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Implications of Tannin Containing Plants for Productivity and Health in Small Ruminant Animals: A Review

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ABSTRACT

Infection with parasitic nematodes is a serious threat to health and production of small ruminant worldwide. It causes reduction in feed intake, weight gain and eventually death of the host. The primary control method of the nematode infection relied on frequent use of anthelmintic drugs. Unfortunately, this control strategy is no longer effective due to widespread anthelmintic resistance, which necessitates search for novel approaches to control nematodes. Condensed tannin (CT) containing forages have been used as anthelmintic to control parasitic nematodes for years. This paper reviews available information about effects of CT on productivity and health of small ruminants infected with parasitic nematodes. Many of temperate and tropical forages are nutraceutical plants (possess both nutritional and health benefits). Consumption of CT containing forages reduced negative impacts of gastrointestinal parasitism in sheep and goat by regulating establishment of worm as shown in reduced worm burdens, fecal egg count (FEC) and worm fecundity. Parasitized sheep and goats fed forages containing CT had high feed intake and body weight gain, probably due to increase in protein and amino acids supply. Condensed tannins containing feeds result in lighter meat color and tend to improve antioxidant activity. Therefore, the use of CT containing forages to control parasitic nematodes and improve production of small ruminants is one the alternatives to anthelmintic drugs.

Key words: Condensed tannin, Goats, Meat, Milk, Parasitic nematodes, Sheep.

Endo-parasitic nematodes represent a major threat to the health and production of small ruminant worldwide. Infection with these parasites could result in a huge economic loss for producers (Pathak *et al*., 2016; Atiba *et al*., 2016). The main clinical signs of the parasitic infection include reduction in feed intake, poor reproduction, growth performance and eventually death (Nnadi *et al*., 2009). Until now, anthelmintic drugs are the basis of nematode control method in sheep and goats. However, the drugs have been rendered ineffective by widespread development of anthelmintic resistance among nematode species (Coles *et al*., 2006; Kaplan and Vidyashankar, 2012). Moreover, this method is not economically viable for some small scale producers due to financial challenges or availability of drugs and consumers demand for chemical free animal products (Hoste *et al*., 2012; Raju *et al*., 2015; Atiba *et al*., 2016). Therefore, affordable and sustainable alternative parasite control methods have been evaluated to reduce dependence on anthelmintic drugs (Arroyo-Lopez *et al*., 2014). Many studies have shown that feeding tannins containing plants can reduce detrimental effects of parasitic nematode infection in sheep and goats (Kahiya *et al*., 2003; Iqbal *et al*., 2007; Marume *et al*., 2012).

Tannins are complex group of polyphenolic compounds that dissolve in water and have similar physical and chemical properties (Acamovic and Brooker, 2005). Generally, tannins are classified into two distinct groups, hydrolysable and condensed. Hydrolysable tannins (HT) are esters of phenolics acids such as gallic acids in gallotannins or other phenolic acids derived from the oxidation of galloyl residues as in ellagitannins and a polyol, usually D-glucose.

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Condensed tannins (CT) also called proanthocyanidins are oligomers or polymers of flavan-3-ol units usually linked together by C-C bonds and occasionally by C-O-C bonds. Tannins have been the focus of many studies in fields of animal and veterinary sciences due to their anthelmintic effects on gastrointestinal nematodes. However, some of phytochemicals such as phenolic and alkaloids compounds found associated with tannins are toxins in nature. The HT are believed to be more toxic to ruminants than CT. Consumption of CT containing plants at an appropriate threshold level, neverthless can improve nutritional status of parasitized ruminants (Min and Hart, 2003; Huang *et al*., 2017). Moreover, tanniniferous forages are rich in nutrient particularly protein content making them potential source of animal feed. In the past two decades, the concept of using tannins containing forages as nutraceutical plants (plants combining both nutrition and health benefits) has emerged as a promising alternative to anthelmintic drugs (Kahiya *et al*., 2003; Marume *et al*., 2012; Arroyo-lopez *et al.,* 2014; Hoste *et al*., 2015). Therefore, this paper reviews available information about effects of condensed tannins on productive performances and hematobiochemical as well as parasitological parameters.

Tannins are heterogeneous polyphenolic compounds found in wide range of plants species and their concentration levels vary greatly not only between plants species but also between the parts (Table 1) .They occur in every part of plant including seeds, leaves, fruits, barks, roots and wood and are present in higher concentration particularly in tropical plants (Pathak, 2013b). However, tannin content in many plant species seems to be greatly influenced by environmental factors such as season, water availability and stage of plant growth (Sampaio *et al*., 2011; Mcmahon *et al*., 2011). The HT are common in dicotyledonous plants whereas, CTs are the most abundant type of tannins found in both angiosperms and gymnosperms (Huang *et al*., 2017). The CT are very common in forages legumes of Fabaceae family (*e.g*. *lespedeza spp* and *Onobrychis spp*) , shrubs (*Acacia* spp) and the leaves as well as barks of other plants (Min *et al*., 2003). These plants are widely distributed and are suitable for feeding ruminants (Vasta *et al*., 2008). They have been exploited as alternative sources of feed to replace cereal concentrate in small ruminant diet and their utilization has increased in recent years. Tanniniferous plants are also believed to have positive effect on animal health as they have been shown to minimize the risk associated with parasitic nematodes infection.

This study focuses on the use of tanniniferous plants to combat parasitic nematode infection in small ruminants. The study applied internet search to specifically identify relevant scientific articles. The literature on the use of tanniniferous plants in sheep and goats production was systematically reviewed between December 2018 and November 2019, at Jilin Agricultural University, China. Relevant scientific papers published in English peer-reviewed journals were searched using the key words combination (tanniniferous plants or forages or legumes, parasitic nematode and small ruminants or sheep or goats). The online electronic database through Google scholar, Scopus, Web of Science and Science direct were searched to capture the latest information. The available relevant papers in the field were reviewed and summarized in the article.

Effect of CT on nutrition and performance of the host

Gastrointestinal parasites are known to be the main cause of poor performances of sheep and goats. Infestation with parasitic nematodes may reduce voluntary feed intake, weight gain, cause anemia and eventually host death. However, it has been known that consumption of tanniniferous forages could reduce negative effects of parasitic nematodes infection in small ruminants (Paolini *et al*., 2003; Hoste *et al*., 2012; Arroyo-Lopez *et al*., 2014). Many plant species of families Fabaceae, Fagaceae, Anacardiaceae among others have been used to improve performance of parasitized sheep and goats (Athanasiadou *et al*., 2001; Iqbal *et al*., 2007; Marume *et al*., 2012; Villalba *et al*., 2014).

Voluntary feed intake

The most significant effect of parasitism with nematodes is reduction in voluntary feed intake, which influences growth performance of small ruminants. Gastrointestinal infection in sheep and goats may result in 6-50% reduction in feed intake. It has been speculated that such effect could raise from abdominal pain or discomfort associated with gastrointestinal nematodes activities, with extend depending on the host age, breed and parasite species (Poppi *et al.,* 1990; Knox *et al.,* 2006).

The CT in forage legumes seem to be effective in suppressing gastrointestinal nematodes in sheep and goats. Sainfoin is a perennial forage legume of family Fabaceae commonly found in temperate regions. This legume has been used as pasture, conserved as hay or silage for sheep and goats. Confinement feeding trial has shown that *Trichostrongylus colubriformis* infected sheep consuming Sainfoin hay (S) containing 2% CT had higher feed intake compared to those on grass hay (G) containing 1% CT (Ríos-De-Álvarez *et al.,* 2008). This could be due to nutritional modulation of host immune responses or ingestion of CT, which would regulate establishment of worm and reduce the degree of anorexia (Hoste *et al.,* 2006; Houdijk, 2012). Moreover, tanniniferous forages are more palatable. Similarly, Romero *et al*. (2018) found that supplementation with perennial peanut (PEA) and *Sericea lespedeza* (LES) hays tended to increase feed intake (757 and 745 g/d, respectively) of nematode infected goats in confinement (Table 2). This could be attributed to the CT content in PEA and LES which suppressed parasitic nematodes. Indeed, a large number of studies have shown that CT containing forages improved feed intake of parasitized lambs (Lisonbee *et al.,* 2009; Merera *et al.,* 2013) and goats (Seng *et al.,* 2007; Moore *et al.,* 2008; Sokerya *et al.,* 2009; Amit *et al.,* 2013). However, some results showed that feed intake of nematode infected sheep (van Zyl *et al.,* 2017) and goats (Lopes *et al.,* 2016) were not affected by feeding tanniniferous forages (Table 2). Nevertheless, high CT concentration level has been associated with decreased diet palatability, reduced voluntary feed intake, disturbed digestibility and decreased nutrient intake (Pathak, 2013b; Addisu, 2016). Heckendorn *et al*. (2007) observed lower feed intake in Swiss lambs artificially infected with *Haemonchus contortus* consuming Chicory, Birds foot and

Table 1: Concentration level of condensed tannin in some plants' species.

Plant species	Part	CT %	Reference
Mucuna	Seed	18.1	Romero *et al.*, 2018
Sainfoin (*Onobrychis viciifolia*)	Whole	10.1	Villalba *et al.*, 2013
Acacia raddiana	Leaves	3.4	Zabré *et al.*, 2017
Sericea Lespedeza	Whole	6.5	Moore *et al.*, 2008
Acacia nilotica	Pod	1.9	Paswan *et al.*, 2016
Pistacia lentiscus	leaves	0.2	Saric *et al.*, 2015
Acacia polyacantha	Twigs	32	Max *et al.*, 2007
Acacia karroo	Leaves	2.1	Marume *et al.*, 2012

CT: Condensed tannins.

Sainfoin containing, respectively, 3.1, 15.2 and 26.1 CT g/kg DM (Table 2). This might be due to CT concentration level or parasite species. *Haemonchus contortus* is the most pathogenic and prolific endoparasitic nematode. Adult female *H. contortus* can lay up to 5000-10000 eggs per day (Sinnathamby *et al*., 2018), increasing worm load and severity of the infection.

Weight again

Endoparasitic nematodes found in the abomasum or small intestine cause reduction in weight gain of sheep and goats. However, consumption of CT containing forages seems to improve weight gain of the host in spite of the infection. In a feeding trial in Pakistan using *H. contortus* infected sheep (Iqbal *et al.,* 2007), diet supplement was offered daily and contained low and high tannin, respectively, 2 and 3% CT. The results showed that weight gain was significantly higher (8.2 kg) in 3% CT supplemented sheep compared to 2% CT supplemented sheep (6.8 kg) and tannin-free sheep (4.8 kg). An increased in weight gain has been used as a marker of resilience in nematode infected ruminants. Additionally, a number of studies are also in agreement with these results in parasitized sheep supplemented with *L. pallida* (Merera *et al.,* 2013), Sainfoin (Arroyo-Lopez *et al.,* 2014) and *Lespedeza cuneata* (Zyl *et al.,* 2017). Most of CT containing forages are rich in protein content and are more digestible (Torres-Acosta *et al.,* 2012).

Albizia, a genus of Fabaceae family comprises of more than 150 species, widely distributed in tropical regions in Africa and in South Central America. *Albizia anthelmintica* is believed to be rich in CT and other bioactive compounds rendering it potential drug for many diseases of animals. Administrating trials with *Albizia anthelmintica* capsules (Gradé *et al.*, 2008) were carried out using parasitized sheep to address some of the shortcomings from feeding experiments. The results showed that CT drenched increased weight gain of the sheep (Table 2). This could be due to increase in amount of protein by-pass ruminal degradation. Moreover, converting the CT containing forages into hay seems to increase protein bound and possibly covalently linked between CT and protein (Mueller-Harvey *et al.,* 2019). Some results from study under temperate condition showed that supplementation with sun-dried *Sericea lespedeza* increased weight gain of goats naturally infected with nematodes (Moore *et al.,* 2008). Similar observations were made by Sokerya *et al*. (2009) in Cambodian goats infected with nematodes fed cassava foliage and Marume *et al.* (2012) in Xhosa lop-eared goats of South Africa fed *Acacia* karroo. Contrary, Seng *et al*. (2007) and Osoro *et al.* (2007) reported that feeding nematode infected goats tanniniferous plants did not increase weight gain (Table 2). This could be due to low total feed intake and availability of nutrient in the feed.

Effect of CT on hematobiochemical parameters of the host

Gastrointestinal parasitism in sheep and goats is directly associated with anemia and hypoproteinaemia resulting from endogenous protein and blood losses. Studies show that supplementation with CT containing forages alleviate impacts of parasitism in sheep and goats (Arroyo-Lopez *et al.,* 2014; Singh *et al.,* 2016). A pasture trial conducted by Merera *et al.* (2013) showed that supplementation with *Leucaene pallida* significantly increased packed cell volume (PCV) of nematode infected Horro lambs compared to those assigned grazing alone. In the United States, Moore *et al.* (2008) evaluated the anthelmintic effects of *S. lespedeza* (SL) on *H. contortus* infected goat kids randomly assigned to two dietary treatments consisting of 75% SL hay (CT) or Bermuda grass (no CT) and 25% concentrate. At the end of experimental period, a significant increase in PCV was recorded in goats in the SL group relative to those in no CT group. Similar results have been obtained by Merera *et al.* (2013) and Arroyo-Lopez *et al.* (2014) from infected lambs fed sainfoin. The increased in PCV could be due to reduce number of blood sucking parasites in abomasum and small intestine by CT or improved protein nutrition allowing the host to replace lost protein more rapidly. Further, Villalba *et al.* (2013) reported increased in MCHb of *H. contortus* infected sheep fed sainfoin (*Onobrychis viciifolia*) but no effect was observed on MCV. In contrast, Sokerya *et al.* (2009) reported that feeding *Manihot esculenta* to nematode infected goats for long-term reduced PCV from 30% to 25% (Table 3). Contrary, Seng *et al*. (2007) have shown that CT had no effect on PCV of nematode infected goats of Cambodia fed fresh *Manihot esculenta* foliage for short-term.

A number of studies have examined the effects of CT on different biochemical variables (hemoglobin, Protein,

Table 2: Feed intake and weight gain of nematode infected sheep and goats fed plants containing CT.

Host	Nematode	Plant	CT %	Parameter		Reference
				FI	DWG	
Sheep	*H. contortus* and *Cooperia curticei*	Chicory Birdsfoot Sainfoin	3.1 1.5 2.6	Increased	Significant increased	Hechendorn *et al*., 2007
Goats	Mixed species	PEA and SL	11.4	Increased	Increased	Romero *et al*., 2018
Sheep	Mixed species	*Albizia anthelmintica*	0.04, 0.08, 0.18	-	NS	Gradé *et al.,* 2008
Sheep	*H. contortus*	Commercial product	3.0	-	Significant higher (8.2 kg)	Iqbal *et al*., 2007
Sheep	*T. colubriformis*	Sainfoin	2.0	No increased	High (75.2 ±8.8 g)	Ríos-De-Álvarez *et al*., 2008
Sheep	*H. contortus*	Sainfoin (*Visnovsky*)	8.1	Slightly increased	No effect	Azuhnwi *et al*., 2013
Goats	*H. contortus*	*Acacia karroo*	2.1	-	Increased	Marume *et al*., 2012
Goats	Mixed species	Cassava (*Manihot esculenta*)	ND	Increased	Significant increased	Seng *et al*., 2007
Goats	*H. contortus* and *T. colubriformis*	Cassava (*Manihot esculenta*)	ND	No effect	increased (42.5 g and 59.0 g)	Sokerya *et al*., 2009
Sheep	Mixed species	*Leucaena pallida*	ND	Increased	Significant higher	Chala *et al*., 2013
Sheep	Mixed species	Quebracho	ND	Increased	No effect	Lisonbee *et al*., 2009
Sheep	*H. contortus* and *T. colubriformis*	Sainfoin	ND	-	No effect	Arroy-Lopez *et al*., 2014
Goats	Mixed species	*Pistacia lentiscus*	20.8	Increased (3.8 ± 0.12 g DM $kgBW^{-1}$)	Increased	Amit *et al*., 2013
Goats	Mixed species	*Bauhinia pulchella*	13	No effect	Increased	Lopes *et al*., 2016
Sheep	Mixed species	*L. cuneata*	8.0	No effect	Significant increased	Zyl *et al*., 2017
Goats	Mixed species	*S. lespedeza*	6.5	Increased (4.94 ± 0.33 kg/d)	Significant increased (104.3 ± 5.0 g/d)	Moore *et al*., 2008

CT: Condensed tannins; NS: Not significant; PEA: peanut; SL: Sericea lespedeza; FI: Feed intake; DWG: Daily weight gain; ND: Not determined; DM: Dry matter; BW: Body weight; d: day; g: gram; kg: kilo gram.

Table 3: Effect of CT on blood and biochemical parameters of nematode infected sheep and goats.

Host	Nematode	Plant	CT%	Parameter		Reference
				Blood	Biochemical	
Lambs	*H. contortus*	Sainfoin (*Visnovsky*)	8.1	No effect on PCV	Increased plasma amino acids	Azuhnwi *et al.*, 2013
Goats	*H. contortus*	*E. jambolana* and *P. guajava*	1.8	-	Increased protein, albumin and globulin	Singh *et al.*, 2016
Goats	*H. contortus*	*S. lespedeza*	ND	Increased PCV	No effect eosinophil	Joshi *et al.*, 2011
Sheep	*H. contortus*	Sainfoin (*Onobrychis viciifolia*)	10.1	Increased MCHb but not MCV	-	Villalba *et al.*, 2013
Sheep	*T. colubriformis*	Sainfoin (*Onobrychis viciifolia*)	2.0	-	Increased Eosinophil, mast cells and pan T cells	Ríos-De-Álvarez *et al.*, 2008
Goats	*H. contortus*	*Acacia karroo*	2.1	Increased PCV	No effect on eosinophil	Marume *et al.*, 2012
Goats	Mixed species	Cassava (*Manihot esculenta*)	ND	No effect on PVC	-	Seng *et al.*, 2007
Goats	Mixed species	Cassava (*Manihot esculenta*)	ND	Decreased PCV	-	Sokerya *et al.*, 2009
Lambs	Mixed species	*Leucaena pallida*	ND	Increased PCV	-	Merera *et al.*, 2013
Lambs	*H. contortus* and *T. colubriformis*	Sainfoin	ND	Increased PCV	-	Arroy-Lopez *et al.*, 2014
Goats	Mixed species	*S. lespedeza*	6.5	Increased PCV	No effect on plasma urea-N	Moore *et al.*, 2008

CT: Condensed tannins; PCV: Packed cell volume, Hb: Haemoglobin; MCV: Mean corpuscular volume; ND: Not determined.

urea, mast cells, pan cells, mean corpuscular cells, globulin, eosinophil) in parasitized sheep (Azuhnwi *et al.,* 2013; Rios-De-Álvarez *et al.,* 2014) and goats (Singh *et al.,* 2016) receiving different tanniniferous forages. Azuhnwi *et al.* (2013) reported increased in plasma essential and semi-essential amino acids (AA) concentration in lambs artificially infected with *H. contortus* fed sainfoin. This increased in essential and semi-essential amino acids concentration could be due to increase in amino acids supply and absorption in small intestine. In addition to improve protein nutrition, CT can also modulate activity of host immune cells. Eosinophil cells are the most important elements in the response to nematode infection and are often associated with the expression of host resistance against the parasites (Terefe *et al.,* 2005; Alba-Hurtado and Muñoz-Guzmán, 2013). Contrary, study carried out by Marume *et al.* (2012) showed that supplementation of Xhosa lop-eared goats of South Africa with *Acacia karroo* did not affect eosinophil cell count. Similar results have been observed by Joshi *et al.* (2011) in *H. contortus* infected goats consuming *Sericea lespedeza* (Table 3). The lack of effect here is difficult to explain; probably, the goat breeds are naturally resistant to nematode infection.

Effect of CT on parasite

The CT have demonstrated good anthelmintic effects in both *in vitro* and *in vivo* studies on endoparasitic nematodes. These effects include reduction in egg excretion, worm number, lower fertility, lower worm establishment as well as impairing hatching and development of egg into third-stage larvae (Hoste *et al.,* 2015).

Early evidence of CT effect on nematodes causing reduction in egg excretion and worm number has been reported under both temperate (Heckendorn *et al.,* 2007; Moore *et al.,* 2008; Joshi *et al.,* 2011; Marume *et al.,* 2012;) and tropical conditions (Kahiya *et al.,* 2003; Seng *et al.,* 2007; Iqbal *et al.,* 2007; Max *et al.,* 2007; Gradé *et al.,* 2008; Sokerya *et al.,* 2009; Minho *et al.,* 2010; Merera *et al.,* 2013). Recent results obtained from *H. contortus* and *T. colubriformis* infected sheep (Ríos-De Álvarez *et al.,* 2008; Azuhnwi *et al.,* 2013; Villalba *et al.,* 2013; Arroyo-lopez *et al.,* 2014; Zyl *et al.,* 2017) showed significant reductions in egg excretion and adult worm number in the presence of tanniniferous forages (Table 4). Counting of worm egg excreted with feces is a practical and cost effective diagnostic tool for determining parasitism in small ruminants (Rinaldi *et al.*, 2019). This method is used to estimate worm burden in sheep and goats. Few tanniniferous forages have been extensively investigated through *in vitro* assays and controlled *in vivo* studies. For instance, the results from *in vitro* assays that evaluated inhibitory capacity of *Ziziphus nummularia* and *Acacia nilotica* extracts against egg hatching and development of larvae were somehow discouraging (Bachaya *et al.,* 2009), however, the results of *in vivo* studies on sheep naturally infected nematodes were much more encouraging. Moreover, goats fed heather

Table 4: Parasitological parameters of nematode infected sheep and goats fed plants containing CT.

Host	Nematode	Plant	CT%	Parameter			Reference
				FEC	Worm burden	Worm fecundity	
Sheep	*T. colubriformis*	Sainfoin (*Onobrychis viciifolia)*	2.0	No effect	No effect	No effect	Ríos-De-Álvarez *et al.*, 2008
Goats	*H. contortus*	*Acacia karroo*	2.1	-	Significant reduced	-	Marume *et al.,* 2012
Goats	Mixed species	Cassava (*Manihot esculenta*)	ND	Significant reduced	-	-	Seng *et al.*, 2007
Sheep	Mixed species	Quebracho	2-3	Reduced	No effect	Reduced	Iqbal *et al.*, 2007
Sheep	*H. contortus*	*A. nilotica and Z. nummularia*	ND	Reduced 79-85%	Reduced	Reduced	Bachaya *et al.*, 2009
Goats	Mixed species	Cassava (*Manihot esculenta*)	ND	Reduced	Significant reduced	Reduced	Sokerya *et al.*, 2009
Sheep	Mixed species	*Leucaena pallida*	ND	Significant reduced	Reduced	-	Merera *et al.*, 2013
Goats	Mixed species	Peanut and *S. lespedeza*	11.4	Reduced	Reduced	-	Romero *et al.*, 2018
Sheep	*H. contortus* and *T. colubriformis*	Sainfoin	ND	Reduced	Reduced	Reduced	Arroy-Lopez *et al.*, 2014
Goats	Mixed species	*B. pulchella*	13.1	No effect	Reduced	Reduced	Lopes *et al.*, 2016
Goats	Mixed species	*S. lespedeza*	6.5	Reduced	-	-	Moore *et al.*, 2008
Goats	*H. contortus*	*S. lespedeza*	ND	Reduced significantly	-	No effect	Joshi *et al.*, 2011
Goats	*H. contortus*	*A. nilotica and karoo*	0.6-2.2	Reduced significantly	10-34% reduced	-	Kahiya *et al.*, 2003
Goats	*T. colubriformis*	Heather	ND	Significantly decreased by 47 and 66%	Reduced	Reduced	Moreno-Gonzalo *et al.*, 2012
Sheep	Mixed species	Sainfoin (*Visnovsky*)	8.1	Decreased by 53%	Reduced	Reduced	Azuhnwi *et al.*, 2013
Sheep	*H. contortus*	*Onobrychis viciifolia*	10.1	Reduced	-	-	Villalba *et al.*, 2013
Sheep	Mixed species	*L. cuneata*	8.0	Reduced	-	-	Zyl *et al.*, 2017
Sheep	*H. contortus* and *O. columbianum*	Mimosa caesalpiniifolia	6.4-12.8	Reduced 66.9%	57.7%	-	Brito *et al.*, 2018
Sheep	Mixed species	*Albizia anthelmintica*	ND	Reduced by 78%	-	-	Gradé *et al.*, 2008
Sheep	*H. contortus* and *Cooperia curticei*	Chicory	3.1	Reduced by 44%	Reduced	-	Hechendorn *et al.*, 2007
		Birdsfoot	1.5	Reduced by 47%			
		Sainfoin	2.6	Reduced by 57%			
Sheep	*T. colubriformis*	*Acacia mearnsii*	15.0	Significant reduced	Significant reduced	-	Minho *et al.*, 2010
Goats	Mixed species	*Acacia polyacantha*	32.4	Reduced by 27%	Reduced by 13%	-	Max *et al.*, 2007

CT: Condensed tannins; FEC: Fecal egg count; ND: Not determined.

(*Calluna vulgaris*) (Moreno-Gonzalo *et al.,* 2012) and perennial peanut or *Sericea lespedeza* (Romero *et al.,* 2018) had lower egg excretion, adult worm number and worm fecundity. Similar results were reported by Brito *et al.* (2018) who observed 57.7% and 66.9% reduction, respectively, in adult *H. contortus* and egg excretion in sheep consuming *Mimosa caesalpiniifolia* (Table 4). It is generally assumed that CT could reduce adult worm number, egg excretion, egg hatching and larvae development through direct or indirect effects. Direct effects of CT could be mediated through CT-parasite interactions, thereby affecting physiological functions of the worms and causing their death (Hoste *et al.,* 2006; Arroyo-Lopez *et al.,* 2014). The CT can also bind to the free proteins, resulting in reduced nutrient availability and hence larvae starvation and death (Athanasiadou *et al.,* 2001; Iqbal *et al.,* 2007). Indirectly, CT can improve host protein nutrition by increasing amount of by-pass protein, thereby improving host resistance to parasites. However, in goats grazed *B. pulchella* in tropical area of Brazil, Lopes *et al*. (2016) found no effect of CT on egg excretion but CT significantly reduced egg hatching percentage (Table 4). The lack of effect could be due to repeated and heavy mixed infection which overwhelmed the effect of CT.

Effect of CT on meat

Little work has be done to investigate effects of CT on carcass characteristics and meat quality of nematodes infected lambs (Pathak *et al.,* 2013a; Zhong *et al.,* 2015) and goats (Min *et al*., 2015) consuming different tanniniferous forages. Parasites infestation causes extensive protein losses leading to poor growth, meat production and meat quality of ruminants. The most convincing evidence to support the effect is that some results indicating an improved meat color (significant increased in redness and antioxidant activity) (Zhong *et al.,* 2015) has been exhibited when lambs consumed green tea polyphenol (4g GTP). The mechanism by which CT effects meat color is unclear but can partly be explained by reducing biohydrogenation and thus exerting positive effects on the oxidative stability of the meat (García *et al.,* 2019). Skatole and indole are the main meat volatiles that strongly affect flavor. According to Priolo *et al.* (2009), skatole and indole were lower in fat of lambs supplemented with tannin compared to non-supplemented animals. In tropical regions of Asia, several trees of Myrtaceace and Moraceace families have been identified and explored for their tannins contain (Pathak *et al.,* 2013a). Parasitized sheep consuming *Ficus infectoria* and *Psidium guajava* had significantly high carcass dressing percentage (Pathak *et al.*, 2013a). However, fresh carcass weight and gastrointestinal weight were not affected in this experiment. Further researches in this area are needed to fully understand the mechanism through which CT affects meat color.

Effect of CT on milk

Up to now, effect of CT on milk yield and composition of nematodes infected sheep and goats has not been intensively investigated. However, milk production and composition of ruminants fed tanniniferous forages have been documented (Vasta *et al.,* 2008; Kushwaha *et al*., 2011; Priolo, 2014; Morales and Ungerfeld, 2015). Recently, Abo-donia *et al*. (2017) reported that increased in dietary tannin increased concentration of *cis*-14 C18:1, *cis*-9, cis-12 C18:2 n-6 LA, total *cis* monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), n-3 and n-6 polyunsaturated fatty acids but reduced fat content in goat milk. Similar observations were made by Keles *et al*. (2017) who noted that increased in tannin level increased in C18:0 and total protein of goat milk. Further ewe receiving Hazelnut skin had greater milk MUFA and 18:1 trans than ewe fed no hazelnut (Campione *et al.,* 2020). Tanniferous forages/ tannin-containing diet could be used as effective means to increase unsaturated fatty acids content in ruminant milk.

CONCLUSION

Consumption of CT containing forages enhanced host resistance to endoparasitic infection as depicted in reduced adult worm number, egg excretion and increased PCV, albumin and total protein. Tanniniferous forages can also improve host resilience to nematode infections by reducing detrimental impacts and increasing feed intake and weight gain. The effect of CT containing forages on meat quality of nematode infected ruminants has been less studied so far. However, tanniniferous forages can improve meat color and antioxidant activity as well as increase unsaturated fatty acids in the milk. Therefore, CT containing forages have great potential to improve production of sheep and goats and potential anthelmintic properties to reduce reliance on anthelmintic drugs to combat endoparasites. Further researches to determine applicable CT doses and develop effective tools as well as methods of extraction are crucial.

Conflicts of interest

No potential conflicts of interest.

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