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Review

Effect of secondary compounds on nutrients utilization and productivity of ruminant animals: A review

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ABSTRACT: Plants produce secondary compounds (include tannins, saponins, flavoids, glucosinolates, mimosine and essential oils) which are not used for their growth, development and reproduction of the plant. The review found out the nutrient utilization and productivity performance of ruminant animals supplementing with secondary compounds containing forages, browse species, shrubs, grains, legumes and others. Secondary compounds influence the digestibility, dry matter intake and absorption of nutrients in ruminant's nutrition. Their dose determines whether they are enhancers or detrimental. Tannins, saponins and essential oils are the major secondary compounds which may improve the health, average live weight gain and milk and wool production. Moreover, ruminant animals consuming secondary compound containing forages support the efficient utilization of energy while reducing the rumen gas production which results in low methane. The main problem of supplementing such kind of forages is the absence of consistent recommended dose. Therefore, this area needs to get more attention and further research should be done to establish much more profitable farm and to boost the economic value of ruminant animals.

Keywords: Flavoids, ruminants, saponins, secondary compounds, tannins.

INTRODUCTION

Chemicals produced in plants after the initial stages of photosynthesis are called secondary compounds (Bodas et al., 2012). Secondary compounds (SCs) are complex chemicals made by plants that are not essential to the life of the plant. These compounds are produced within the plants besides the primary biosynthetic and metabolic routes for compounds associated with plant growth and development, and are regarded as products of biochemical "side tracks" in the plant cells and not needed for the daily functioning of the plant.

Plants having SCs are well adapted in high mean annual temperature (~35^{0}C) and low rainfall (< 250 mm) with soil mostly dry (average 2% moisture). Additionally, these plants represent a viable choice as they can be grown without encroaching on agricultural lands and fresh water resources and could promote ruminant animal production which may improve socio-economic conditions of poor farmers in a sustainable and eco-friendly manner (El Shaer, 2010; Njidda, 2010).

Secondary compounds are widely distributed throughout the plant kingdom, especially among trees, shrubs and herbaceous leguminous plants. Plants containing these compounds (Acacia, Cullen, and Kennedia) have significant potential to improve fatty acid profiles in the rumen and reduce enteric methane that can lead to improved production, limiting lactic acidosis (Eremophila) and reducing intestinal pathogens (Melaluca and Eucalyptus). Biserrula pelecinus is a forage legume from the Mediterranean basin has been found to produce seven times less methane followed by grasses Urochloa and Sorghum, and legumes Calliandra and Stylosanthes compared to lucerne (Medicago sativa) or subterranean clover (*Trifolium subterraneum*) (Durmic et al., 2017).

There are at least 35,000 different secondary compounds produced by plants (Berdal, 2010). Tannins are widespread in plants, especially in legumes, cereals, and fruits and restrict nutritional value and digestibility of plants significantly when their amount is higher than 5% (Atiku et al., 2016). The acceptable limit of oxalates in ruminant ration is 2 to 5% (El Shaer, 2010; Njidda, 2010).

Generally, the SCs found in most of shrubs and herbs are 0.13-4.05% total phenols, 0.38-6.99% of tannins, 0.15-1.50% of flavonoids, 0.10-1.15% of nitrates, 0.45-8.68% of saponins and 0.36-2.34% of oxalates (Ehsen et al., 2016).

Plant secondary compounds are a natural resource that is largely unexploited in conventional ruminant animal production system (Mirzaei, 2012). After the ban on nutritive antibiotics in 2006 in the European Union, the EU Directive EC 1831/2003 provided an opportunity to exploit plant secondary compounds as natural alternatives to improve ruminant animal productivity (Cobellis et al., 2016). These compounds taken as poisonous are becoming the most important part of ruminant animal nutrition by affecting the quality. Plant secondary compound tolerate harsh environments (arid and semi-arid) to feed, provide the health, optimum yield and product quality of ruminants (Bodas et al., 2012; Vasta et al., 2008). On the other hand, their presence could restrict nutrient utilization of plant communities such as shrubby vegetation. Plant secondary compounds had antimicrobial effects by acting against bacteria, protozoa and fungi (Bodas et al., 2012).

Ruminant species such as cattle and sheep have large forestomachs, where ingested secondary compound containing plants are considerably diluted. Moreover, microbial action in the forestomachs may destroy the ingested toxins, although the breakdown of plant material may also lead to the release of poisonous compounds. The huge amounts of plant secondary compounds have a broad range of effects, from being acute deadly to being healthy or curative (Bernhoft, 2010).

Therefore, the review aimed to search the effect of secondary compounds on nutriets utilization and productivity of ruminant animals.

SECONDARY COMPOUND ON NUTRIENTS UTILIZATION

Among the promising natural feed additives to improving feed efficiency and ruminant animal productivity are PSCs such as saponins and tannins (Jayanegara et al., 2012). Low-molecular weight tannins in legume species including L. leucocephala (Molina et al., 2016), Calliandra calothyrsus (Wina, 2010) and subterranean clover (Trifolium subterraneum) (Kaur et al., 2017) do not reduce protein digestibility, compromising ruminant animal intake and thus its performance. Allium sativum, Coriandrum sativum, Eucalyptus globules, Foeniculum vulgare, Mentha piperita, Ocimum sanctum, Populus deltoids and Syzygium aromaticum are some of the plants which contain high concentration of essential oils and are effective against protozoa growth in the rumen, but have adverse effects on degradability of feed and nutrient utilization by ruminants (Agrawal and Kamra, 2010).

Various findings have reported the effect of tannins on digestibility and nutrient utilization of feeds. **C**ondensed tannin (CT) might increase the intestinal digestibility and efficient energy utilization through reducing rumen methane production of organic matter. However, other authors reported a negative effect of tannins on feed digestion and nutrient absorption from the small intestine (Gemeda and Hassen, 2018) (Table 1).

Classification of plant secondary compounds

Plant secondary compounds, sometimes grouped into categories such as Phenolic compounds, flavonoids, glucosinolates, mimosine, phenolic acids and tannins, are the most common phytochemical groups found in plants which exhibit several bioactivities such as antimicrobial, antioxidant, antiviral and anti-inflammatory (Kaçar, 2008). Flavonoids are benzo-l-pyrone derivatives from fruits, vegetables and seeds that have anti-inflammatory, antioxidant and antimicrobial properties (Balcells et al., 2012).

Tannins, known as polyphenols, are water-soluble polyphenolic compounds in the range of 500-5000 molecular weight units. They are naturally occurring as PSC that are present in many plant species commonly consumed by ruminants. Tannins found mostly in forbs and leaves of some woody plants (Bodas et al., 2012). They can be classified into two subtypes, condensed and hydrolysable types, which can form potent complexes with proteins, sugars, and starches stable at pH 3.5 to 7 (Szumacher-Strabel and Cieślak, 2010; wina, 2010).

Hydrolysable tannin (HT), with molecular weight between 500 and 3000 $gmol^{-1}$, can be degraded in the rumen. They are made up of a carbohydrate core whose hydroxyl groups are esterified with phenolic acids. HT can be hydrolyzed and utilized by rumen microbes (Cieslak et al., 2013).

Condensed tannins (CTs), with molecular weight up to 20,000 $gmol^{-1}$, are resistant to hydrolysis and rumen degradation (Cieslak et al., 2013). They are non-branched polymers of flavonoid units and usually have a higher molecular weight relative to hydrolysable tannins. CTs are oligomers and polymers of flavanols and have been found in the leaves and stems of several forage legumes, such as birdsfoot trefoil, sainfoin, sulla (*Hedysarum coronarium* L.), sericea lespedeza (*Lespedeza cuneata* G. Don) and also in the flowers of Trifolium species (Piluzza et al., 2014).

The word ‘saponin’ is derived from the Latin word sapo (soap) and traditionally saponin-containing plants have been utilized for washing in ancient time (Mirzaei, 2012). Ruminant animal supplemented with 0.1g saponin/kg feed tend to improve productivity and health since gastrointestinal parasitism has been classified as a major problem (Mirzaei, 2012). The saponin content in most plant seeds is about 100 g/kg and press cake is >200 g/kg (Verstraete, 2010). Saponins constitute primarily sapogenins and glycosides found generally in angiospermous plants. Lucerne and soybeans are the main examples of saponin-rich plants which are widely used in ruminant diets.

Table 1. Effect of tannins or its extracts on rumen CH_4 production and fermentation parameters.

Tannin Sources	Ruminant used	Level of Inclusion	Feed Used in the Study	Effect on CH4 (Decrease)	Effects on Other Fermentation Parameters
Acacia Mearnsii	Sheep	41gkg-1 diets (extract)	Mixture of ryegrass and lucerne (1:1)	9.90%	Digestibility, TVFA & total protozoa numbers unaffected, A: P decreased
Acacia Mearnsii	Cattle	8.6 and 14.6gkg- 1 DM	Grazing rye grass pasture with 4.5 kg grain	117.1 and 30%	Digestibility decreased
Hedysarum coronarium	Dairy cows	As sole feed	Rye grass pasture	2.35%	No information
Lespedeza cuneata	Goats	As sole feed	L. cuneata	51.40%	Digestibility & protozoa numbers decreased TVFA &A: P unaffected
Lespedeza cuneata	Goats	As sole diet	In pasture of crabgrass/tall fescue	30.20%	TVFA & A: P unaffected
Lespedeza striata	Goats	33-100%	Sorghum sudangrass	32.9- 58.4%	Digestibility & protozoal numbers decreased, TVFA &A: P unaffected
Lotus pedunculatus	Sheep	As sole feed	lucerne pasture In ryegrass &	No effect	No effect
Quebracho tannins	Beef cattle	10-20gkg DM -1 of	barley grain and Barley silage, rye grass mixture	No effect	No effect on digestibility; TVFA decreased; A: P decreased

Source: Gemeda and Hassen, 2018.

Mimosine is a secondary compound that affects ruminants, can induce toxicity and cause death if animals not adapted to leucaena are feed above 30% dietary DM. Depending of the variety, the foliage of leucaena contains between 2.3 to 12% mimosine (García et al., 2008). The presence of different bacteria to *Sarracenia jonesii* that would have the ability to degrade mimosine is becoming the most important to overcome the toxicity problem.

Alkaloids, nitrogen-containing secondary plant compounds, are of major interest to veterinary toxicology because of their occurrence in plant species commonly involved in animal poisoning (Cortinovis andCaloni (2015). Alkaloids are secondary metabolites found in approximately 20% of plant species and represent a diverse group of compounds related only by the occurrence of a nitrogen atom in a heterocyclic ring. Alkaloid containing plants responsible for many cases of poisoning of cattle in Europe (Caloni and Cortinovis, 2015).

The glucosinolates are a large group of sulphur-containing secondary plant compounds, which occur in all the economically important varieties of Brassica. To date, more than 120 different glucosinolates have been identified (Aachary and Hiyam, 2012). Rapeseed meal is the chief source of glucosinolates (Gls).

Effect of secondary compounds on nutrients utilization

Brassica originated feed and fodders are the chief source of glucosinolates in ruminants diets (Tripathi and As, 2017). Low glucosinolates containing meals may be good source of protein especially of sulfur containing amino acids. Recent research on glucosinolates shown that feeding of low glucosinolates containing Brassica meals reduce increased peripheral fat with higher contents of unsaturated fatty acids in carcass and milk fat.

Ammonia (NH_3), acetic/propionic ratio and total volatile fatty acid (tVFA) are not affected by tannic acid (TA) (Al-Jumaili et al., 2017) and saponin (Jayanegara et al., 2015) after 24 H and 28 H respectively. On the other hand, Hydrolyzed tannin inhibit fiber degradation (Bhatta et al., 2013a), forming undegradable rumen lipid and protein complexes (Buccioni et al., 2015).

Nitrogen and ammonia utilization

When ruminants eat tanniniferous legumes, they excrete less urinary N and slightly more faecal N which will contribute to soil organic matter for further forage production (Woodward et al., 2009). Anantasook et al. (2013) found that supplementation with RPM and/or PO (Samanea saman with 88 g/Kg of DM condensed tannins and141g/Kg of DM crude saponins) to dairy cows diets did not show negative effect on blood urea nitrogen and milk urea nitrogen concentration ($p > 0.05$). However, supplementation with RPM resulted in lower ammonia nitrogen (NH3 -N) concentration ($p < 0.05$). It was found that higher nitrogen in feces from sheep fed tannin containing forages (Wina, 2010). The level of 25% of *Leucaena leucocephala* in the ration was also found to be a good supplement to rice straw in terms of promoting nitrogen utilization without reducing DM and OM digestibilities and could therefore be used as a source of tannins for protecting protein provided as concentrate from degradation in the rumen (Myint et al., 2010).

The effects of saponins on nitrogen metabolism in the rumen were attributed mainly to their toxic effect on protozoa which are largely responsible from nitrogen retention in the rumen because of their proteolytic activity on both dietary and microbial proteins (Patra and Saxena, 2009). However, some studies showed that protozoa count unchanged (Kang et al., 2016) or even increased (Ramírez-Restrepo et al., 2016) in the presence of saponins. Chentli et al. (2014) investigated the influence of oxalate containing spineless cactus, *Acacia nilotica* and *A. saligna* on reduction of ammonia concentration ($p<0.001$), rumen protozoa count (3.68; 5.59 and 5.34 times, respectively) ($p<0.05$).

The supplementation of a 60 g/kg mixture of coconut oil (CO) and sunflower oil decreased NH_3-N concentration of dairy cows by depressing protein degradation (Mapato et al., 2010; Wanapat et al., 2011). However, earlier studies reported that NH_3-N concentration in the rumen of lamb and goat was not affected by PO supplementation, respectively (Otaru et al., 2011).

Castillejos et al. (2008) observed that addition of essential oil from *Thymus vulgaris* at 5, 50 and 500 mg/l in 24 h *in vitro* batch cultures of rumen fluid decreased NH_3-N concentration. Additional research done on Peppermint and *T. vulgaris* (containing Essential oil) diets supplementation confirmed the reduced ammonia-N concentrations ($P < 0.05$) by 70% and 50% in 0 h and 2 h after feeding of lambs, respectively (Khamisabadi et al., 2016). However, Wanapat et al. (2013) found lemongrass meal supplementation at 100 g/d plus peppermint powder at 10 g/d (LP), decreased ruminal NH_3-N concentration in beef due to the presence of essential oils. Patra and Yu (2012) also observed that essential oil of peppermint and thyme (1g/liter) did not affect ammonia N concentration. Benchaar et al. (2008) provided evidence that essential oil (EO) and their components have the potential to improve N and/or energy utilization in ruminants. Estimated that about 0.3 of the N consumed by the dairy cow is excreted in urine. Therefore, improving N utilization has a positive impact on efficiency of animal production and on the environment (Brus et al., 2017).

Dry matter intake

Plant SCs with both beneficial and adverse functions according to their concentration and chemical structure in ruminants, is vast and often contradictory (Piluzza et al., 2014). In the past, tannins were classified as “anti-nutrients” because they can cause a reduction of feed intake and nutrient utilization. Relatively low concentration of tannins (0.5% of DM intake) is sufficient to destabilize the bloat proteins while high concentration (2-4% of DM intake) is needed for improvement of protein utilization. High concentration (> 5% of dry weight reduces feed intake and feed conversion efficiency (Addisu, 2016). It has generally been advised that tannin concentrations greater than 50 g/kg dry matter (DM) diet may negatively affect feed intake whereas lower concentrations of tannins have no influence on intake by ruminants. However, there were no significant changes in DMI due to supplementation of 100 – 200 g/cow/day QT (quebracho tannins) at transition period of dairy cows (Attia et al., 2016). On the other hand, feeding wilted calliandra containing SCs reduce voluntary intake of sheep were observed (Wina, 2010).

Paswan and Sahoo (2010) have studied the feeding of HT in oak leaves to cattle bulls and found an increase in feed and nutrient intake and a positive shift on microbial energetic efficiency and enzymatic (fiber-degrading and proteolytic activity) profile.

The effect of tannins (CT and HT) on feed intake can either be short-term (20 to 60 minutes) or long-term (1 to 7 days and more). At CT levels, over 9% toxic and even lethal effects have been reported to have negative effects on voluntary feed intake when animals consumed a variety of *Lotus pedunculatus* (Derix, 2017). The SCs effect on ruminants dry matter intake is also dependent on the type of ruminants. Derix (2017) noted that the goats consumed significantly less hay (10.9%) and leaves of *M. ferruginea* containing SCs (27.7%) compared to the sheep. Cattle often select familiar plants and avoid plants containing toxic secondary compounds (Brunsvig et al., 2017).

Moreover, different PSCs containing forages have not the same impact on dry matter intake of ruminants. Ruminants consuming mimosine and tannins containing leucaena can tolerate 30 to 50% inclusion in the diet without having a negative effect on production (Arjona-Alcocer et al., 2012; Ruz-Ruiz et al., 2013). The intake of high amounts of leucaena may have negative impact on the productive indicators of animals mainly due to the presence of mimosine, which can induce toxicity or death in ruminants (Dalzell et al., 2012), and condensed tannins that form protein-tannin complex limiting the degradation of nutrients (VFA).

Furthermore, the use of essential oils as feed additives in ruminants seems to be difficult and limited for several reasons. Essential oils can also negatively affect taste and smell of feed; hence, they can restrict consumption of feed by ruminant (Cobellis et al., 2016). Surprisingly, Brassica

Table 2. Glucosinolate tolerance level in ruminant animals.

Ruminant species	Maximum glucosinolates level
Growing steers	10 to 15 µmol per gram diet
Growing calves	7.7 µmol per gram diet
Dairy cow	11 µmol per gram diet
Goat	16 µmol per gram diet
Young lamb	2 µmol per gram dry diet

Source: Tripathi and AS, 2017.

meal with 72.58 mol Gls/g DM could be incorporated in the ruminant concentrate mixtures up to225 g/kg and lactating goats can tolerate a daily intake of Gls 11.76 mmole, which amounts 9.45 µmol Gls/g diet DM increased the milk production (Durge et al., 2014). Young ruminants can tolerate total Gls up to 4.22 µmole/g diet. Generally, the maximum upper limit intake of Gls is presented in Table 2.

For the reason of long term effect of SCs on ruminants, there are recommendations put in to practice to limit the intake of forages which are rich in SCs. For instance, ruminants should not graze on only *Kochia scoparia* for more than 90 to 120 days to prevent oxalate toxicity which ranged from 6% to 9% in fresh form (Shereef, 2016)

Digestibility of nutrients

Evergreen shrubs are usually high in SCs (tannins, oils, toxins) which make them difficult to be digestible (Bodas et al., 2012). Promising results have indeed been obtained by co-ensiling sainfoin and Lucerne which further improved digestibility in sheep (Niderkor et al., 2012). Tannin levels of 5 to 9% lead to a reduction of the ruminal digestibility of fibre. This occurs because of the inhibiting effect that tannins have on the activity of bacteria and anaerobic fungi. Sheep fed with Albezia cyanophylla (high in CT content) showed the lowest digestibility of fiber fractions and organic matter (Derix, 2017). Tannins might bind to macromolecules (proteins, structural carbohydrates and starch) and decrease their availability to digestion (Addisu, 2016). However, supplementing tannic acid in the ration of beef cattle has been reported to decrease digestibility of crude protein in all received doses (Yang et al., 2017).

Essential oils are volatile essences which can be derived from leaves, flowers, barks, seeds and roots of various plant species with steam distillation or solvent extraction methods. Pawar et al. (2014) reported that the lowest level of garlic oil (167 µl/l) containing essential oils was the most appropriate level of inclusion while higher doses (333, 500, 667 and 833 µl/l) were detrimental for feed digestibility and fermentation. Similarly, cinnamon bark oil adversely affected the digestibility ruminal feed has been reported. However, supplementation with EO compounds has increased ruminal total VFA concentration, which may indicate improved feed digestion were reported in a limited number of studies (Brus et al., 2017). More differently, Khamisabadi et al. (2016) results suggested that the addition of peppermint and *T. vulgaris* (containing EO) in fattening lambs diets had no effect on dry matter, crude protein, ether extract, NDF and ADF digestibility but increased calcium and phosphorus digestibility.

Mulberry leaf flavonoid and resveratrol containing flavoids were found to improve the digestibility and utilization of nutrients in sheep (Chen et al., 2015). Achillea millefolium (yarrow) also increased both degradability of crude protein and cell-wall constituents. Fortunately, Effects of saponins on feed digestibility were closely related to its inclusion levels. Low levels of saponins increased nutrient digestibility while high levels decreased it (Demirtaş et al., 2018).

Energy utilization

Almost 36% CH4 reduction was observed with the methanol extract of *Mangifera indica* at a concentration of 0.5 ml/30 ml of incubation medium in the study of Kumar et al. (2011). Methane (CH4) production accounts for 2 to 12% loss of dietary gross energy in ruminants (Bhatta et al., 2013b) and ~14% of the metabolizable energy intake (Durmic et al., 2017). Jayanegara et al. (2009) found out that feeding *Acacia mearsnii,* tannins were able to reduce methane release by 13%. Similarly, feeding of *Sericea lespedeza* (17.7% CT) decreased methane emission were studied in angora goats (Agrawal and Kamra, 2010). On the other hand, herbs and spices (containing EO) inhibit the growth of *E. coli* and increase the extracellular ATP concentration (Mirzaei, 2012).

Degradation of rumen protein

Microbial protein synthesis in the rumen provides the majority of protein supplied to the small intestine of ruminants, accounting for 50 to 80% of total absorbable protein were investigated (Anantasook et al., 2013). Supplementation of RPM or RPO (rain tree palm oil) having SCs resulted in the greatest microbial protein synthesis in terms of quantity and efficiency. Similarly, Anantasook et al. (2013) reported that efficiency of microbial protein synthesis was increased in dairy steers supplemented with RPM. Chanthakhoun et al. (2011) also found that feeding Phaseolus calcaratus hay resulted in an increasing efficiency of microbial protein synthesis in swamp buffalo. Therefore, reducing protozoa populations could improve dietary N utilization and increase MPS (microbial protein synthesis) flow to the intestine (Wang et al., 2012).

Flavonoids in plant extract can promote protein degradation (Balcells et al., 2012). Saponin and tannins may also have co-benefit in reducing ruminal protein degradation to ammonia (Kreuzer and Soliva 2008). Low levels of tannins appear to decrease breakdown of protein by microbes in the rumen to make it digestible and absorbed in ruminant small intestine. However, high levels of tannins create a protein deficiency up to an average of 2% were observed in ruminants supplementing junipers oil (Bodas et al., 2012). The role of condensed tannins in reducing ruminal protein degradation (Waghorn, 2008) and reducing autolysis simply by complexing with enzymes has been well documented (Kingston-Smith et al., 2010). Despite the lower CP intake of PSCs for the goats, the latter showed an increased apparent CP digestibility (65.12%) compared to that of the sheep (63.34%) (Derix, 2017).

Effect of secondary compounds on productivity of ruminants

Plant extracts, rich in plant secondary compounds, could positively affect nutrients feed intake and digestibility, ruminal fermentation activities, animal performance and reducing nutritional stress such as bloat has been reported (Demirtaş et al., 2018). Similarly, Khamisabadi et al. (2016) results showed that addition of thyme or peppermint (containing Essential oil) at a concentration of 3% on DM basis to diet improved nutrient digestibility and increased feed intake and average daily gain.

Since the consumption of tannin-rich plant material can affect the voluntary feed intake and the digestive utilization of the feed, these effects will definitely reflect on the productivity of the animals that consume tannin rich plant material. In moderate amounts, tannins can have positive effects such as the improved utilization of feed by ruminants, mainly because of a reduction in ruminal protein degradation and, as a consequence, a higher availability of amino acids for absorption in the small intestine has been documented (Derix, 2017). Nonetheless, research is needed to adjust daily doses to the ruminants' diet (Salem et al., 2012).

Meat, body weight gains and growth

Plant extracts with secondary compounds improved animal growth performance (Jiménez-Peralta et al., 2011) which result in more muscle deposition and, consequently, higher slaughter weights and heavier carcasses and meat quality (Mapiye et al., 2010). Ghani et al. (2017) confirmed that the inclusion of oil palm fronds (OPF), contains secondary compounds, pellets (200 g/kg DM) in a complete ration has been found to increase the unsaturated fatty acid (UFA) content in ruminants. It was also found that feeding tannin– containing legumes mixed with other non-tannin containing legumes or protein source improved ruminant growth performance ((Wina, 2010).

Furthermore, co-feeding of fresh secondary compound containing calliandra with another legume (*Gliricidia sepium*) to goat gave a better ADG than feeding Gliricidia alone was also reported by Cortes et al. (2009). The most significant increase in average daily gain (ADG) (64.6% higher) occurred when sheep was supplied with additional starch/energy source (dried powder cassava) since the intake and the digestibility increased. Feeding 30% of fresh calliandra containing tannins to pregnant ewes (5 months feeding) significantly reduced the body weight loss of the ewes, reduced the interval post-partum-estrus and improved the ADG of lamb (Wina, 2010).

Supplementation of forages containing secondary compounds showed better ADG of Hanwoo steers (Kim et al., 2013). Brus et al. (2017) suggested that the group supplemented with tannin wood extract showed higher ADG than the control group after the month when a drop in ADG was detected. Jolazadeh et al. (2015) also reported that treatment of soybean meal with pistachio extract concentrate (containing tannins) did not affect final body weight or dry matter intake, but adding pistachio extract linearly increased ADG and feed efficiency. Similarly, supplementation of Leucaena having tannin, saponin and mimosine compounds increased LW gain of cattle and sheep have been reported (Barros-Rodríguez et al., 2012).

However, goats had an average decrease of 2.08 kg (or 8% of the initial body weight), while the sheep only had an average decrease of 0.33 kg (or 1% of the initial body weight) ($p = 0.037$) due to supplementation of condensed rich forages (Derix, 2017). Animals fed condensed tannin had lower dressing percent than controlled one; with dressing percent being intermediate for animals fed hydrolysable tannin were reported (Addisu, 2016). More differently, Marley et al. (2018) research has shown there were no substantive effects of including chicory (tannin bearing plant) in the swards of grazing beef cattle on meat stability, fatty acid composition or sensory properties of the *M. Longissimus* muscle when compared with beef steers grazing ryegrass-only swards.

Different authors have been hypothesized that tannin-rich feeds could reduce vaccenic acid (VA) to stearic acid, resulting in the accumulation of VA (Patra and Saxena, 2009). However, lambs grazing CT containing sulla increased LNA (linoleic acid) content in intramuscular fat (IMF) in longissimus dorsi muscle without affecting RA (rumenic acid) or VA. On the other hand, Whitney and Smith (2015) observed that the inclusion of increasing amounts of juniper (from 5% to 36% DM) in the diet No effects on RA and VA were reported. Generally, effects of

Table 3. Effects of tannins supplementation on ruminant meat quality.

Species	Tannin Source	Dosage and Tannin fraction	Duration of treatment (D)	Effects
Ovine	Fresh sulla (*Hedysarum coronarium*)	1.8% DM CT (leucocymidin equivalents)	63	↑ LNA
Ovine	Carob pulp (*Ceratonia siliqua*)	2.7% DM CT (leucocymidin equivalents)	45	↓ RA and VA ↓ n-3 FA
Bovine	High-tannin-sorghum (*Sorghum bicolor*)	1.7%-3.5% DM CT	103-123	No effect in muscle FA Composition
Ovine	Quebracho tannins extract *S. quebracho-colorado* (456 g kg-1 DM)	4.0% DM CT	60	↑ t10-18:1 and total trans-18:1 in concentrate + CT diet ↑ PUFA ↓ SFA ↑ BH in concentrate diets
Ovine	GSE CL leaves	1.3%-1.4% DM CT 2.1% DM CT	42	No effect in FA abomasum digestion and muscle FA composition
Bovine	*Acacia mearnsii* extract	14.1% DM CT	260-283	↓ RA
Ovine	Redberry (*Juniperus pinchotii*) juniper Leaves	Period 1: 3.1%-4.4% DM CT Period 2: 0.4%-2.3% DM CT	86 (period 1 = 28; period 2 = 58)	↑ SFA ↑ RA ↑ Δ-9 Desaturase index
Caprine	*Terminalia chebula* extract	0.6%-1.8% DM CT	90	↑ MUFA, VA, RA and n-3 FA ↓ SFA and t9-18:1 ↑ Δ-9 Desaturase index
Ovine	*Aspidosperma quebracho* extract	8% DM CT	64	No effect on muscle FA composition
Ovine	Alpine pasture highly biodiverse herbaceous shrub type (0.9:0.1)	0.3% DM CT 1.3% DM HT	63	↑ LA, LNA and PUFA ↓ Oleic (c9-18:1), RA and MUFA
Ovine	Leaves and soft stems of CL	2.5%-16.3% DM CT	42	↑ Other trans-18:1 and trans-MUFA in the highest dosage. No effect on RA and VA
Ovine	Redberry juniper branches with leaves	Period 1: 0.1%-2.3% DM CT Period 2: 0.3%-1.5% DM CT	91(period 1=35; period 2 = 56)	↑ t10-18:1 and Total trans-18:1 No effect on RA and VA

tannins on ruminant's meat quality were summarized in Table 3.

Milk production and quality

Supplementation of saponin and tannin containing shatavari 50 to 100 g/day/animal irrespective of body weight have been found to increase milk production significantly in crossbred cows (Mirzaei, 2012), cows and buffaloes (Tanwar et al., 2008) and supplementation of Leucaena on cattle and sheep (Barros-Rodríguez et al., 2012). Flavonoids also causes changes in the fermentation end products and also alter the concentration and composition of lactate-utilizing bacteria (*M. elsdenii*) which increases milk production (Seradj et al., 2014). Higher rumen pH values were recorded in high grain feed heifers supplemented with flavonoids in enhancing lactateconsuming microorganisms i.e. *M. elsdenii* (Balcells et al., 2012).

Few studies have been published on effects of EO or their constituents on milk production and composition of dairy cows (Brus et al., 2017). Tannin feedstuffs resulted in efficient nutrient utilization in ruminants in the form of better growth rates, milk yields and milk composition, higher production and better fertility (Patra and Saxena, 2009). Woodward et al. (2009) studied in New Zealand also found higher milk yields in dairy cows when feeding increasing proportions of legumes containing condensed tannins (birdsfoot trefoil in perennial ryegrass diets).

In addition, propionic acid and milk production increased while acetic acid, acetic to propionic ratio and protozoal population decreased with RPM and/or PO supplementation (Samanea saman with 88 g/Kg of DM condensed tannins and141g/Kg of DM crude saponins). Furthermore, addition of PO and RPO in the diets increased milk fat while supplementation of RPM resulted in greater milk (Anantasook et al., 2013).

However, according to Attia et al. (2016) research, out put of 100 and 200 g/cow/day QT supplementation at either level decreased milk yield, Fat Corrected Milk (FCM) and Feed Efficiency compared to untreated dairy cows. Moreover, it had no significant effect on milk fat, lactose percentage and protein and solid nonfat (SNF) yield, while protein percentage increased significantly in treated compared to control cows. Treatment time had significant effects on milk composition. Thus, the supplementation of commercial QT to dairy cows at their transition period had negative impacts on productive performance. In general, the effects of tannin supplementation on milk production and fatty acid composition have been variable (Morales and Ungerfeld, 2015). Therefore, the effect of tannins on milk quality is summarized Table 4.

Wool production

The wool production increased by 10 to 14% after the grazing of *L. corniculatus* (30 to 35 g CT/kg DM) has been investigated (Derix, 2017). The researcher suggest that this increase is due to a bigger absorption of essential amino acids (particularly sulphur- containing amino acids) in the intestine. However, more research should be carried out to make a general conclusion about the effect of SCs on wool production.

Health performance of ruminants

Ruminant animals reduce internal parasites by selecting food high in primary and secondary compounds. Sheep with parasite burdens increase the intake of needed nutrients. Sheep with high parasite burdens have an increased preference for a tannin-containing food compared with non-parasitized sheep until their parasite infection is terminated by dosing with ivermectin. As parasite loads increase, sheep eat more tannin (Juhnke et al., 2012; Distel and Villalba, 2018). Some farmers in the USA already rely on the legume *Lespedeza cuneata*, rather than on veterinary drugs to control *Haemonchus contortus* infections (Burke et al., 2012).

The positive effect of PSCs (saponins, tannins, EO, organosulphur compounds and flavonoids) on nutritional stress (bloat or acidosis), productivity and health of ruminant animals have been demonstrated in may studies (Seradj, 2015). Makkar et al. (2009) in their research investigated the levels and activities of a number of PSCs are known to increase in response to increase in stress.

Fortunately, using saponins properly is relevant to animal health due to their potential haemolytic activity, while with using tannins the major problem consists of low palatability and potential impairment of ruminal digestion (Jayanegara et al., 2012). Asparagus racemosus (Shatavari), which is a rich source of saponin, is suggested in nervous disorders, dyspepsia, diarrhoea, dysentry, tumors, inflammations, hyperdipsia, neuropathy, hepatopathy, cough, bronchitis, hyperacidity and certain infectious diseases (Mirzaei, 2012).

Especially, CT represent a relatively untapped natural resource and can modulate nematode biology at key life-cycle stages (Martınez-Ortız-de-Montellano et al., 2013). Wina (2010) suggested that the level of tannin in plant for reducing fecal egg count (FEC) is within the range of 45 to 55 g/kg DM. Similarly, Unbounded CT can bind to the brush border of the epithelial layer of the intestine. It could prevent colonization of pathogenic bacteria. According to Weyl-Feinstein (2014) findings, supplementing the milk of neonatal Holstein Friesian calves with 3.75% concentrated pomegranate extract (CPE) (containing 10% DM polyphenols), caused a lower oocyte count and a lower intensity of diarrhea.

Durmic et al. (2017) investigated that EOC (essential oil concentration) performed better than antibiotic commonly used to prevent lactic acidosis. However, Hairy vetch, flax, sorghum, millet and some sweet clovers which contain SCs can be poisonous to cattle. Many small grasses accumulate nitrates, legumes can cause bloat and brassicaceae family can cause polioencephalomalacia and nitrate poisoning (Sun et al., 2012). Therefore, further research need to be done to mitigate the negative impacts and to boot the positive roles of SCS on ruminants' health.

Mitigation methods of the negative effect of secondary compounds in ruminant nutrition

Goat mouth structure allows them to select the high quality parts of the woody plants and they can also effectively detoxifiy secondary compounds such as tannins and terpens (ANR, 2015). But it is not always true for all species so that several methods were tested to deactivate PSCs include PEG (Polyethylene glycol) addition, soaking

Table 4. Effects of dietary tannins on ruminant milk production and fatty acids composition.

Species	Tannin Source	Dosage and Tannin fraction	Duration of treatment (D)	Effects
Bovine	Quebracho (*Schinopsis quebracho-colorado*)	150 g d-1 DM 70% CT	28-d periods (4×4 Latin Square)	No effects in milk fatty acids profile
Ovine	Sulla (grazing) (*Hedysarum coronarium*)	2.50% to 2.74% DM CT	56	↑ LA, LNA and milk fatcontent ↓ RA, VA, t10-18:1 and milk urea content
Ovine	Lentil (*Lens culinaris*) straw	0.84% DM 74% hydrolyzable	50	↓ LA, LNA, oleic (c9-18:1) and stearic (18:0) acids and milk fat content
Ovine	Olive (*Olea europaea*) leaves	1.12% DM 94% hydrolyzable	50	↑ RA ↓ LA, LNA, c9-18:1 and 18:0. ↓ energy-corrected milk yield ↑ RA and VA
Bovine	Quebracho (*S. balansae*)	3% DM CT	21-d periods (4×4 Latin Square)	↓ Milk urea content ↑ LNA and total transC18:1
Bovine	Buckwheat (*Fagopyrum esculentum*)	1.8% DM 82% hydrolysable	25	↑ LA and LNA ↓ t10-18:1 + VA
Ovine	1:1 Red quebracho (*S. quebrachocolorado*): chestnut (*Castanea sativa*)	1% DM 50% hydrolysable	28	No effects on milk fatty acids profile
Bovine	Buckwheat silage	0.73% DM 87% hydrolysable	15	↑ LA and total PUFA
Ovine	Red quebracho (*S. quebracho-colorado*)	2% DM CT	28	No effects on milk fatty acids profile
Bovine	*Acacia mearnsii* extract	400 g d-1 CT	21-d periods (4×4 Latin Square)	No effects on milk fatty acids profile

in water or alkaline solution. Starch (Cassava supplementation) addition is one of the alternatives to mask the effect of tannin as it improved the performance of sheep fed tannin-containing legumes. It was found that feeding tannin– containing legumes mixed with other non-tannin containing legumes or protein source improved ruminant growth performance (Wina, 2010). Moreover, the high content of Secondary compound (SC) in Atriplex halimus tends to reduce fodder palatability and feed intake of sheep and goats. There was an increase in intake and digestibility of DM, OM and NDF, as well as N utilization, by feeding sheep dried Atriplex foliages supplemented with exogenous enzymes (ENZ) (Salem et al., 2012)

PEG is still an effective chemical to deactivate tannin. Spraying polyethylene solution to tannin containing legumes (ratio PEG:CT = 2:1) could reduce the tannin level to 50% lower and improved ADG of sheep by 37%. Spraying 4% PEG solution to calliandra forages (12 g PEG in 1kg DM calliandra) improved the nutritional quality of this forage as it was shown by higher daily gain of sheep fed PEG-treated calliandra. However, as the price of PEG is quite expensive, its application should be considered carefully (Wina, 2010).

Although soaking in calcium hydroxide, lime or water reduced tannin content, they did not improve the animal performance. Further evaluation to see the effect of ash treated forages on animal performance is warranted since wood ash solution may be an alternative and cost effective

Table 5. Effect of processing methods for secondary compounds (Glucosinolate) decomposition on ruminant's responses.

Treatment	Conditions of treatment	Animal Response
Water soaking	Seed to water ratio; 1:10 for 6 hr and dried at 60ºC	Improved intake and nutrient utilization in sheep
Water extraction	Seed to water ratio; 1:8	Detoxified meal improved ruminants performance
Formaldehyde treatment	0.8 g/100 g CP	No significant effect of treatments on milk yield and goitrogenic substance secretion in milk

Source: Tripathi and AS, 2017.

way to deactivate tannin in the village area where people used fire wood for cooking their food. According to Sikosana et al., (2008) research, wood ash increases rumen degradation of protein and this could improve protein utilization of acacia Nilotica in goats. Some of the different processing methods of SCS on ruminant animals' response is presented Table 5.

CONCLUSIONS AND RECOMMENDATIONS

Plant secondary compound are chemicals produced by plants but they are not used for growth and development of plants to support their daily life. These compounds involve majorly tannins, saponins, flavoids, glucosinolates and essential plant oils. Secondary compounds may have positive or adverse effect on ruminant animals feed intake, digestibility, and nutrient utilization depends on the type of the species, the nature of chemicals and the amount included and supplemented. Ruminants' growth, average body weight gain, milk and wool production and quality of their products are affected by secondary compounds as well. Moreover, since the antibiotics is banned by the European Union, these compounds are taken as a better opportunity to raise healthy animals.

However, these compounds may have a negative impact on the ruminant's production because of different factors. Among the factors determination of the content of each secondary compounds is not easy and the materials needed to measure them is not also available. On the other hand, unavailability of consistent research output associated with the dose of secondary compounds for each species is another problem. Finally, most of peoples do not recognize the use of these compounds. Therefore, the following points should be considered while using secondary compounds as feeds of ruminant:

- The dose of different secondary compounds which need to be offered to ruminants should be fixed to avoid the toxicity effect.
- More research should be done to effectively utilize naturally occurring plant secondary compounds.
- Awareness should be created for rural dwellers in order to optimize benefits from ruminant animal production.

Abbreviation

ADF, Acid Detergent Fiber; **ADG,** Average Daily Gain; **ANR,** The University of California Division of Agriculture and Natural Resource **CO,** Coconut Oil; CP, Crude Protein; **CT,** Condensed Tannin; DM, Dry Matter; **DMI,** Dry Matter Intake; **EC,** European Council; EE, Ether Extract; **EO,** Essential Oil; **EOC,** Essential Oil Concentration; **EU**, European Union; **GIs,** Glucosinolates; **HT,** Hydrolzable Tannins; **IMF,** Intramuscular Fat; **LNA,** Linoleic Acid; **MPS,** Microbial Protein Synthesis; **NDF**, Neutral Detergent Fiber; OM, Organic Matter; **OPF,** Oil Palm Fronds; **PEG,** Polyethylene Glycol; **PO,** Plant Oil; **PSCs,** Plant Secondary Compounds; **QT,** Quebracho Tannins; **RA,** Rumenic Acid; **RPM**, Rain Tree Palm Meal; **RPO,** Rain Tree Palm Oil; **SCS,** Secondary Compounds; **TA,** Tannic Acid; **tVFA,** Total Volatile Fatty Acid; **UFA,** Unsaturated Fatty Acid; **VA,** Vaccenic Acid; **VFA,** Volatile Fatty Acid.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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