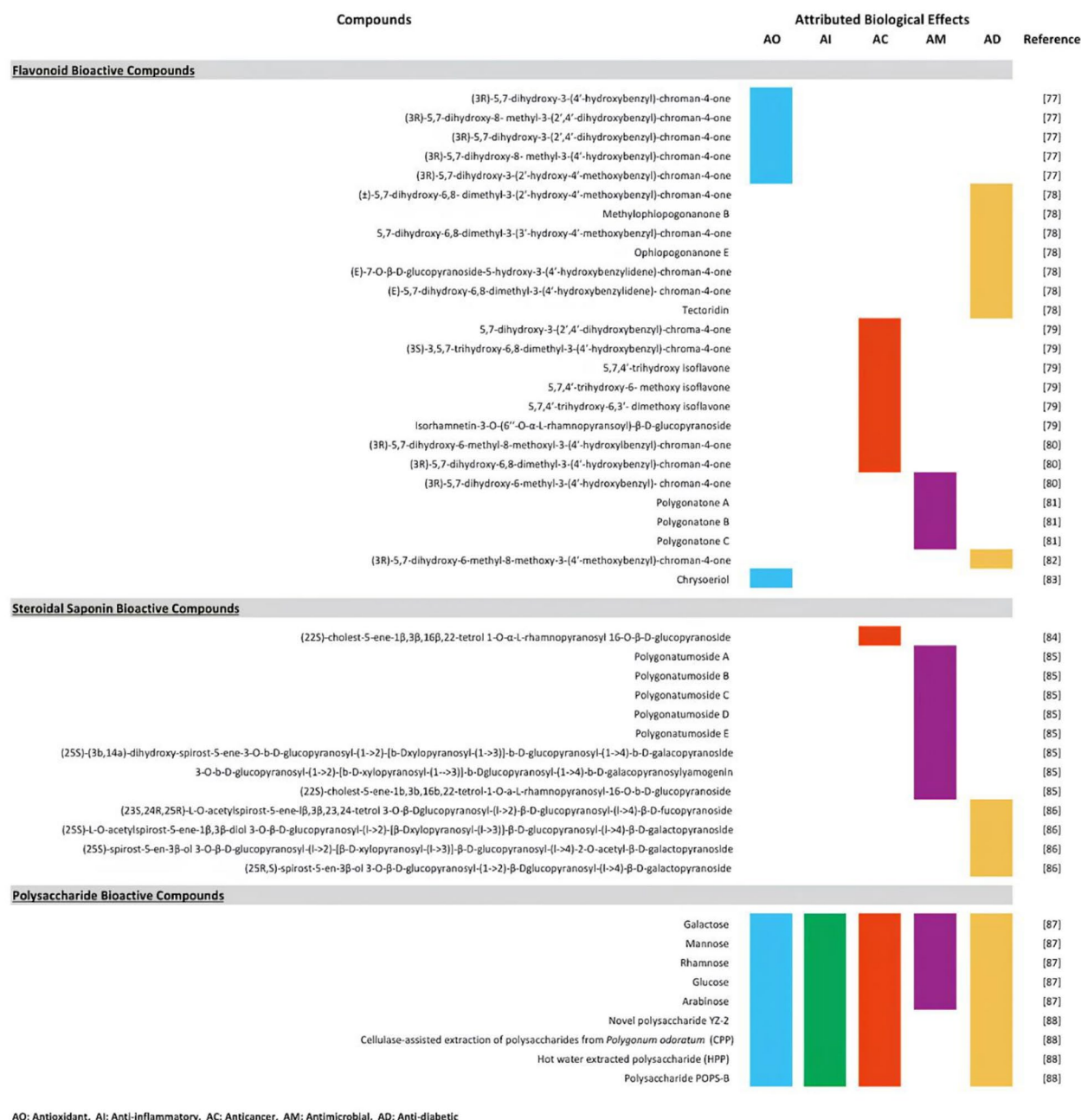


Fig. 3 Phytochemical compounds isolated from *P. odoratum* and their biological activities

may occur between phytochemicals and the intestinal microbiota. Most polyphenolic phytochemicals are poorly absorbed in the small intestine, and the catabolic activity at large intestine by the gut microbiota account for 90–95% of polyphenols absorption [9]. For instance, common polyphenols such as anthocyanins are metabolized by intestinal flora into 3,4-dihydroxyphenyl propionic acid, 3-hydroxyphenyl propionic acid, and 3, 4-dihydroxyphenylacetic acid, and this metabolic activity in turn promote the abundance of beneficial gut microbiota and reduction of harmful microbes. The phytochemicals also possess the ability to improve the integrity of intestinal barrier and maintain the balance in dynamics of gut immune cells [77, 78]. Future studies should investigate whether *P. odoratum* modulates gut microbiota composition and function.

The high fiber content of *P. odoratum* reported in two identified studies [47, 48] represents another potential mechanism for gut microbiota modulation. In addition, this high fiber content may partly explain the traditional use of *P. odoratum* within traditional Thai medicine to treat flatulence and constipation. Dietary fiber influences stool formation indirectly through fermentation by colonic microflora to stimulate fecal bulking, while the direct action of fiber influence stool formation via water retention [79]. These mechanisms warrant further investigation to determine whether they contribute to the traditional use of *P. odoratum* for flatulence and constipation.

Although several inflammatory mediators have been shown to be modulated by *P. odoratum*, the precise intracellular signaling pathways remain largely unknown. Future mechanistic studies should therefore investigate molecular pathways such as Nrf2, NO signaling, NF- κ B, MAPK, cyclooxygenase (COX), and prostaglandin signaling to better define the mechanisms responsible for the observed biological activities.

Although the available evidence suggests promising anticancer activity, the current findings are derived predominantly from cell-based studies. Future research should prioritize validation in animal tumor models, characterization of active compounds, pharmacokinetic studies, toxicity evaluation, and ultimately well-designed clinical trials to determine the therapeutic potential of *P. odoratum*. In addition, studies investigating combination therapy with conventional anticancer agents may help determine whether synergistic effects can improve treatment efficacy while reducing toxicity.

Furthermore, for the identified anti-microbial activity of *P. odoratum*, several mechanisms have been identified as possible mode of bactericidal effect of phytochemicals, including inhibiting bacterial virulence factors such as enzymes and toxins, interacting with the cytoplasmic membrane or reducing the pH values, suppressing biofilm formation, and reducing the extracellular polysaccharide (EP) activity [80]. Future studies should investigate these potential mechanisms in *P. odoratum* to better understand its antimicrobial properties and facilitate the development of standardized phytochemical preparations for therapeutic applications. Fig. 4 summarized the future perspectives into the research on *P. odoratum*.

Conclusions

The present systematic review demonstrates that *P. odoratum* possesses diverse biological activities, including antimicrobial, antioxidant, anti-inflammatory, anticancer, and organ-protective effects. However, most available evidence is derived from in vitro and animal studies, with limited clinical evidence. Future mechanistic investigations and well-designed clinical studies are still required before translation into conventional medicine can be recommended.

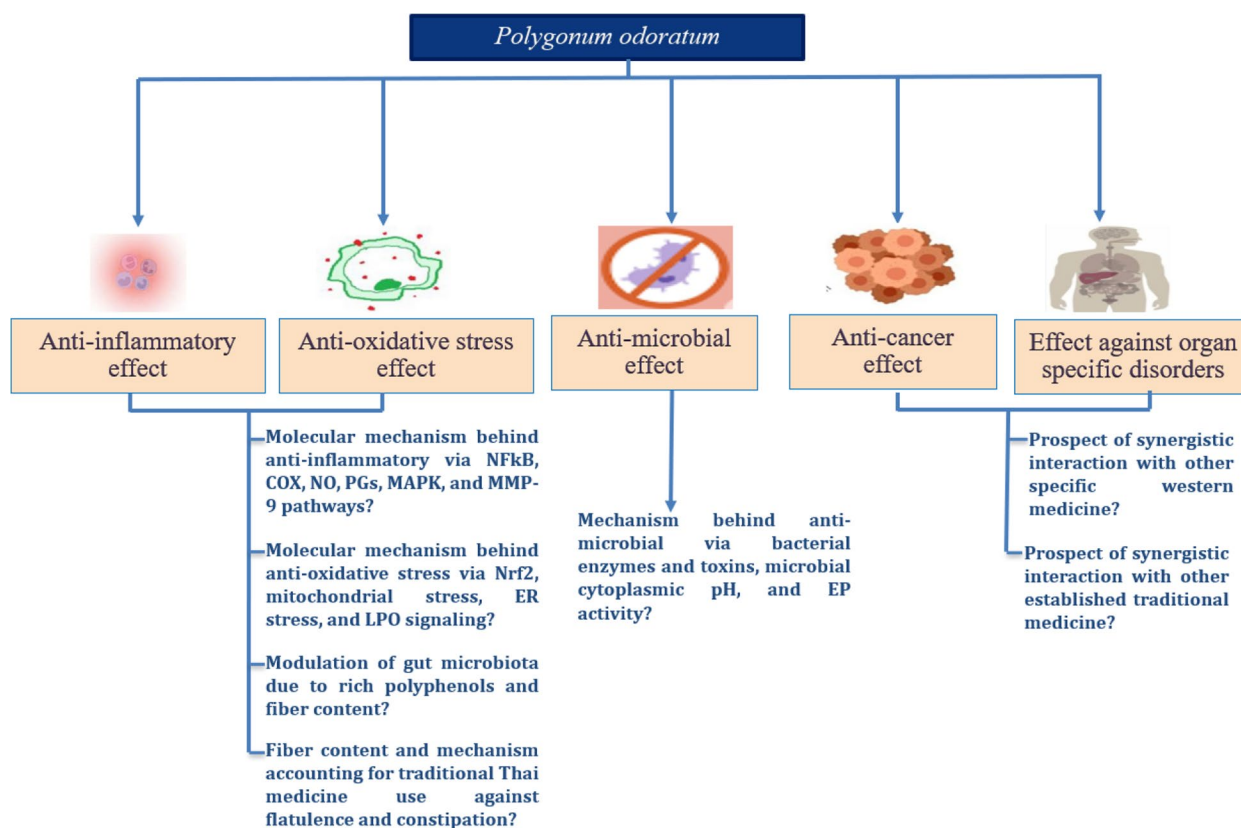


Fig. 4 Future perspective illustrating unexplored areas of research on *P. odoratum*

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Data availability All data generated or analyzed during this study are included in this article and its supplementary information files.

Declarations

Ethics approval and consent to participate Not applicable. This study was a systematic review based exclusively on previously published data and did not involve the recruitment of human participants, the collection of human biological materials, or the use of animals by the authors.

Consent for publication Not applicable.

Competing interests The authors declare that they have no competing interests.

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