



REVIEW ARTICLE

Phytochemicals as Emerging Therapeutics for the Control of *Giardia duodenalis* in Canines

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ARTICLE HISTORY (26-234)

Received: March 10, 2026
Revised: May 21, 2026
Accepted: May 24, 2026
Published online: May 27, 2026

Key words:

Giardia duodenalis
Canines
Botanical compounds
Alternative therapies
Zoonosis

ABSTRACT

Giardia (G.) duodenalis is a ubiquitous enteric protozoan, which infects canines in all parts of the globe, resulting in acute or chronic diarrhea, malabsorption and poor growth, especially among puppies and those with weakened immunity. Traditional chemotherapeutics, including metronidazole, benzimidazoles are still the foundation of therapy; however, drug resistance, residue issues and toxicity problems raised the attention to new alternative strategies. Medicinal plants yield phytochemicals with varied bioactivities, such as antiparasitic activity, antioxidant, anti-inflammatory and immunomodulatory effects and would be potential candidates in the management of canine giardiasis. However, most of the available evidence is derived from *in vitro* and experimental animal models, with very limited direct validation in naturally infected dogs. Polyphenols, flavonoids, saponins, tannins and terpenoids have direct trophozoiticidal activity and disrupt adhesion, membrane integrity and parasite metabolism. This highlights a significant translational gap between experimental findings and clinical veterinary application. This review critically examines the pathogenesis and zoonotic importance of *G. duodenalis* in dogs, represents the constraints of conventional treatments and covers botanical compounds as a new form of therapeutics, their mechanisms of action and future research in veterinary parasitology.

To Cite This Article: Alkheraije KA, 2026. phytochemicals as emerging therapeutics for the control of *Giardia duodenalis* in canines. Pak Vet J, 46(5): 1081-1091. <http://dx.doi.org/10.29261/pakvetj/2026.098>

INTRODUCTION

Canine giardiasis is an enteric parasitic infection caused by *Giardia (G.) duodenalis*, a flagellated protozoan (Ayana, 2023; Barasa *et al.*, 2025). The small intestine of many vertebrate hosts is infected by the parasite, such as dogs, cats, livestock, wildlife and humans (Mendoza *et al.*, 2023; Pal *et al.*, 2023). In dogs, the infection is mostly among puppies, populations in kennels, shelters and poor hygiene areas (Solanki *et al.*, 2023; Grellet and Mila, 2024). The worldwide prevalence of *G. duodenalis* demonstrates its effective fecal-oral pathogenesis, as well as its environmental capability of surviving long periods of time in moisture (Ayana, 2023; Ghazy *et al.*, 2025). The parasite is characterized by relatively great genetic diversity and belongs to separate assemblages (A-H), assemblages C and D infect mostly canines and assemblages A and B have zoonotic potential (Laidoudi *et al.*, 2022). Transmission occurs primarily through the ingestion of infective cysts present in contaminated water, food, soil, or fomites (Shaltout, 2024). The trophozoites attach to the mucosal surface after excystation in the small intestine and divide by

binary fission (Benchimol and de Souza, 2022; ElShewy, 2024). In addition to its clinical significance, the problem of canine giardiasis has gained significant attention because of its public health concerns (Drake *et al.*, 2022). Dogs are able to transmit zoonotic assemblages because they are in close contact with humans (Esposito *et al.*, 2023). As a result, the successful management of *G. duodenalis* in dogs correlates with the concept of One Health which combines veterinary and human health measures (Ubirajara Filho *et al.*, 2022; Massetti *et al.*, 2023).

Traditional treatment regimens are mostly based on nitroimidazole like metronidazole and benzimidazoles like fenbendazole (Bourque *et al.*, 2022; Golla *et al.*, 2024). Although these drugs are most effective, they have some restrictions such as gastrointestinal (GI) symptoms, neurotoxicity, partial clearance of cysts and newly decreased susceptibility (Hamamoto Filho *et al.*, 2022). Infections frequently occur, especially in crowded animal habitats. In addition, the issue of antimicrobial stewardship and drug resistance has provoked interest in alternative and complementary therapies (Endale *et al.*, 2023).

The recent years have seen the development of phytochemicals (plant-derived bioactive secondary metabolites) as potential antiparasitic agents (Shakeel *et al.*, 2025; Shang *et al.*, 2025). Traditional veterinary medicine has been relying on the use of medicinal plants to treat GI diseases (Hussain *et al.*, 2021; Khoja *et al.*, 2022). Through the progress of phytochemistry and pharmacology, the isolation and characterization of compounds with specific antiprotozoal activity have become possible (Shang *et al.*, 2025). Polyphenols, flavonoids, saponins, tannins and terpenoids have a complex mode of action, which consists of membrane disruption, oxidative stress, adhesion inhibition and parasite metabolism interference (El-Saadony *et al.*, 2025). Furthermore, most phytochemicals have antioxidant and anti-inflammatory effects that can help to relieve intestinal injury caused by giardiasis (Alrumaihi *et al.*, 2024). The fact that natural therapeutics have increasingly become the preferred choice by consumers in companion animal medicine also encourages the search into botanical substitutes (Stanossek and Wehrend, 2022). The compounds from plant source can also be characterized by good safety profiles and could decrease the use of synthetic chemotherapeutics (Pathak *et al.*, 2022). Nonetheless, efficacy and selection of optimal dosing schedules cannot be achieved without scientific validation by controlled *in vitro* and *in vivo* studies to support efficacy (Sun *et al.*, 2022).

The objective of this review is to summarize existing information on the pathogenesis and zoonotic importance of *G. duodenalis* among dogs, assess the weaknesses of standard treatments and critically review phytochemicals as a new treatment in place. This article can illustrate the possible application of botanical compounds in developing long-term control measures in the field of canine Giardiasis, by combining the viewpoints of parasitology, pharmacology and clinical.

***Giardia duodenales* pathogenesis in canines:** The infection mechanisms of the *G. duodenalis* in dogs are a multifactorial process that implies both mechanical and biochemical changes in the environment in the host (Peruzzo *et al.*, 2023; Šmit *et al.*, 2023). Following ingestion, Excystation of cysts occurs is triggered by the acidic gastric environment in the stomach leading to the release of trophozoites, which migrate to duodenum and jejunum (Irwin, 2024). The characteristic feature of *Giardia* pathogenesis is the adhesion of trophozoites to the microvillous border of enterocytes through a ventral adhesive disc (Solaymani-Mohammadi, 2022). This binding is not just physical but includes highly complicated hydrodynamic activities as well as lectin-mediated association that produces a suction impact on the intestinal epithelia (Walia and Arya, 2023). The inability to absorb nutrients is a direct consequence of the physical presence of the parasite and leads to direct damage of the microvilli (Sardinha-Silva *et al.*, 2022).

Diffuse shortening of the microvilli and villous atrophy is common in infected dogs and disables a large part of the absorptive surface area of the small intestine (Jablonski, 2022; Geboes and Jouret-Mourin, 2024). This damage to the architecture causes malabsorption of glucose, electrolytes and water, which causes the typical

osmotic diarrhea manifested in clinical cases (Ahmad and Morsy, 2022; Peretti and Mas, 2022). Moreover, *Giardia* trophozoites also interfere with the enzyme activity of the brush border, which decreases the activity of disaccharidases, such as lactase, sucrase and maltase (Solaymani-Mohammadi, 2022). This leads to the buildup of unabsorbed sugars in the intestinal lumen, which pulls water into the intestine, causing fermentation by bacteria and subsequent production of gases and intestinal discomfort (Shahsavari and Parkman, 2022).

Other than mechanical destruction, the parasite causes a host immune reaction that is also contributory to the disease pathogenesis (Ezema *et al.*, 2023). T-lymphocytes activation which is followed by the release of cytokines, may increase the turnover rate of enterocytes, resulting in the appearance of immature cells at the tip of the villus that lack the ability to absorb (Kapembwa *et al.*, 2024). The parasite also causes apoptosis of enterocytes as well as interferes with the tight junctions between the epithelial cells, which enhances intestinal permeability (Ali *et al.*, 2025). The result of this leakiness of the gut is the ability of luminal antigens to cross the mucosal barrier, which may cause allergic reactions or systemic inflammation (Niewiem and Grzybowska-Chlebowczyk, 2022). Interestingly, *Giardia* does not penetrate the tissue, but its surface proteins and metabolic products are high enough to trigger a local inflammatory reaction that increases the dysfunction of the intestine (Klimczak *et al.*, 2024).

Zoonotic importance of *Giardia duodenalis*: The epidemiology of *G. duodenalis* has been extensively investigated and remains a major concern for public health systems, globally (Aliyi and Yusuf, 2023). The species is classified into eight different genetic assemblages referred to as A through H and these differ in terms of host specificity (Möckel *et al.*, 2022). Host-specific assemblages C and D are the main pathogens of dogs and are not common in humans (Huggins *et al.*, 2022). Nevertheless, assemblage A and B that are the most common genotypes causing human infections, can also be present in dogs (Genath *et al.*, 2024). This overlapping of host susceptibility implies that dogs would theoretically be reservoirs of human Giardiasis but the extent of direct dog-to-human transmission is controversial (Barasa *et al.*, 2025).

Studies have shown that prevalence in dogs can range from approximately 7-30% in household populations to over 40% in kennels and shelters, with one study reporting 41.07% prevalence in sheltered dogs and another reporting around 20.5% in kennel populations (Agresti *et al.*, 2021). It has been shown that although the majority of canine infections are due to dog-specific genotypes, a subpopulation of the canine population, especially those closely associated with humans, might harbor potentially zoonotic assemblages (de Ree *et al.*, 2024). In immunocompromised patients who keep infected pets, the risk is said to be greater (Moore *et al.*, 2022). Although dog-specific assemblages are common, the assemblage of potentially zoonotic genotypes in the feces of infected dogs requires the treatment of infected dogs not only to treat them but also as a safeguard against infection in people (Perec-Matysiak *et al.*, 2023). The

adequate level of hygiene and immediate feces elimination are the most important control factors to minimize the impact on the environment and minimize the risk of spreading the infection to other animals and humans (Endale *et al.*, 2023).

Current control strategies and their limitations: The main medications applied in giardiasis in dogs are metronidazole, fenbendazole and albendazole (Mushynskiy *et al.*, 2024; Jones *et al.*, 2025). Metronidazole is a nitroimidazole drug which has an antiprotozoal action developed through the formation of reactive nitro radicals that destroy DNA and other vital biomolecules in the anaerobic environment (Gupta *et al.*, 2022). The benzimidazole group of fenbendazole and albendazole are known to interfere with the formation of microtubules by binding to β -tubulin and isolating cytoskeleton and cell division (Pech-Santiago *et al.*, 2022). Despite the efficacy rates of 80-100% of the anthelmintic drugs including Metronidazole and Fenbendazole, limitations including recurrence, dose dependent adverse effects and incomplete cyst clearance remains significant (Weth *et al.*, 2024). Metronidazole is linked to dose related neurotoxicity, anorexia, vomiting and lethargy (Sahu *et al.*, 2025). Prolonged or repeated use can alter the equilibrium of intestinal microbiota, which can slow down intestinal recovery (Tian *et al.*, 2025). Benzimidazoles, which are usually safer, can either lead to bone marrow suppression or teratogenic effects when administered in high doses (Venugopal *et al.*, 2023).

The failure of treatment and frequent infections are typical, especially in kennel settings when reinfection due to the contaminated surfaces takes place rapidly (Spratt *et al.*, 2024). The fact that cysts are resilient even in wet conditions makes it difficult to eradicate them (Poglayen *et al.*, 2023). In addition, there are new indications of decreased sensitivity or resistance to metronidazole in some isolates that create apprehension of the development of resistance (Reissier *et al.*, 2023). Cyst shedding may not be completely removed after therapy and this may lead to environmental persistence (Durairaj *et al.*, 2023). Moreover, there are dogs that are asymptomatic carriers and they form reservoirs of infection (Pal *et al.*, 2023). These complications highlight the necessity to use adjunctive or alternative therapies which affect several phases of the parasite and help intestinal recovery (Oliveira *et al.*, 2022).

Recent studies indicate that the low susceptibility of the protozoan parasite *G. duodenalis* to the antiprotozoal drug Metronidazole is linked to several molecular changes rather than target-based drug resistance. These include lower drug activation through changes in pyruvate: ferredoxin oxidoreductase; increased antioxidant capabilities through thioredoxin reductase; and enhanced oxygen consumption. Furthermore, biofilm-like encystation and reinfection in the environment also contribute to therapy failure, thereby making it difficult to tell apart pharmacological resistance from epidemiological reinfection (Almatroudi, 2025). These observations suggest the events leading to resistance of giardiasis are complex and yet to be completely understood.

Issues relating to antimicrobial stewardship also promote non-antibiotic interventions (Alhassan *et al.*, 2025). With veterinary medicine converging with the rest

of the world to control the misuse of antimicrobials, it is clear that phytochemicals have a role to play in the development of a more complementary approach to the challenge that is less likely to result in resistance development (Ashraf *et al.*, 2023).

Botanical compounds as an alternative control strategy: A variety of diverse plant-based secondary metabolites that have been reported to have antiparasitic activity are botanical compounds (Ranasinghe *et al.*, 2023; Abbas *et al.*, 2025). They are good alternatives or adjuncts to traditional medicines because their multi-modular processes, such as membrane disruption, enzyme inhibition, induction of oxidative stress and immunomodulation, are appealing (Strzelec *et al.*, 2023). Phytochemicals do not require modification as they can work synergistically in complex plant extracts, unlike single-target synthetic agents, which may contribute to the development of resistance (Choudhury, 2022). In addition, most botanicals have antioxidant and anti-inflammatory activities that can stimulate the recovery of the mucosa in infected dogs (Guo *et al.*, 2024). To have assurance of safety, efficacy and standardization, scientific validation is necessary by use of controlled experiments and clinical studies (Wang *et al.*, 2023). Botanical compounds have diverse biological activities by multiple mechanisms of actions (Table 1 & 2). Detailed mechanisms of major botanical compounds have been discussed as follows:

Polyphenols: Polyphenols are a general group of secondary plant metabolites that share the feature of having numerous phenolic hydroxyl functional groups (Zagoskina *et al.*, 2023). They are common in fruits, vegetables, herbs and medicinal plants and they are also reported to have strong antioxidant and antimicrobial effects (Deshmukh and Gaikwad, 2024). Polyphenols in canine giardiasis have been shown to have a high potential as they are capable of affecting both the host and parasite intestinal environment (Palomo-Ligas *et al.*, 2022). Among the key polyphenol action mechanisms on *G. duodenalis*, there is also damage to the trophozoite membrane integrity (Alawfi, 2024). Lipid bi-layers may react with polyphenolic compounds that may change the fluidity and permeability of the membrane (Pozos-Nonato *et al.*, 2023). This contact disrupts structural integrity and causes leaking of cytoplasmic contents, eventually causing a death of the parasite. Also, polyphenols have the ability to interact with proteins attached to the membrane, disrupting nutrient uptake transport systems (De Rossi *et al.*, 2025).

Oxidative stress in the trophozoites is also caused by polyphenols (Pawłowska *et al.*, 2023). Though they are commonly known to be antioxidants in a mammalian environment, in protozoan cells they can be pro-oxidants in a given condition and cause the formation of reactive oxygen species (Kapoor, 2022). ROS over-accumulation causes destruction of nucleic acids, lipids and proteins, leading to apoptosis-like pathways and the impairment of mitochondrial-like organelles that are called mitosome (Yang *et al.*, 2022). This can cause a significant decrease in ATP and cellular viability (Khalef *et al.*, 2024). The other significant process is suppression of enzymes in the metabolic process (Bian *et al.*, 2022). Polyphenols can compromise glycolytic enzymes and redox systems,

which play a key role in the anaerobic energy metabolism of *Giardia* (Karpe *et al.*, 2023). They reduce trophozoite proliferation and replication by interfering with these biochemical pathways are given in Fig. 1 (Tarannum *et al.*, 2023).

In addition to the direct antiparasitic action, polyphenols have protective anti-intestinal action on the host intestinal mucosa (Palomo-Ligas *et al.*, 2023). Their anti-oxidant activity decreases the occurrence of oxidative damage to the epithelial cells and the anti-inflammatory action regulates the generation of cytokines and lessens the mucosal inflammation (Albano *et al.*, 2022). The overall effects of these include not only the inhibition of parasite load but also the recovery and normalization of intestinal absorption in infected dogs (Henke *et al.*, 2023).

Flavonoids: Flavonoids are one of the most studied phytochemicals because of antiparasitic activity and they form a major subclass of polyphenols (Soto-Sánchez, 2022). Flavonoids are structurally characterized by a C6-C3-C6 backbone and are found in abundance in fruits, vegetables, tea and other medicinal herbs (Arora *et al.*, 2023). Their wide biological activity will make them effective in controlling canine giardiasis (Jones *et al.*, 2025). The main action of flavonoids against *G. duodenalis* is the blockage of adhesion in trophozoites (Ticona *et al.*, 2022). The effective colonization of the small intestine must be through the ventral adhesive disc (Klimczak *et al.*, 2024). Flavonoids may interact with surface proteins or cytoskeleton structural components that relate to this disc and compromise its activity and lower binding ability (Nassarawa *et al.*, 2023). Consequently, the trophozoites can be more readily displaced by the intestinal peristalsis and colonization and the severity of the infection are restricted (Sardinha-Silva *et al.*, 2022).

Parasite redox homeostasis is also disrupted by Flavonoids (Pawłowska *et al.*, 2023). The mechanism is consistent with that described in section 5.1 (polyphenols) (Zandi and Schnug, 2022). Certain flavonoids prevent topoisomerases and other enzymes that react with the replication of DNA, therefore, inhibiting the growth of trophozoites (Memariani *et al.*, 2024). Also, disruption of cytoskeleton proteins can lead to disruption of cell division and motility (Yadav *et al.*, 2022). The other

factor is their ability to regulate variant-specific surface protein (VSP) expression, which contributes to immune evasion (Tenaglia *et al.*, 2023). Fig. 2 demonstrates how flavonoids can positively impact immune recognition and antibody-mediated clearance by disrupting the regulation of VSP (Li *et al.*, 2020).

Flavonoids enhance the integrity of epithelial barriers in the host by enhancing the expression of tight junction proteins and reducing inflammatory signaling by topics like NF- κ B inhibition (Al-Khayri *et al.*, 2022). The effects are added to reduced intestinal permeability, less fluid secretion and quicker recovery from diarrhea (Keely and Barrett, 2022). Therefore, flavonoids are a twofold advantage: they not only suppress the growth of the parasites directly but also maintain the health of the intestine of the host (Yang *et al.*, 2023).

Saponins: Saponins are naturally occurring glycosides which are amphiphilic with a hydrophobic aglycone group attached to hydrophilic sugar chains (Oakenfull and Sidhu, 2023). Their strong membrane-active effects are based on this structural characteristic and are a major contribution to their antiparasitic effect on *G. duodenalis* (Hagemann *et al.*, 2024). The major action of saponins is to act on the sterols in the membrane, which causes the creation of the pore and enhanced permeability (Xiao *et al.*, 2025). In spite of the fact that *Giardia* is unable to synthesize cholesterol, it includes host-derived sterols in their membrane (Kořený *et al.*, 2022). These sterol components are bound to saponins, forming transmembrane pores which interfere with ionic gradients and lead to leakage of vital intracellular molecules (Oakenfull and Sidhu, 2023). This impairment of the membrane integrity leads to the rapid lysis of the trophozoites as well as decreased viability of the parasites (Reyes-López *et al.*, 2022). The presence of saponins can also disrupt nutrient uptake mechanisms which prevent uptake of glucose and amino acids used in anaerobic metabolism (Zhang *et al.*, 2024). Alteration of metabolism affects energy production and reduces the quasispecies replication of trophozoites (Saraiva *et al.*, 2022). Moreover, saponins have the potential to decrease adherence of parasites by changing the membrane surface properties, hence reducing colonization effectiveness as depicted in Fig. 3 (Ramdani *et al.*, 2023).

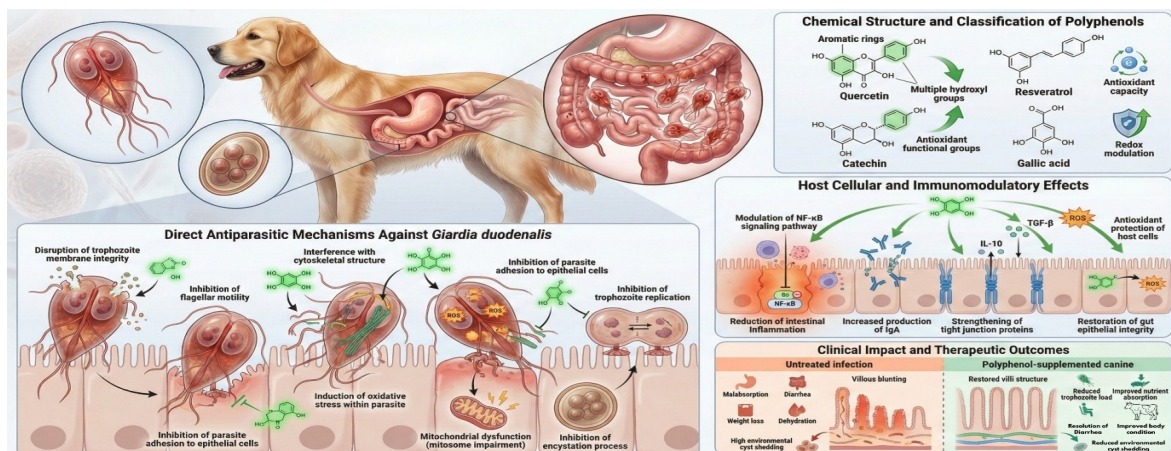


Fig. 1: Mechanism of polyphenols against *G. duodenalis* in canines

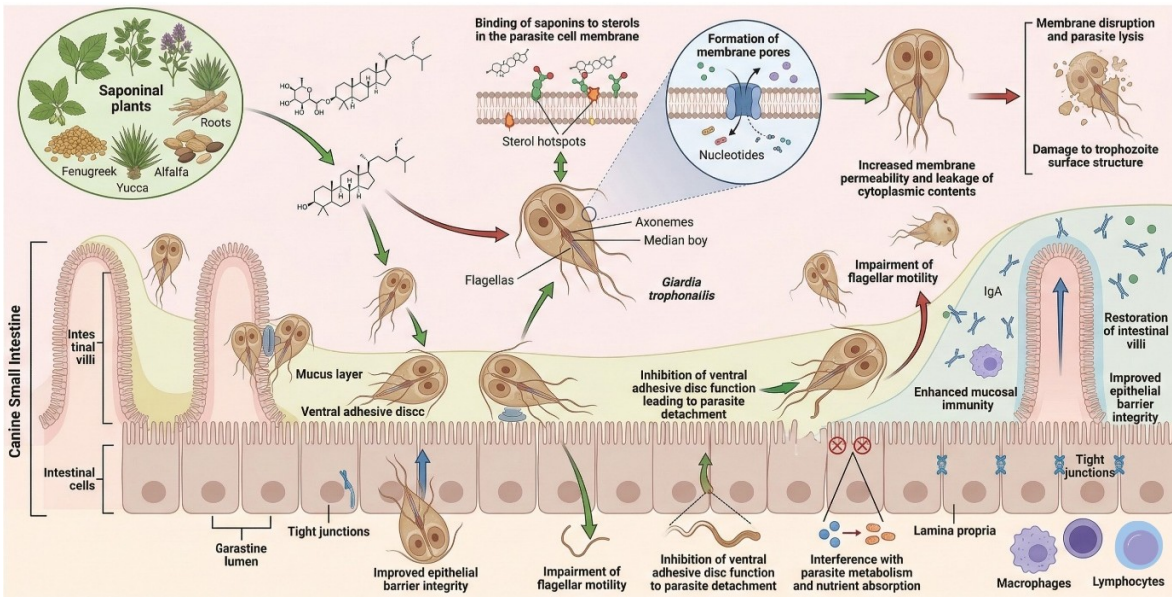


Fig. 3: Mechanism of saponins against *G. duodenalis* in canines.

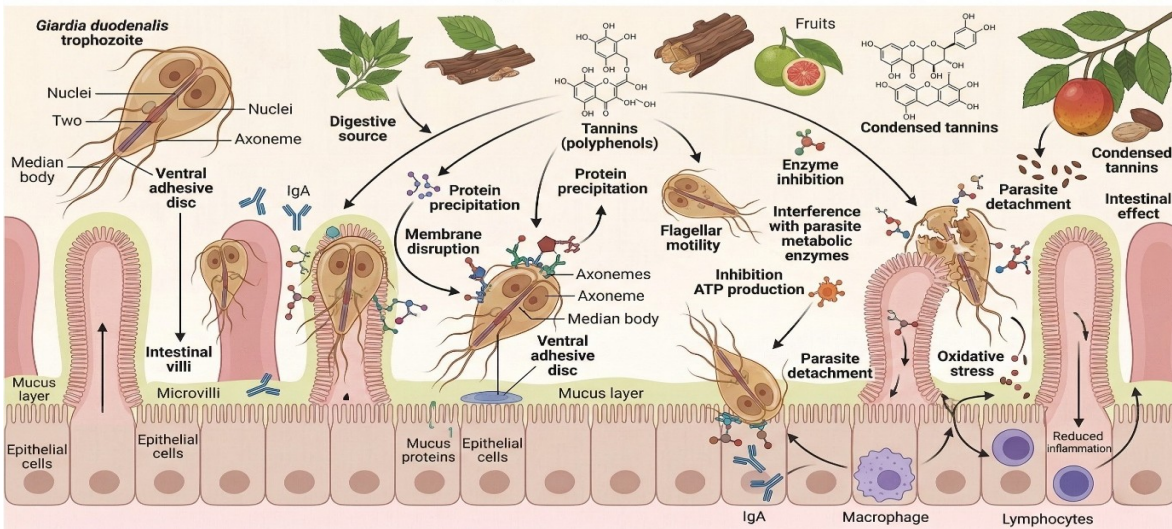


Fig. 4: Mechanism of tannins against *G. duodenalis* in canines.

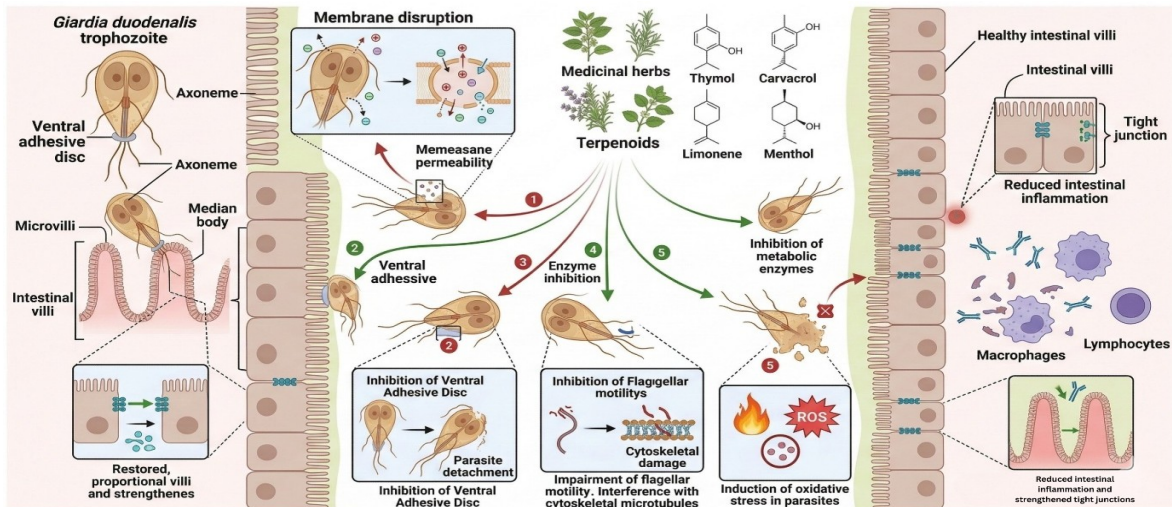


Fig. 5: Mechanism of terpenoids against *G. duodenalis* in canines.

Although the results of *in vitro* research are promising, the standardization and dosage are to be evaluated with caution, as the essential oil composition varies and mucosal irritation may occur (Infante *et al.*, 2022). Terpenoids have a lot of potential to be used as complementary agents in managing giardiasis in dogs when formulated well (Wiles *et al.*, 2025).

Comparative analysis of botanical compounds: Among the evaluated phytochemical classes, terpenoids and certain polyphenol-rich extracts demonstrate

comparatively stronger and more consistent anti-giardial activity. These compounds exhibit rapid trophozoite membrane disruption and high *in vitro* lethality. Flavonoids show moderate activity but provide additional host-protective effects through antioxidant and anti-inflammatory mechanisms, making them more suitable candidates as adjunct therapies. Tannins show variable efficacy depending on their molecular size and degree of polymerization while saponins exhibit potent membrane-disrupting effects but lack sufficient *in vivo* validation because of potential GI irritation at higher doses.

Table 1: Botanical interventions (*in vitro*) as alternative control strategies against canine

Sr. No.	Plant Used	Family	Compound Identified	Class	Plant Part Used	Extract Type	Dose / Concentration	Animal Used	Mechanism	Results	References
1	<i>Piper betle</i>	Piperaceae	Phenolics / flavonoids	Phenolic / flavonoid	Leaf	Aqueous	100 µg/mL	NA	Direct trophozoite inhibition	Reduced trophozoite growth significantly	(Pecková <i>et al.</i> , 2025)
2	<i>Andrographis paniculata</i>	Acanthaceae	Andrographolide (rich)	Diterpenoid	Leaf	Ethanol	IC ₅₀ ~51.3 µg/mL	NA	ROS generation, morphology alteration & cell cycle interference	Significant trophozoite death	(Haldar <i>et al.</i> , 2024)
3	<i>Archidendron fagifolium</i>	Fabaceae	Not yet isolated	Likely polyphenols	Leaf	Methanol	400 µg/mL	NA	Growth inhibition	Significant reduction in trophozoites	(Pecková <i>et al.</i> , 2025)
4	<i>Foeniculum vulgare</i>	Apiaceae	trans-2,4-undecadienal	Aldehyde + terpenoids	Fruit	Hexane	Variable	NA	Membrane disruption (terpenoid)	Demonstrated anti-giardial activity	(Domínguez-Vigil <i>et al.</i> , 2022)
5	<i>Stemona collinsiae</i>	Stemoneaceae	Stemofoline & derivatives	Alkaloids	Roots	Dichloromethane/hexane	IC ₅₀ ~60–66 µg/mL	NA	Motility & adherence inhibition; apoptosis	Highly active trophozoite inhibition	(Koompong <i>et al.</i> , 2025)
6	14 diverse medicinal plants	Various	Variable (phenolics / flavonoids)	Various phytochemicals	Various	Methanol/chloroform/water	<100 µg/mL	NA	Direct inhibition	Several extracts showed active IC ₅₀ values	(Kaewjai <i>et al.</i> , 2023)
7	<i>Ageratum conyzoides</i>	Asteraceae	Sesquiterpenes, chromenes	Terpenoids	Leaves/flowers	Crude + EO	IC ₅₀ ~45.7–96 µg/mL	NA	Organization disruption (flagella/disc)	High activity vs trophozoites	(Ranasinghe <i>et al.</i> , 2023)
8	<i>Zingiber officinale</i> (ginger)	Zingiberaceae	Gingerols / shogaols	Phenolic terpenoids	Rhizome	Dichloromethane	1–50 mg/mL	NA	Membrane disruption	Dose/time dependent cyst fatality	(Zagórska <i>et al.</i> , 2023)
9	<i>Justicia spicigera</i>	Acanthaceae	Phenolics / flavonoids	Phenolic	Aerial parts	Methanol	~90% mortality	NA	Likely membrane/ROS	High anti-giardial action vs trophozoites	(Palomoligas <i>et al.</i> , 2022)
10	<i>Psidium guajava</i>	Myrtaceae	Tannins & flavonoids (rich)	Tannins / flavonoids	Leaves/fruit	Methanol	~87% mortality	NA	Protein binding & enzyme inhibition	High efficacy vs trophozoites	(Pecková <i>et al.</i> , 2025)
11	<i>Oregano (Lipia berrandieri)</i>	Lamiaceae	Phenolics/oils	Terpenoids / flavonoids	Aerial parts	Methanol	~90% mortality vs trophozoites	NA	Membrane/oxidative damage	Comparable to metronidazole	(Albalawi and Alanazi, 2023)
12	<i>Punica granatum</i> (pomegranate)	Lythraceae	Ellagitannins	Tannins	Fruit	Methanol	~78% mortality	NA	Protein precipitation & enzyme inhibition	Strong trophozoite inhibition	(Shaverdi <i>et al.</i> , 2024)

Table 2: Botanical interventions (*in vivo*) as alternative control strategies against canine

Sr. No.	Plant Used	Family	Compound Identified	Class	Plant Part Used	Extract Type	Dose / Concentration	Animal Used	Mechanism	Results	References
1	<i>Piper betle</i>	Piperaceae	Phenolics/flavonoids	Phenolic / flavonoid	Leaf	Aqueous/Methanol	40 mg/100 g BW	Mongolian gerbil	Reduced cyst shedding	Significant decline in cysts vs control	(Ristani <i>et al.</i> , 2024)
2	<i>Curcuma longa</i>	Zingiberaceae	Curcumin	Polyphenolic	Rhizome	Dichloromethane	10–20 mg/kg	Mice	Structural damage	Reduced cysts & trophozoites, improved mucosa	(Abdel-Hamed <i>et al.</i> , 2022)
3	MicrobiomeX® (Citrus extracts) + BIOintestil® mix	Rutaceae/Zingiberaceae	Geraniol/6-gingerol + flavonoids	Terpenoids & flavonoids	Supplement mixture	Defined formulation	100 mg/day	Mice	Multimodal microbiome & immune effects	100% infection elimination	(Solnier <i>et al.</i> , 2023)

Conclusions and Future Perspectives: Canine giardiasis is a common and clinically important enteric disease, which has implications for animal and human health issues. The shortcomings of traditional chemotherapeutics, such as side effects, relapse and possibility of resistance, support the necessity of implementing alternative approaches. There is a promising future for phytochemicals owing to their varied modes of action, which include membrane disruption, oxidative stress generation, enzyme inhibition and immunomodulation. However, despite these mechanisms, most evidence remains confined to in vitro studies and clinical validation in canine population is still very limited. Polyphenols, flavonoids, saponins, tannins and terpenoids exhibit high in vitro anti-giardial activity and possible impact on intestinal health. Although this is promising, more validation of this fact is required by conducting stringent clinical trials using canine populations. The standardization, safety testing and pharmacokinetic profiling are still necessary on the way to practical implementation. Controlled in vivo studies in dogs should be given priority in future research to confirm the efficacy of phytochemicals in the treatment of *G. duodenalis* and their safety. Small intestine bioavailability and delivery may be increased by nano-formulations and encapsulation technologies. Explorations of synergistic dosing of botanical compounds with standard drugs will decrease dose requirements and prevent the emergence of resistance. To be approved by regulators and used medically, standardization of plant extracts and identification of active constituents are vital. In addition, lack of regulatory frameworks, batch-to-batch variability of plant extracts and insufficient toxicological profiling represent major barriers to clinical translation. Metabolomics, transcriptomics, or proteomics advances can explain molecular targets and can be used to design therapies in an optimized manner. To reduce zoonotic transmission, incorporation of phytochemicals into multimodal parasite management approaches, in line with One Health concept, can greatly reduce zoonotic transmission.

Acknowledgements: The researcher would like to thank the Deanship of Scientific Research, Qassim University, Saudi Arabia, for funding the publication of this project (QU APC 2026).

Funding: No external funding was received for this work.

Declaration of competing interest: The author declares no competing interests.

Generative AI Statement: The author declares that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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