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Medicinal plants as alternative to anthelmintics for livestock : An overview with particular reference to Indian subcontinent

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ABSTRACT

In livestock farming helminthiasis remains a major constraint to productivity, performance and profitability. Anthelmintics have been in use since long to combat the problem, but the emergence of anthelmintic resistance, particularly in gastrointestinal (g.i.) parasites has compelled a relook at alternative control strategies. The application of ethno-veterinary practices and plant derivatives as deworming agents is gaining popularity worldwide. The acceptability of this approach depends on the scientific validation of the plant products for their anthelmintic properties. Several controlled studies recently carried out in the Indian subcontinent, generated a large volume of data on *in vitro, in vivo* and clinical efficacies of plants and herbs singly and in combination. Most have used internationally accepted guidelines as parameters for evaluation of the candidate plants. The target helminths in these studies belonged to 3 major classes, but gastrointestinal (g.i.) nematodes, liver flukes of ruminants and intestinal worms of poultry were predominant. Active principles and mode of action were identified in majority of plants, which have proven anthelmintic potential. Lately, the use of forages containing condensed tannins, is finding favour in the management of g.i. nematodes in ruminants. A cross-section of recent studies, an overview of the current scenario, and the road ahead, are presented in this review.

Key words: Anthelmintic activity, Condensed tannins, Indigenous plants, Plant extracts, Tanniferous forages, Validation

Helminth infections are a major cause of reduced productivity in livestock worldwide. More than 300 helminth species parasitize livestock in India with mostly multiple infections because the environment is favourable for their development (Singh and Srivastava 1977). The gastrointestinal (g.i.) worm infections account for the highest economic losses, but are generally neglected due to their chronic and insidious nature. Synthetic anthelmintics are being used for the control of parasites for about last five decades. The indiscriminate anthelmintic usage led to chemical residues in milk, meat, eggs, environment, and also the emergence of resistant strains of parasites, causing serious concerns. The search is for alternative methods of control with prime emphasis on safety, sustainability and minimal chemical interventions. There has been dramatic resurgence of interest toward plant-based anthelmintics. Phytomedicine is widely used as part of traditional healing and ethno-veterinary practices. Approximately 80% of the world's population depends on traditional medicine for meeting primary health-care needs of humans as well as livestock (Danoe and Bogh 1999). Phytotherapeutic drugs, especially plant anthelmintics are safe, non-toxic, biodegradable and do not leave any residue in animal products, hence plants with anthelmintic properties were included in the pharmacopoeias. The chenopodium oil (Gibson 1965) derived from *Chenopodium ambrosioides* as well as leaves and dried flowers (Guarrera 1999) are used to treat nematode parasite infections in monogastric animals. Male fern (*Dryopteris felix-mas)* and *Artemisia* spp. are useful against *Moniezia* in ruminants, *Raillietina* and nematodes, ascarid, in poultry (British Veterinary Codex 1965). Arecoline and other alkaloids from *Areca catechu* seeds, are active against tapeworms in dogs and poultry. Kamala from the fruits of *Mallotus philippinensis* is also used against cestodes.

WHO has also recommended to all member countries to actively promote native medicines and also to initiate steps to conserve and cultivate medicinal plants. There are some valuable reviews with the focus on usage of plant anthelmintics, particularly for g.i. helminths of small ruminants (Hammond *et al.* 1997, Van Veen Schillhorn 1997, Akhtar *et al.* 2000, Tagboto and Townson 2001, Githiori *et al.* 2006). The therapeutic armamentarium of plant origin in India contains nearly 750 medicinal plants (Anjaria *et al.* 2000) for both human and animal treatment.

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Estimates of plant species known to possess anthelmintic activity vary from below 100 (Tripathi 1998, Akhtar *et al.* 2000) to about 160 (Garg 2007). In the recent past, numerous studies were carried out in the Indian subcontinent, as theme conferences (Rangnekar 1998, Vadlamudi *et al.* 2004), symposia (Katoch 2007), project reports (Rai 1993, Anonymous 2003) and PG dissertations. However, as per Githiori *et al.* (2006), scientific evidence on the anti-parasitic efficacy of most plant products is limited. Helminth parasites from all 3 major groups were utilized as experimental models to evaluate the anthelmintic activity of various plants, but g.i. nematodes were subjected more frequently to *in vitro* as well as *in vivo* trials (Kumar *et al.* 2012). *In vitro* tests using free-living stages of parasitic nematodes help evaluating the anthelmintic activity of new plant compounds (Robinson *et al.* 1990). Plant preparations used in such studies are generally aqueous or alcoholic extracts, decoctions, dried powders, pastes and essential oils extracted from leaves, seeds, flowers tubers, stems and fruits. The criteria for anthelmintic efficacy *in vitro* had ranged from inhibition of motility or paralytic effect, inhibition of glucose uptake/enzyme activity to disruption of tegument. *In vivo* studies rely on faecal egg counts (FEC) and/or recovery of dead worms on autopsy as the measure of efficacy. In several cases, there is no correlation between the efficacy of *in vitro* and *in vivo* studies as the conditions and concentrations used in the 2 assays are different. The scientific validation for both *in vitro* and *in vivo* assays are prerequisites to determine whether biologically significant levels of parasitic reduction, in comparison to a broad spectrum anthelmintic as standard, are achieved. Additionally, identification of active compounds in the herbal remedies and absence of potential anti-nutritional and other side effects, are desirable parameters to be considered prior to their wide-scale usage.

Studies in the Indian subcontinent

In vitro *studies:* Nama and Bhatnagar (1990) found that exposure of cercariae of flukes to aqueous extracts from garlic bulb and neem leaves killed them. Salient studies on trematodes, cestodes and nematodes are listed in Table 1. Common names of plant/herb, the part and preparation used and the standard control are given as indicated by the authors. The investigators used varying concentrations and accordingly the time taken for effective results by the plant derivatives was variable. Combination of 2 plant products such as *Artemisia maritima* (*kirmala*) and *Butea frondosa* (*palas*) enhanced their individual anthelmintic effect (Jangde *et al.* 2001). In Bangladesh, *in vitro* anthelmintic efficacy of 20 indigenous plants (Amin *et al.* 2009) was screened against g.i. nematodes of cattle. Of these, 10 plants viz. neem, tobacco, Barbados lilac, betel leaf, pineapple, jute, turmeric, garlic, dodder and bitter gourd showed 100% adulticidal efficacy. *In vitro* efficacy of 5 indigenous plants namely *bishkatali* (*Polygonum hydropiper*), neem (*Azadirachta indica*), papaya (*Carica papaya*), *korolla* (*Momordica charantia*) and mahogany (*Swietenia macrophylla*) were studied against the development of *Ascaridia galli* eggs (Islam *et al.* 2008) at varying concentrations in Bangladesh; methanol extract of papaya leaves was observed as the best plant. Similar studies against *A. galli* were carried out by Ahmad *et al.* (2013) in India, using aqueous and hydroalcoholic extracts of *Mentha longifolia*.

In vivo *studies:* Studies using plant products of single plants for evaluation of their anthelmintic activity are presented (Table 2). Only about 14 plants/herbs feature in both *in vitro* and *in vivo* listings. This underscores the need for extending the *in vivo* studies to cover more plant species for validating their potential anthelmintic quality. A combination of active botanicals from *Vernona anthelmintica* seeds and *Embelia ribes* fruit mixed in equal parts was used against g.i. nematodes of sheep in Pakistan (Iqbal and Akhtar 1990). Therapeutic efficacy of *Punica granatum* and *Cucurbita maxima* against clinical cases of nematodiosis in calves was reported (Pradhan *et al.* 1992). *Acacia auriculiformis* and *Centella asiatica* were employed against canine dirofilariasis (Sarkar *et al.* 1998). A formulation of equal proportions of *Azadirachta indica* (neem) bark, *Butea frondosa (palas)* seeds, *Nigella sativa (kala jeera)* seeds and *Piper longum* (*pipli*) fruit in powdered form administered at 30g / calf / day as drench for 3 consecutive days was evaluated for anthelmintic activity (Raje *et al.* 2003). The cow calves (24) were having heavy natural infections of *Haemonchus contortus, Oesophagostomum columbianum* and *Paramphistomum cervi* on basis of faecal egg count (FEC). The group administered with albendazole single oral dose as reference drug showed the least FEC but there was significant reduction also in the calves treated with the test formulation in 10-day observation. The same formulation was also tried in goats having similar helminthic infections (Raje *et al.* 2004) at 10 g / goat / day for 3 consecutive days. Significant reduction in FEC count in 10 days was observed. It was concluded that the efficacy of the formulation could be increased with repeated doses at weekly intervals. Another mixture formulation comprising *Azadirachta indica* (neem) bark, *Butea frondosa* (palash) seeds, *Nigella sativa* (*krishna jeera*) seeds and *Piper longum* (*pimpli*) fruits against clinical helminthic infection in goats at dose levels of 5 and 10 g/ day/animal twice a day (Ramteke *et al.* 2008) significantly reduced the worm load leading to clinical recovery. Ethanolic extracts of 10 indigenous medicinal plants evaluated both *in vitro* and *in vivo* revealed that *labanga*, neem, *karolla* (bitter gourd) and pineapple at dose rate of 100 mg/kg had a significant and potent nematocidal effect against g.i. nematodes of goats (Sujon *et al.* 2008). A herbal preparation containing dried seeds of *Embelia ribes* (*vayvidanga*), *Butea frondosa (palash)*, *Carica papaya* (papaya), *Terminalia chebula (hirda)* and *Nigella sativa (kala jira)* in equal proportion was effective against g.i. nematodes in local pigs (Jumde *et al.* 2011). The preparation was given orally @ 5 g / animal twice a day and reduced FEC to zero level in 13 days post-treatment. The helminthic infection in pigs was predominantly (78.60%) *Ascaris* sp.

Table 1. Plants of Indian subcontinent with documented anthelmintic activity (*in vitro* studies) : Trematoda

Herb/plant	Scientific name	Part used / used as (active principle)	Optimum concentration	Target parasite	Mode of action	Standard control	Reference (s)
Garlic	*Allium sativum*	Bulb/alcoholic extract (allicin)	100 µg/ml	*Fasciola gigantica and Gigantocotyle explanatum*	Inhibition of glucose uptake and paralysis	Oxyclozanide	Singh *et al.* (2007)
Garlic	*Allium sativum*	Bulb/aqueous extract (allicin)	5.0%	*Fasciola gigantica*	Inhibition of motility and death	Oxyclozanide	Jeyathilakan *et al.* (2012)
Galangal	*Alpina nigra*	Shoot/Ethanol extract	20 mg/ml	*Fasciolopsis buski*	Reduction in enzyme activity	Destruction of surface tegument	Praziquantel Roy and Swargiary (2009)
Areca nut	*Areca catechu*	Nut/Aqueous extract	2.5 and 5%	*Fasciola gigantica*	Paralysis disintegration and death	Praziquantel	Jeyathilakan *et al.* (2010)
Neem	*Azadirachta indica*	Leaves/Ethanol extract (Benzyl isothiocyanate)	10–30 µg/ml	*F.gigantica*	Inhibition of muscular and AchE activity (paralysis)	-	Kushwaha *et al.* (2004)
Neem	*Azadirachta indica*	Seed kernel (Azadirachtin)	0.005%	*Cotylophoron cotylophorum*	Inhibition of motility	-	Veerakumari and Priya (2006)
Mahua	*Barleria lupulina*	Deoiled seed cake Aqueous extract (Tannins and saponins)	60 µg/ml	*F.gigantica* juvenile	Destruction of tegument and death	Triclabendazole	Jacob *et al.* (2012)
Palas	*Butea frondosa*	Seeds/Benzene extract (Palasonin)	0.5%	*F.gigantica*	Loss of motility and death	Closantel	Upadhyay *et al.* (2009)
Palas	*B.monosperma*	Seeds/Aqueous extract (Palasonin)	-	*Paramphistomum cervi*	Reduction in enzyme activity	-	Chopra *et al.* (1991)
Hemp	*Cannabis sativa*	Leaf/Crude extract in PBS	-	*Fasciolopsis buski*	Paralysis and death (more lethal than control)	Oxyclozanide	Roy and Tandon (1997)
Papaya	*Carica papaya*	Seeds/Ethanol extract (Benzyl isothiocyanate)	10–30 µg/ml	*Fasciola gigantica*	Insignificant effect	-	Kushwaha *et al.* (2004)
Brahma manduki	*Centella asiatica*	Methanol extract	77.61 ppm.	*Paramphistomum cervi*	Adulticide	-	Bagavan *et al.* (2009)
Baberang	*Embelia ribes*	Seeds/Aqueous extract	-	*P. cervi*	Reduction in exzyme activity	-	Chopra *et al.* (1991)
Sehphlang (Meghalaya)	*Flemingia vestita*	Root peel crude extract (genistein)	20 mg/ml (0.5 mg/ml of active compound)	*Fasciolopsis buski*	Reduction in enzyme activity	Oxyclozanide	Kar and Tandon (2004)

(Contd...)

(Table 1. continued)

Herb/plant	Scientific name	Part used / used as (active principle)	Optimum concentration	Target parasite	Mode of action	Standard control	Reference (s)
Sehphlang (Meghalaya)	*F. vestita*	Root peel crude extract (genistein)	20 mg/ml (0.5 mg/ml of active compound)	*Paramphistomum sp.Artyfechinostomum sufrartyfex*	Alterations in tegumental architecture (Paralysis)	Praziquantel	Tandon *et al.* (1997) Roy and Tandon (1996)
Kalihari	*Gloria superba*	Methanol extract	60.16 ppm.	*Paramphistomum cervi*	Adulticide		Bagavan *et al.* (2009)
Henna	*Lawsonia inermis*	Leaves/Alcoholic extract	5.0%	*Fasciola gigantica*	Inhibition of motility and death	Oxyclozanide	Jeyathilakan *et al.* (2012)
Kamala	*Mallotus philippinensis*	Seeds/Ethanol extract	10-30 µg/ml	*F.gigantica*	Inhibition of muscular and AchE activity (Paralysis)		Kushwaha *et al. (*2004)
Spring cactus	*Opuntia ficus indica*	Stem with spines/ Alcoholic extract	2.5 and 5.0%	*F.gigantica*	Rupture of organs and death		Oxyclozanide Jeyathilakan *et al.* (2012)
Dudhi	*Pergularia daemia*	-Methanol extract	59.61 ppm	*Paramphistomum cervi*	Adulticide	-	Bagavan *et al.* (2009)
Amla	*Phyllanthus emblica*	-Methanol extract	60.60 ppm	*P.cervi*	Adulticide	-	Bagavan *et al.* (2009)
Peepli	*Piper longum*	Fruit/Alcoholic extract	1000 $\mu g/ml^{-1}$	*F.gigantica and Gigantocotyle explanatum*	Inhibition of motility, reduced glucose uptake resulting in paralysis	Oxyclozanide	Singh *et al.* (2007)
Vajradanti	*Potentilla fulgens*	Root peel/ Ethanol extract	100 mg/ml	*Gastrothylax crumenifer*	Inhibition of enzyme activity, paralysis and death	Praziquantel	Roy *et al.* (2010)
Kuda	*Rottlesia tinctoria*	-Aqueous extract	-	*Paramphistomum cervi*	Reduction in enzyme activity		- Chopra *et al.* (1991)
Ginger	*Zingiber officinale*	Rhizome/Aqueous	5%	*Fasciola gigantica*	Immobility and death	Oxyclozanide	Jeyathilakan *et al.* (2010)
				Cestoda			
Hedychium coronarium		Rhizome/Essential oil	-	*Taenia solium*	Reduction in enzymic activity	-	Dixit and Verma (1975)
Kala jeera	*Nigella sativa*	Seeds/Essential oil	-	*Taenia solium*	Reduction in enzymic activity	-	Agarwal *et al.* (1979)
Acacia	*Acacia auriculiformis*	Triterpinoid saponins (Acaciacide A and B)			Cestodicidal activity		Ghosh *et al.* (1996)
Khang (Mizoram)	*Acacia oxyphylla*	Methanolic extract (condensed tannins)	10 mg/ml	*Raillietina echinobothrida*	Reduction in enzyme activity	Praziquantel	Roy *et al.* (2010)
Kre (Meghayala)	*Carex baccans*	Root tubers/Ethanolic extract	50 mg/ml	*R. echibobothrida*	Reduced enzymic activity (Flaccid paralysis)	Praziquantel	Challam *et al.* (2012)
Sehphlang (Meghalaya)	*Flemingia vestita*	Root tuber peel/ Crude alcoholic extract (genistein)	50 mg/ml (0.5 mg/ml genistein)	*Raillietina echinonothrida*	Alteration in tegumental architecture (paralysis)	Praziquantel	Tandon *et al.* 1997) Pal and Tandon (1998)
Vajradanti	*Potentilla fulgens*	Root peel/Ethanolic extract	100 mg/ml	*R. echinobothrida*	Reduction in enzymic activity	Praziquantel	Roy *et al.* (2010)

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(Table 1. continued)

Herb/plant	Scientific name	Part used / used as (active principle)	Optimum concentration	Target parasite	Mode of action	Standard control	Reference (s)
Shisiak (Mizoram)	*Securinega virosa*	Whole plant/Ethanolic extract	25 mg/ml	*R. echinobothrida*	Decrease in tengumental enzymes, free amino acids and trace elements	Praziquantel	Dasgupta *et al.* (2013)
Maharukh	*Ailanthus excelsa*	Leaves/Methanol extract	10/20/40 mg/ml	*Haemonchus contortus*	Adulticidal	-	Yadav *et al.* (2010)
Garlic	*Allium sativum*	Bulb/Aqueous extract (Allicin)	200/100/50 mg/ml	*Bunostomum trigonocephalum*	Cessation of motility (death)	-	Khobragade *et al.* (1994)
Garlic	*A. sativum*	Bulb/Oil extracted with ether/(6% stock solu. In distilled water)	2/4/6%	*Asaridia galli Heterakis gallinarum*	Reduction in glucose uptake glycogen, content and enzymic activity	-	Singh and Nagaich (2000)
Garlic	*A. sativum*	Bulb/Methanol extract	-	*Haemonchus contortus*	Death but mode of action unclear	-	Iqbal *et al.* (2001)
Garlic	*A. sativum*	Bulbils/Hedon-Fleig solution	10%	*H. contortus*	Cessation of motility (death)	-	Veerakumari and Lakshmi (2006)
Kalmegh	*Andrographis paniculata*	Leaves/Aqueous extract	1.25 mg/ml	*H. contortus*	Inhibition of embryonation and hatching Larvicidal	-	Singh *et al.* (2011)
Kirmala	*Artemesia maritima*	Root powder/Essential oil (santonin) Aqueous extract	50/75 mg ml^{-1}	*H. contortus*	Cessation of motility	-	Jangde *et al.* (2001)
	A.absinthium	Root powder/ Aqueous extract		G.I. nematodes (sheep)		Cessation of motility	- Tariq *et al.* (2009)
Neem	*Azadirachta indica*	Leaves/Ethanol extract	0.1%	*Trichuris globulosa*	Inhibition of enzyme activity	-	Sarwal *et al.* (2000)
Neem	*Azadirachta indica*	Leaves/Methonal extract	20 mg/ml	*H.contorus*	Larvicidal adulticidal	-	Arora *et al.* (2010)
Neem	*A.indica*	Leaves/Aqueous extract	1.25 mg ml^{-1}	*H. contortus*	Reduction in egg embryonation and egg hatch	-	Singh *et al.* (2008)
	Bauhinia tomentosa	Leaves/Aqueous and ethanol extracts	2,4,8 mg/ml	*H. contortus*	Larvicidal	-	Vihan *et al.* (2007)
Kachnar	*Bauhinia variegata*	Leaves/Methanol extract	8 mg/ml	*H. contortus*	Inhibition of egg hatching (100%)	-	Bhardwaj *et al.* (2010)
Palas	*Butea frondosa*	Seeds/Alcoholic extract	-	*Ascaridia galli*	Adulticidal	-	Lal *et al.* (1976)
Palas	*B. frondosa*	Seeds/Ether extract in aqueous wash	-	*A.galli*	Complete inhibition of motility	-	Sharma and Sisodia (1976)

(Contd...)

(Table 1. continued)

Herb/plant	Scientific name	Part used / used as (active principle)	Optimum concentration	Target parasite	Mode of action	Standard control	Reference (s)
Palas	*B.frondosa*	Seeds/Palasonin	-	*Ascaris lumbicoides*	Blockage of neuro-muscular junction sites leading to paralysis	-	Rao *et al.* (1977)
Palas	*B.frondosa*	Seeds/Isolated a purified/Palasonin	5 mg/ml	*Ascaridia galli*	Larvicidial (100%)	-	Kumar *et al.* (1983)
Palas	*B. frondosa*	Seeds/Solution in ammonia (Palasonin)	7.5–10.0 mg/ml	*Haemonchus contortus*	Larvicidial	-	Sathianesan *et al.* (1984)
Palas	*B. frondosa*	Seeds/Ether and Alcoholic extracts	0.1% concentration in aqueous solution of tween – 80	*Ascaridia galli*	Loss of motility (death)	Piperazine adipate	Shilaskar and Parashar (1989)
Palas	*B. frondosa*	Seeds/Aqueous extract (Palasonin)	5.0%	*H.contortus*	Cessation of motility (Death)	-	Jangde *et al.* (2001)
Palas	*B. frondosa*	Seeds/Aqueous, alcohol, ether and chloroform	1.25 mg ml^{-1}25 mg ml^{-1}	*H.contortus*	Ovicidial and Larvicidial	-	Swarnkar *et al.* (2008a)
Palas	*B. frondosa*	Seeds/Chloroform extract	2, 4, 8 mg/ml	*H.contortus*	Larvicidial	-	Vihan *et al.* (2007)
Aak	*Calatropis gigantea*	Leaves/Extract (Methanol) Triterpinoids anthrocyanins	10, 20 and 40 mg/ml	*H. contortus*	Adulticide	-	Yadav *et al.* (2010)
Papaya	*Carica papaya*	Seeds/Alcoholic extract (Benzyl isothiocyanate)		*Ascaridia galli*	Adulticide (100%)	-	Lal *et al.* (1976)
Papaya	*C.papaya*	Seeds/Aqueous extract	12.0%	*A.galli and Heterakis gallinae*	Inhibtiion of enzyme activity leading to death	-	Singh and Nagaich (1999)
Charota	*Casia tora*	Seeds/Alcohol and aqueous extracts	100 mg/ml	*Ascaridia galli*	-	Piperazine citrate	Deore *et al.* (2009)
Bathua	*Chenodium album*	Seeds/Methanol extract	10, 20 and 40 mg/ml	*Haemonchus contortus*	Adulticide	-	Yaday *et al.* (2010)
Kashiphal	*Cucurbita mexicana*	Methanol extract	-	*Haemonchus contortus*	Adulticide	-	Iqbal *et al.* (2001)
Lemon grass relative	*Cymbopogon flexuosus*	Leaves/Essential oil	0.1% in 1% aqueous solution of Tween-80	*Ascaridia galli*	Inhibition of AchE activity (paralysis)	Piperazine	Sahoo *et al.* (1993)
Baberang	*Embelia ribes*	Seeds/Aqueous extract and Alcoholic extract		*Haemonchus contortus*	Ovicidal and mild larvicidal activity	-	Swarankar *et al.* (2009)
Heeng	*Ferula asafoetida*	Extract	2,3, and 4%	*Ascaridia galli and Heterakis gallinae*	Significant reduction in glucose uptake and enzyme activity	-	Nagaich and Singh (2001)

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(Concluded Table 1.)

Herb/plant	Scientific name	Part used / used as (active principle)	Optimum concentration	Target parasite	Mode of action	Standard control	Reference (s)
Peepal	*Ficus religiosa*	Leaves/Methano extract		*Haemonchus contortus*	Adulticide (100%)	-	Iqbal *et al.* (2001)
Sehphlang (Meghalaya)	*Flemingia vestita*	Tuber/Extract (genistein)	20 mg/ml	*Ascaris suum*	Paralysis	-	Yadav *et al.* (1992)
Labanga	*Luvunga scandena*	Ethanol extract		*Haemonchus contortus*	Nematocidal	-	Sujon *et al.* (2008)
Kamala	*Mallotus philippinensis*	Leaves/Methanolic extract	-	*Haemonchus contortus*	Larvicidal	-	Singh *et al.* (2004)
Kamala	*M. philippinensis*	Leaves/Chloroform extract	2, 4, 8 mg/ml	*Haemonchus contortus*	Larvicidal	-	Vihan *et al.* (2007)
Tobacco	*Nicotiana tabacum*	Dried leaves/Decoction (Nicotine)	10%	*H.contortus*	Cessation of motility/death	Piperazine hexahydrate	Raje and Jangde (2003)
Tobacco	*N.tabacum*	Dried leaves/Aqueous and methanol extracts (Nicotine)	-	*H.contortus*	Cessation of motility/ death	-	Iqbal *et al.* (2006)
Tulsi	*Ocimum sanctum*	Leaves/Alcoholic extract	6, 8 and 12%	*Ascaridia galli and Heterakis gallinae*	Reduction in glucose uptake	-	Singh and Nagaich (2002)
Betel leaf	*Piper betle*	Leaves/Essential oil	-	*Ascaridia galli*	Loss of motility (death)	Piperazine adipate	Shilaskar and Parashar (1989)
Karanj	*Pongamia glabra*	Seeds/Ether extract	20 mg /ml	*H.contortus*	Larvicidal and adulticidal	-	Arora *et al.* (2010)
Gainda (Marigold)	*Tagetes Patula*	Flowers/Methanol extract	-	*Haemonchus contortus*	Inhibition of egg hatching	-	Bhardwaj *et al.* (2010)
	Thuja sinensis	Leaves/Ethanol	ml	2, 4 and 8 mg/	*H. contortus*	Larvicidal	- Vihan *et al.* (2007)
Bishop's weed	*Trachispermum ammi*	Seeds/Extract with various solvents (Ethanol, methanol)	5 mg/ml	*Setaria cervi*	Flaccidity in the microfilariae by inhibiting enzyme activity	-	Rizvi *et al.* (2012)
Bakchi	*Vernona anthelmintica*	Seeds/Ether and alcoholic extracts	0.1 concentration in aqueous solution of Tween-80	*Ascaridia galli*	Paralysis, loss of Piperazin motility and death	Piperazine adipate	Shilaskar and Parashar (1989)
Chhotta *Gokharu*	*Xanthium flexuosus*	Leaves/Fresh Juice (Xanthinin)	1:2 and 1:0 in distilled water	*Haemonchus contortus*	Inhibition of egg hatching and larval paralysis	-	Sharma *et al.* (2003)
Ginger	*Zingiberus officinale*	Rhizome/Methanol extract	-	*H.contortus*	Death	-	Iqbal *et al.* (2001)

Table 2. Plants of Indian subcontinent with documented anthelmintic activity (*In vivo* studies) measured by reduction in faecal egg count (FEC)

Herb/plant	Botanical name	Plant part/preparation (active principle)	Dose rate/ concentration	Target parasite	Animal species	Standard control	Reference
Kankrej	*Caesalpinia crista*	Seed powder	40 mg/kg b.w.t.	*Fasciola gigantica*	Buffalo	-	Kailani *et al.* (1995)
Kala jeera	*Nigella sativa*	Seed powder	2.5 mg/kg b.w.t.	*F. gigantica*	Buffalo	-	Kailani *et al.* (1995)
Anar	*Punica granatum*	Root bark powder	10 g/pup/day (5 days)	*Echinococcus granulosus* (Experimentally infected pups)	Dog	Niclosamide	Rai *et al.* (1993)
Kamala	*Mallotus Philippinensis*	Fruit		*Moniezia* and *Avitellina*	Goat	Levamisole (Nilzan)	Akhtar and Ahmad (1992)
Flowering plant	*Gladiolus gandavensis*	Bulb/Ethanolic extract	300 mg/kg b.w.t.	*Hymenolepis diminuta*	Rat	Praziquantel	Saha *et al.* (1999)
Chameleon	*Houttuynia cordata*	Leaves/Methanolic extract (alkaloids flavanoids and essential oil)	800 mg/kg b.w.t.	*H. diminuta*	Rat	Praziquantel	Yadav and Temjenmongla (2011)
White wormwood	*Artemisia herba-alba*	Powdered shoots	10-30 g/animal (sentonin)	*Haemonchus contortus*	Sheep and goat (naturally infected)	-	Idris *et al.* (1982)
Bakain (Persian lilac)	*Melia azedarach*	Fruit (Powdered)	-	G.I.nematodes	Goat	-	Akhtar and Riffat (1984)
Baberang Bakchi	*Embelia ribes Vernonia anthe lmintica*	Seed/Methanol extract/Fruit Mixed in equal parts	2 g/kg. b.w.t.	G.I. nematodes *(Trichostongylids)*	Ruminants Morantel tartrate	-	Iqbal and Akhtar (1990)
Neem	*Azadirachta indica*	Fruit seed and oil		G.I. nematodes *(Trichostongylids)*	Small ruminants	-	Mostofa *et al.* (1996)
Ginger	*Zingiber officinale*	Rhizome/Extract		*Ascaris lumbricoides*	Man	-	Akhtar *et al.* (2000)
Bakain	*Melia azedarach*	Seed/Alcoholic extract	30 mg/kg b.w.t.	*H.contortus*	Goat (experimental infection)	-	Misri *et al.* (2002)
Miah (Zanskar)	*Artemisia brevifolia*	Crude methonolic and aqueous extract of whole plant	1/2/3 g/kg b. wt.	*Haemonchus contortus*	Sheep		Iqbal *et al.* (2004)
Ginger	*Zingiber officinale*	Rhizome/Extract		G.I. nematodes	Sheep (naturally infected)	-	Iqbal *et al.* (2006)

(Contd...)

(Table 2. continued)

Herb/plant	Botanical name	Plant part/preparation (active principle)	Dose rate/ concentration	Target parasite	Animal species	Standard control	Reference
Tobacco	*Nicotiana tabacum*	Leaves/Aqueous and methanolic extracts	-	*H.contortus*	Sheep (naturally infected)	-	Iqbal *et al.* (2006)
Ajowain	*Trachyspermum ammi*	Seed/Extract	-	*H.contortus*	Sheep (naturally infected)	-	Lateef *et al.* (2006)
Lemon grass	*Cymbopogon flexuosus*	Leaves/Essential Oil	0.1 mg/kg b.w.t.	Strongyles	Goat	Fenbendazole	Sahoo and Tripathy (2007)
Neem	*Azadirachta indica*	Bark/Alcoholic extract (Azadirachtin)	50 mg/kg b.w.t.	*Haemonchus contortus*	Sheep	-	Swarnkar *et al.* 2008b)
Baberang	*Embelia ribes*	Seed/Aqueous and Alcoholic extracts	6 ml / sheep	*Haemonchus contortus*	Sheep	-	Swarnkar *et al.* (2009)
Arjun Chhal	*Terminalia arjuna*	Bark/Crude methanolic extract	3g/kg b.w.t.	*Haemonchus contortus*	Sheep	-	Bachaya *et al.* (2009)
Baberang	*Embelia ribes*	Leaves powder	10 g/animal/ day orally for 3 days	G.I. nematodes	Small ruminants	-	Kumar *et al.* (2010)
Baberang	*Embelia ribes*	Aqueous extract	125 mg/kg b.w.t.	*H.contortus*	Goat	-	Arora *et al.* (2010)
Neem	*Azadirachta indica*	Leaves/Methanol extract	200 mg/kg b.w.t.	*H.contortus*	Goat	-	Arora *et al.* (2010)
Asafoetida	*Ferula costata*	Crude methanol and aqueous extract of	1/2/3 g/kg b. wt.	*Haemonchus contortus*	Sheep	-	Kakar *et al.* (2013) aerial parts
Poultry							
Palas	*Butea frondosa*	Seeds/Decoction	5 g/kg b.w.t. daily for 6 days	*Ascaridia galli* (Experimentally infected birds)	-	-	Sharma and Sisodia (1976)
Palas	*B.frondosa* (71.25% reduction)	Seeds/Alcoholic extract	200 mg/chick (single dose)	*A.galli*	Experimentally infected birds	Piperazine hexahydrate (98.96% reduction)	Rao and Krishnaiah (1982)
Papaya	*Carica papaya* (41.66% reduction)	Seeds/Aqueous extract	200 mg/chick (single dose oral)	*A.galli*	Experimentally infected birds	Piperazine hexahydrate (98.96% reduction)	Rao and Krishnaiah (1982)
Worm Killer	*Aristolochia bracteata* (70.80% reduction)	Leaves/Alcoholic extract	200 mg/chick (single dose oral)	*A.galli*	Counts of worms recovered on day 3 post treatment		

(Contd...)

(Concluded Table 2.)

Herb/plant	Botanical name	Plant part/preparation (active principle)	Dose rate/ concentration	Target parasite	Animal species	Standard control	Reference
Babchi	*Psoralea corylifolia*	Seeds/Ether/alcoholic extracts	500 mg/kg b.w.t. oral	*Ascaridia galli*	Reduction in FEC (EPG) (61.63%)	Piperazine adipate (91.95%)	Shilaskar and Parashar (1985)
Paan (Betel leaf)	*Piper betle*	Leaves/Essential oil	500 mg/kg b.w.t. oral (2 doses)	*A.galli*	Reduction in FEC (EPG) (62.50%)	-	
Bakain	*Melia azedarach*	Fruit		*A.galli*	Reduction in FEC (EPG) (62.50%)	-	Akhtar and Riffat (1985)
Baberang	*Embelia ribes*	Seeds/Aqueous extract (D/salt of Embelin)	100/200 mg oral (total dose)	*A.galli*	Experimentally infected birds	Reduction in FEC (EPG) (67.61%)	Piperazine citrate (73.83%) Wanjari *et al.* (2000)
Papaya	*Carica papaya*	Latex	500 mg/kg b.w.t. 3 consec. days	*A. galli* inturkeys	-	-	Jagatheesan and Senthil Kumar (2011)
Vidhang	*Embelia ribes*	Seeds/Methanol extract	0.3 g/kg daily for 9 consec. days	*A. galli* Naturally infected chicks	100% efficacy (reduction of worm counts)	-	Dama and Kirdak (2012)

A herbal-mineral (HM) combination, which is fed by equine farmers of north-western Rajasthan as a traditional practice was evaluated in 110 horses by faecal examination. All equines given herbal-mineral mixture were faecally negative for endoparasites, while those given neither HM combination nor allopathic dewormer were positive for strongyles, *Parascaris equorum* and *Trichuris* sp. (Dedar *et al.* 2012). The composition of HM formula included 6 minerals and as many as 26 herbs including *Terminalia chebula (herad)* fruit, *T. belerica (behada)* fruit, *Citrullus colocynthis (tumba)* dried fruit and root. *Punica granatum (anar)* dried outer rind, *Tinospora cordifolia (giloy)* stem, *Andrographis paniculata (chirayta)* stem, *Aegle marmelos (bael)* fruit, *Holorrhena antidysentrica (kuda)* bark, *Trigonella faenum qraecum (maithi)* dried leaves and seed, *Trachyspermum ammi (ajwayan)* seed, *Foeniculum vulgare (saunf)* seed, *Withania coagulens* (paneer *dodi*) dried fruit, *Emblica officinale (amla)* dried fruit, *Curcuma aromatica (Amba haldi)* dried root, *Linum* sp. *(alasi)* seed, *Ferula asafoetida (heeng)* and *Adhatoda vasica (bansa)*. It is likely that the ingredients of this formulation also acted by providing nutrients, tonics and immune-enhancing effects on the animals, as suggested elsewhere (Athanasiadou and Kyriazakis 2004). A proprietary formulation containing *palasha*, male-fern, *Chenopodium album, Artemisia maritima, Guduchi, Vidang (baberang), Poogi phalam* and *Rechanka* given in feed @ 500 mg / chick infected with *Ascaridia galli* and *Heterakis gallinae* was effective in reducing FEC (97.9%) in comparison to 100% reduction by parbendazole (Mukherjee 1996).

In view of their predominant harmful effects, gastro-intestinal nematodes of small ruminants and more frequently *Hemonchus contortus* is the target parasite in both *in vitro* and *in vivo* studies. The descriptive in *vitro* and *in vivo* studies against *H. contortus* had been carried out by Zaman *et al.* (2011) and Badar *et al.* (2011) in the recent past using a number of anthelmintic herbal derivatives. This trend is adequately evident in the documented use of ethnoveterinary plant preparations in different parts of the world. *Tinospora rumphii* in Philippines (Fernandez 1999), *Allium sativum, Annona squamosa, Azadirachta indica* and *Chenopodium ambrosioides* in Brazil (Vieira *et al.* 1999), *Calatropis procera* in East Africa (Al-Qarawi *et al.* 2001), *Alium sativum* in France (Cabaret *et al.* 2002), *Annona senegalensis* and *Vernonia amygolalina* in Nigeria (Alawa *et al.* 2003), *Caesalpinia crista, Embelia ribes* and *Fumaria parviflora* in New Zealand (Hordegen *et al.* 2003).

Tanniferous plants and forages: Many of the plants reported to have anthelmintic properties actually contain compounds that are directly active against parasites. These active compounds are secondary metabolites which were identified for some parasites. Among these compounds are the condensed tannins (CT) which are also present in certain forage plants and impart potential anthelmintic value to them. Currently there is a global search and emphasis on evaluating such forages. Since, their consumption can combine high nutritive value and anthelmintic effects, they

could be ideal alternative candidates for parasite control in ruminant production. The evidences from abroad have suggested that when parasitized sheep or goat have access to tanniferous pastures containing 20–60g of CT per kg dry matter, there was reduction of parasitism level concurrent with improved performance of the animals (Marley *et al.* 2003, Paolini *et al.* 2003, Hoste *et al.* 2006, Iqbal *et al.* 2007, Heckendorn *et al.* 2007, Moreno-Gonzalo *et al.* 2012). CT can disrupt the life cycle of nematodes by preventing eggs from hatching and by preventing larvae from developing to the infective L_3 stage (Molan *et al.* 2002). It was suggested that the reduced FEC in CT fed animals was through improved nutrient utilization. Consistent with this trend, there are some *in vitro* and *in vivo* studies in India, to evaluate the potential anthelmintic benefit of the consumption of bioactive plants in small ruminants to find sustainable alternative to conventional chemotherapy. A tanniferous plant of Rajasthan, *Prosopis cineraria (khejri)* which forms an important feed resource for small ruminants, demonstrated ovicidal property *in vitro* and caused marked reduction in FEC in sheep (Swarnkar *et al*. 2008c). Anthelmintic activity of *Artemesia absinthum* against g.i. nematodes of sheep *in vitro* and *in vivo* (Tariq *et al.* 2009) was attributed to tannins contained in the plant extracts. Extracts of CT containing plants *Psidium guajava, Ficus infectoria, F. glomerata, Eugenia jambolina* and *Artocarpus heterophyllus* leaves were found to possess anthelmintic property, effective against both larvae and adult *H. contortus* (Pathak *et al.* 2013). The two first named (*P. guajava* and *F. infectoria*) were the most effective CT sources, and aqueous and acetone: water extracts were found better than other extracts. The methanolic extract of another tannin-rich plant *Euphorbia helioscopia* possess anthelmintic effect *in vitro* against *H. contortus* (Lone *et al.* 2013). However, all tannin-rich plants do not posses beneficial anthelmintic property (Mackown *et al.* 2011).

Plants as molluscicides : Plants also contribute to the control of snail-transmitted trematodes by their molluscicidal properties. In this context, one can cite the documented activities of *Azadirachta indica* seed (Muraleedharan *et al.* 1997, Alam *et al.* 2010, 2011) against *Indoplanorbis exustus* and *Lymnaea* spp. *Lawsonia inermis* seed powder in combination with *Cedrus deodora* oil and *Azadirachta indica* oil was more toxic than the individual plant components (Singh and Singh 2001), *Datura fastuosa, Imperata cylindrica, Melia composita* and *Polygonum orientale* (Devi *et al.* 2007) against *Lymnaea acuminata, L. luteola, Indoplanorbis exustus* and *Digoniostoma pulchella.* Molluscicidal activity of *Carica papaya* latex powder and *Areca catechu* seed powder against freshwater snail *L.acuminata* was also reported (Jaiswal and Singh 2008).

A concerted drive on development and validation of plant products identified for anthelmintic potential as well as identification of their active principles will have to be undertaken to create an environment for confidence in their wider acceptance. There is an obvious need for critical appraisal and standardization of the methods currently used to validate the anthelmintic activity of products sourced from plants. Guidelines on the minimum number of animals for *in vivo* testing of anthelmintic efficacy and the acceptable levels of reductions in FEC (Wood *et al.* 1995, Vercruyss *et al.* 2001, Githiori 2004) should be followed for testing of plant products. The role of plants in acting as adjuvants for enhancing and extending the efficacy of existing anthelmintics should be explored. There are a number of forages that contain CT (or other secondary metabolites) in tropical countries like India. Their identification and exploitation of anti-parasitic properties should be prioritized with the twin objective of providing protection against nematodes and valuable nutritional source, eventually resulting in better animal performance. Plant-based anthelmintics have the potential to form part of a strategic integrated control.

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