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The beneficial impact of legume supplementation on nutrient intake, digestibility, growth and reproductive performances of goats: A brief review

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ABSTRACT

The productivity of goats in small-scale farming is largely influenced by the availability and affordability of high-quality forages all year round. Grasses commonly used for pastures in tropical regions tend to have low protein levels, which may not be sufficient for optimal production in ruminant animals. Despite potential concerns such as anti-nutritional elements and toxins, the addition of legumes to goat diets could be a beneficial way to address nutritional deficiencies in the diet of goats. This review discussed the beneficial impact of some legumes supplementation (*Gliricidia sepium*, *Sesbania grandiflora*, and *Leucaena leucocephala*) on nutrient intake, digestibility, growth and reproductive performance of goats. Studies have shown that *G. sepium* supplementation can improve nutrient intake, nutrient digestibility, N retention, and body weight of goats. *S. grandiflora* supplementation had a beneficial impact on nutrient intake and digestibility, semen quality, and body weight. *L. leucocephala* supplementation to the goat diets have been reported to improve production of volatile fatty acid and urinary purine derivatives, growth performance, dressing percentage, and overall yield of kid per animal, as well as reduce the incidence of abortion. This suggests that supplementation with high-quality foliage is very beneficial to increase nutrient intake, digestibility, growth and reproductive performance of goats fed low quality grass.

Introduction

Goats are among the first species of livestock to be domesticated. The worldwide population of domestic goats is estimated to be over one billion animals and has doubled in the last four decades (Utaaker *et al*., 2021). According to the Food and Agriculture Organization, the majority of goats, which mostly belongs to indigenous goats, are kept by smallholder farmers in low-income or developing countries, particularly in Asia and Africa (Kronqvist *et al*., 2021). Asia has the highest percentage of the global goat population, with Africa coming in second (Miller and Lu, 2019). Goats have been categorized into different breeds and are raised in various environments worldwide. Compared to cattle or sheep production, goat production is generally less intensive in many regions. Goats have been indispensable to human societies around the world for centuries. They provide food sources and livelihood, especially to local farmers and by consequently, goats continue to play a vital role in supporting communities and ensuring food security (Miller and Lu, 2019; Hariyono and Endrawati, 2023).

In tropical developing countries, goat farming relies on a traditional, free-range system where goats graze on low-quality natural pastures (Ndona *et al*., 2024). Smallholder farmers typically raise indigenous goat breeds that can adapt to various production environments. Unfortunately, goat production under these conditions is marked by a high mortality rate, high levels of morbidity, and low productivity (Mayberry *et al*., 2018; Dosseh *et al*., 2021). In tropical climates, small ruminants such as goats typically have lower productivity levels compared to breeds found in temperate regions. This is often a result of animals being either continuously grazed or permanently confined. The poor performance of these animals, which is often linked to reduced annual growth, can be attributed in part to the low nitrogen and high fiber content of local plants and crop residues commonly used in their diets by farmers (De Angelis *et al*., 2021). Despite these challenges, ruminant animals are able to survive even under the inadequate dietary conditions. Goats and other ruminant animals have the ability to degrade and use forages because of their symbiotic relationship with rumen microbes.

Generally, goats need to consume a diet that is mainly made up of high-quality forage or browse, such as hay (grass or legume), silage, or pasture/range. Forage is essential for the microorganisms in the rumen that supplies most of the protein needed by goats for energy (Wu *et al*., 2023). In small-scale farming, the productivity of goats depends heavily on the availability and affordability of high-quality forages throughout the year. Breeders frequently have to provide low quality feed because there is a scarcity of forage, resulting in feeding below standard requirements. In tropical areas, grasses used for pastures often have low protein levels, which are insufficient for high levels of production in ruminants. The incorporation of arboreal and shrub fodder supplements, despite sometimes containing anti-nutritional elements and toxins that restrict their usage, may offer a profitable solution in addressing the nutritional deficits in basal diets (Harun *et al*., 2016; De Angelis *et al*., 2021; Koura *et al*., 2021). Therefore, high-quality feed supplements are necessary to address the deficiency and enhance livestock productivity.

The utilization of legume forages as a protein source in ruminant diets is recognized and accepted. Research has demonstrated that supplementation of legumes to diets consisting of grasses with less than 7% crude protein can increase forage digestibility, feed intake, microbial protein synthesis, and animal performance (Ash, 1990; Gusha *et al*., 2015a; 2015b; de Miranda Costa *et al*., 2021). Legumes are considered a valuable protein source for animal feed due to their high protein content. They can enhance the availability of nitrogen for rumen fermentation and enhance the mineral composition of a diet. The forage legumes that possess rumen undegradable protein can provide essential amino acids like lysine and methionine, which are important for growth (Mazinani *et al*., 2019). These improve rumen fermentation kinetics and enhance the production of rumen microbial protein, which is a crucial source of nutrients for rumi-

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nant animals. Various types of legumes, such as *Indigofera zollingeriana*, *Leucaena leucocephala*, and *Calliandra calothyrsus*, can serve as alternative forage options. *Sesbania grandiflora* have the potential to suppress methanogenesis (Bhatta *et al*., 2012). Research has shown that *I. zollingeriana* has a protein content of 23.1% (Ali *et al*., 2014), *L. leucocephala* contains 15% to 38% protein (Karti *et al*., 2022), and *C. calothyrsus* leaves have a protein content of 19.3% (Stürm *et al*., 2007). To date, numerous studies have noted beneficial effects of legume supplementary feeding on nutrient intake, nutrient digestibility (Aregheore and Perera, 2004; Oyedele *et al*., 2016; Pervin *et al*., 2023), productive (Shahjalal and Topps, 2000; Akingbade *et al*., 2001; Sadi *et al*., 2015; Dharmawan *et al*., 2019), and reproductive performances of goats (Pamo *et al*., 2006; Zaenuri *et al*., 2023).

In this review, the effects of legume supplementation on nutrient intake, nutrient digestibility, growth and reproductive performance in goats. The legumes discussed in this review included G. sepium, S. grandiflora, and L. leucocephala (Fig. 1).

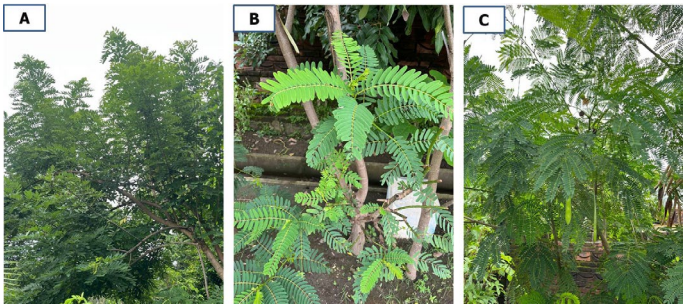

Figure 1. The legumes discussed in this review. (A). G. sepium, (B). S. grandiflora, and (C). L. leucocephala.

Gliricidia sepium

Gliricidia sepium, a medium-sized leguminous plant, is widely distributed in tropical and subtropical regions. Local communities in Indonesia and the Philippines have utilized it for its medicinal properties and as an ingredient in rodenticides (Aulanni'am *et al*., 2021). The tree can grow up to 15 meters in height (Mussali-Galante *et al*., 2023). Studies have identified active substances in *G. sepium*, such as polyphenols, tannins, anthraquinonic glycosides, amino acids, and fatty acids (Romero *et al*., 2020; Hertel Pereira *et al*., 2022). Comparative evaluation of ethanol extracts from three commonly used forage species, including *G. sepium*, *L. leucocephala*, and *Pithecellobium dulce* in dry tropical forests, revealed that *G. sepium* showed better larval exsheathment inhibition (LEI) of third-stage larvae, larval development, and egg hatching inhibition in sheep infected with *Hemonchus contortus* (Romero *et al*., 2020).

G. sepium is a tree legume known for its various agricultural uses, although there is limited information on how agrisilvicultural systems impact nitrogen cycling. A study by Figueiredo *et al*. (2023) was conducted to assess the effect of different *Gliricidia* densities (667, 1000 and 1333 plants ha^{-1}) on nitrogen cycling in agrisilvicultural systems. Results indicated that the system with 1000 plants ha-1 was particularly effective in mineral N recovery, making it a promising option for integrated production systems in tropical regions (Figueiredo *et al*., 2023). *G. sepium* has the potential for phytoremediation of soils contaminated with Fe, Cu, and Pb, as well as for phytostabilization of soils polluted with Fe, Pb, Zn, and Cu. Additionally, it has the ability to thrive in polluted environments, bioaccumulate heavy metals in its roots and leaves, and effectively translocate those metals (Mussali-Galante *et al*., 2023).

Some studies have documented the role of *G. sepium* in goat feeding. As reported by Rusdy *et al*. (2020), adding *Gliricidia* up to 40% to the diet can significantly enhance dry matter and nutrient intake, digestibility, and nitrogen retention in goats that are primarily fed *Panicum maximum*. It is suggested that ensiling cassava peels with *G. sepium* (ratio of 1:1, kg/kg) or *L. leucocephala* foliage (ratio of 2:1, kg/kg) is a suitable feeding option for West African dwarf goats, especially during the dry season when forage availability is limited (Oduguwa *et al*., 2013). According to Oduguwa *et al*. (2013), ensiling *L. leucocephala* and *G. sepium* with cassava peels did not impact fermentation but it increased the crude protein content of the resulting silage. Koura *et al*. (2021) highlighted *G. sepium* as a promising option for goat supplementation in sub-humid areas during dry seasons. Steaming *G. sepium* by 0.8% based on dry matter needs in the dry period had positive effects on birth weight, weaning weight, and average daily gain of Etawah crossbreed (Dharmawan *et al*., 2019). Aregheore and Perera (2004) in their study also explored the impact of supplementing a maize stover basal diet with *Erythrina variegata*, *G. sepium*, or *L. leucocephala* on feed intake and digestibility in goats. They noted that feeding goats with 50% maize stover + 46% *G. sepium* + 4% sprayed molasses can increase dry matter intake and nutrient digestibility. Additionally, the inclusion of *G. sepium* leaf up to 40% in the ration can increase crude protein and fat content in Peranakan Etawah goat milk (Hidayati, 2015). Phimphachanhvongsod and Ledin (2002) noted that addition of 30% of *G. sepium* leaves in the Guinea grass can increase live weight gain and growth rate in local goats in Laos. Goats fed diet combination of the low cost concentrate with a forage combination of equal mixture of *G. sepium* (25%) and *Moringa oleifera* (75%) showed a better growth rate (Oyedele *et al*., 2016). Goats fed 70% of *G. sepium* to the basal diet of *Ischaemum rugosum* had higher dressing percentage and meat yield (Sadi *et al*., 2015).

Sesbania grandiflora

Sesbania grandiflora, also called "Agati," is a perennial tree that belongs to the *Fabaceae* family and is commonly found in tropical countries (Unnawong *et al*., 2021a), including India, Malaysia, Myanmar, and Philippines (Karmakar *et al*., 2016). It serves as a significant source of nutrition in the diet. Leaves, seeds, pods and flowers of *S. grandiflora* are edible (Karmakar *et al*., 2016). The green leaves of *S. grandiflora* contain high protein content and low fiber content, making them suitable as nutritious fodder for goats (Giridhar *et al*., 2021). *S. grandiflora* acts as a good source for controlling the microbial population (Gandhi *et al*., 2017). Its chemical compositions on a dry matter basis have been reported to be 20.31% of dry matter, 91.27% of organic matter, 24.27% of crude protein, 4.42% of ether extract, 8.73% of total ash, and 30.26% of neutral detergent fiber (Giridhar *et al*., 2018). The pods of the *S. grandiflora* contain 35% of crude protein (CP) as well as various plant secondary compounds (PSCs) such as tannins, flavonoids, steroids, and triterpenes (Unnawong *et al*., 2021a). The PSCs can serve as a dietary supplement in ruminant feeding to eliminate the use of antibiotics. The phenolics and flavonoids present in *S. grandiflora* could serve as alternative antibiotics or potential feed additives for controlling animal pathogenic bacteria (Lee *et al*., 2014). The saponin extract from *S. grandiflora* can enhance protein utilization and improve rumen fermentation particularly lowering CH4 production (Unnawong *et al*., 2021a). The leaf juice of *S. grandiflora* revealed significant antiurolithiatic properties against calcium oxalate-type stones and displayed antioxidant characteristics. Therefore, the findings offer support for the effectiveness of *S. grandiflora* leaf juice as an antiurolithiatic agent (Doddola *et al*., 2008).

Dietary supplementation with *S. grandiflora* led to a significant reduction in acetate (C2) levels, the acetate to propionate ratio, methane production, and fecal N excretion, while also resulting in a notable increase in total volatile fatty acids (VFAs) and propionate (C3) concentration (Unnawong *et al*., 2021b). A study conducted by Pervin *et al*. (2023) demonstrated that Black Bengal goats fed *S. grandiflora* foliage showed increased feed intake, digestibility, and average daily weight gain compared to those fed hybrid Napier and local native grasses, without any detrimental effects. Feeding *S. grandiflora* as a sole feed had a positive impact on live weight and nutrient digestibility in Black Bengal goats

Table 1. The impact of legume supplementation on nutrient intake, digestibility, growth and reproductive performance of goats.

Legume	Breed of goats	Effect	Source
Gliricidia sepium	Kacang from Indonesia	Goats fed old guinea grass 60% + *Gliricidia* 40% showed increased dry matter and nutrients intake, digestibility, and N retention	Rusdy *et al*. (2020)
	West African dwarf goats	Cassava peels supplemented with *G. sepium* (ratio, 1: 1, kg/kg) improved the crude protein content and improved growth rate of the goats	Oduguwa *et al*. (2013)
	Etawah crossbreed	Steaming up using *Gliricidia* by 0.8% based on dry matter needs in the dry period can improve birth weight, weaning weight, and average daily gain (ADG)	Dharmawan *et al*. (2019)
	Angola-Nubian x Fiji local	Feeding goats with 50% maize stover + 46% *G. sepium* + 4% sprayed molasses can increase dry matter intake and nutrient digestibility	Aregheore and Perera (2004)
	Etawah crossbreed	Adding *G. sepium* leaf of up to 40% DM in the ration can increase crude protein and fat content in milk	Hidayati (2015)
	West African dwarf	75% browse plant *G. sepium* plus 25% concentrate gave better live weight	Awah and Marigui (1996)
	Toggenburg x Saanen	Higher live weight gain in goats supplemented with a mixture of *Gliricidia* and maize bran diet (69 g/day)	Ondiek *et al*. (1999)
	Local goat in Laos	Addition of 30% of *Gliricidia* leaves in the Guinea grass gave better live weight gain, double growth rate compared to grass only	Phimphachanhvongsod and Ledin (2002)
	West African dwarf	Goats fed diet combination of the low cost concentrate with a forage combination of equal mixture of *G. sepium* (25%) and *Moringa oleifera* (75%) gave better growth rate	Oyedele *et al.* (2016)
	Katjang crossbred	Goats fed 70% *G. sepium* to the basal diet of *Ischaemum rugosum* had higher dressing percentage and meat yield	Sadi *et al*. (2015)
Sesbania grandiflora	Black Bengal	Goats fed basal diet supplemented with *Sesbania* showed higher feed intake and nutrient digestibility of dry matter, crude protein, organic matter, neutral detergent fiber, and acid detergent fiber than those fed only basal diet	Pervin *et al*. (2023)
	Black Bengal	Goats fed *Sebania* leaves showed higher live weight and nutrient digestibility than those fed rode-side grass	Shahjalal and Topps (2000)
	Fiji × New Zealand cross	Supplementation with *S. grandiflora* and *G. sepium* significantly increased total dry matter intake	Ash (1990)
	Kacang	*S. grandiflora* tablet (SGtab) supplementation in the basal diet has a positive impact on the semen quality	Zaenuri *et al*. (2023)
	Bangladeshi goat	Supplementation with *S. grandiflora* (33%) in the feeding system of goat resulted in better weight gain, digestibility and nitrogen balance compared to green grass	Rahman *et al*. (2015)
	Kacang	Goats fed 20% natural grass, 40% *L. leucocephala*, 40% *S. grandiflora* showed higher feed consumption and average daily gain	Luruk (2016)
	Osmanabadi	Goats fed concentrate mixture plus a combination of three legumes from *S. grandiflora*, *L. leucocephala*, and *D. virgatus* show higher dressing percentage	Shaikh *et al*. (2023)
Leucaena leucocephala	Boer	Incorporating 25% of *L. leucocephala leaves* and 50% of *M. esculenta* leaves into the goat diet can enhance production of volatile fatty acid and urinary purine derivatives	(Harun *et al*. (2016)
	South African indigenous	During gestation, pregnant goats showed improved growth performance when fed a mixture of *L. leucocephala* and grass, leading to higher birth weights for the kids	Akingbade *et al*. (2001)
	Boer × Spanish crossbreds	Goats fed Sudan grass (60% of the diet offered) supplemented with *L. leucocephala* (40%) and corn (0.2 kg/day) gained higher average daily gain and total feed intake than those fed diets supplemented with *Medicago sativa*, *Dolichos lablab*, and *Desmanthus bicornutus*	Kanani *et al*. (2006)
	Angora and Spanish	Goats can be fed diets containing moderate to high levels of *L. leucocephala* (e.g., 45%) mixed with 0.75% mimosine without negative impact on their weight gain or fiber growth	Yami *et al*. (2000)
	West African dwarf	Supplementation of *L. leucocephala* reduced the incidence of abortion and increased the overall yield of kid per animal	Pamo *et al*. (2006)
	Bangladeshi goat	Supplementation with *L. leucocephala* in the feeding system of goat resulted in better weight gain, digestibility and nitrogen balance compared to green grass	Rahman *et al*. (2015)
	Osmanabadi	Goats fed concentrate mixture plus a combination of three legumes from *S. grandiflora*, *L. leucocephala*, and *D. virgatus* show higher dressing percentage	Shaikh *et al*. (2023)
	West African dwarf	Supplementation with a combination of *Caliandra calothyrsus* and *L. leucocephala* reduced the incidence of abortion and increased the overall yield of kid per animal	Pamo *et al*. (2006)

(Shahjalal and Topps, 2000). A research showed that giving small quantities (~18% of total DM intake) of *S. grandiflora* leaf to goats will significantly increase total DM intake compared with a mature tropical grass given alone (Ash, 1990). The combination of 20% natural grass, 40% *L. leucocephala*, 40% *S. grandiflora* in the ration can increase feed consumption and average daily gain of Kacang goats (Luruk, 2016). *S. grandiflora* tablet (Sgtab) supplementation in the basal diet had a positive impact on the semen quality (semen volume, spermatozoa concentration/ejaculate, plasma membrane integrity, viability and progressive motility, and normal spermatozoa) of Kacang bucks (Zaenuri *et al*., 2023). Rahman *et al*. (2015) noted that supplementation of *S. grandiflora* (33%) in the goat diet can improve weight gain, digestibility and nitrogen balance compared to green grass alone.

Leucaena leucocephala

Leucaena leucocephala, commonly known as *Leucaena*, is a palatable forage legume grown in tropical and subtropical areas worldwide. It is a long lived perennial legume tree. It is non-climbing, erect, thornless shrub or small tree, grow in arid and semi-arid areas. It is used as soil fertility improvement (Verma, 2016). It produces edible pods known by the same name. The seed is flattened in shape and is used in various dishes such as huaxmole. This tree grows wild in warm areas between 800 and 1700 m above sea level (Hernández-Santos *et al*., 2022). *L. leucocephala* (*Fabaceae*) is native to Central America and has invaded many climatic regions of the tropics (De Angelis *et al*., 2021; Sithole *et al*., 2021).

The *Leucaena* genus consists of a total of 24 native species, with 19 being diploid and five being tetraploid (Abair *et al*., 2019). In South Africa, the species is categorized as an emerging or incipient weed used as fodder, timber, firewood and in erosion control on degraded habitats (Sithole *et al*., 2021). One of its uses includes forage for livestock, but introduction of *Leucaena* outside its indigenous range often has led to acute and chronic toxicosis (Hammond, 1995). It is widely known to contain a toxic compound called mimosine, a depilatory and potent goitrogen (Hammond, 1995; Widaad *et al*., 2022). Mimosine is a nonprotein amino acid biosynthesized from OAS (O-acetylserine) and 3H4P (3-hydroxy-4-pyridone or its tautoisomer 3,4-dihydroxypyridine). This amino acid constitutively occurs in all parts of *L. leucocephala* (Lam.) de Wit plants and is found at higher concentrations in seeds and leaves. This metabolite has several useful activities, such as antioxidant, allelochemical, insecticidal, antimicrobial, metal chelating, and antitumor (da Silva Rodrigues-Honda *et al*., 2022). As a result, this factor may decrease their nutritional value as sole feed but increased their value as supplemental feed to low quality forages as well as agricultural by-product. For local farmers to utilize them effectively, manipulation of both forages is necessary to overcome or reduce the presence of anti-nutritive elements before it can be safely incorporated into the ruminant feed. In the tropics, wilting process has been a common practice for most forages (Harun *et al*., 2016). Ensiling may be an appropriate method for preservation and toxic reduction because *L. leucocephala* is harvested during the rainy season when drying is rather difficult (Phesatcha and Wanapat, 2016).

A research indicated that including 25% of *L. leucocephala* and 50% of *M. esculenta* leaves in the diet can increase the production of volatile fatty acid and urinary purine derivatives, along with the presence of total protozoa and cellulytic bacteria in the rumen (Harun *et al*., 2016). Therefore, it can be inferred that feeding goats a diet supplemented with 25% of *L. leucocephala* leaves and 50% of *M. esculenta* leaves is acceptable without causing a detrimental effect on the animals (Harun *et al*., 2016). Another study suggested that an inclusion of 12% DM of ration as dried *L. leucocephala* leaves enhanced digestible CP and reduced daily production of enteric CH4 without adversely affecting DMI, rumen microbial population, and fermentation parameters (Montoya-Flores *et al*., 2020). Akingbade *et al*. (2001) studied the reproductive performance of South African indigenous goats inoculated with DHP-degrading rumen bacteria. The results noted that *L. leucocephala*/grass mixture favoured growth performance of pregnant goats during gestation and high kids' birth weight. The absence of deleterious effects associated with *L. leucocephala* during the study showed that it can be safely fed without restriction once the indigenous goats have been transferred the DHP-degrading rumen bacteria (Akingbade *et al*., 2001). Evaluation of tropical forage legumes (*Medicago sativa*, *Dolichos lablab*, *L. leucocephala* and *Desmanthus bicornutus*) suggested that *L. leucocephala* had more potential for feeding growing goats in tropical regions compared to the other forage legumes (Kanani *et al*., 2006). Goats fed *L. leucocephala* had better ($p < 0.05$) gain efficiency (ADG/total feed intake) compared to goats fed *D. bicornutus* (Kanani *et al*., 2006). Diets of moderate to high levels (e.g., 45%) of *L. leucocephala* with 0.75% mimosine can be fed to goats without adverse effects on body weight gain or fiber growth (Yami *et al*., 2000). Furthermore, the supplementation of *L. leucocephala* with a combination of *Calliandra calothyrsus* can reduce the incidence of abortion and increase the overall yield of kid per animal (Pamo *et al*., 2006). Despite showing potential as a high-quality feed for growing goats, the use of *L. leucocephala* is restricted due to the presence of the toxic non-protein amino acid, mimosine. However, a research indicated that ruminants that have not been inoculated with *Synergites jonesii* can typically consume diets consisting of 30-40% *L. leucocephala* without experiencing negative effects (Hammond, 1995; Yami *et al*., 2000; Akingbade *et al*., 2001; Harun *et al*., 2016).

Conclusion

Substituting low-quality roughages with foliages is a promising and best way for addressing nutrient deficiencies in ruminant animals. Various forms of supplemental feeding are recommended to increase goat production, with feeding leguminous tree leaves such as G. sepium, S. grandiflora, and L. leucocephala being particularly beneficial for feeding goats by positively impacting their nutrient intake, digestibility, growth rate, and reproductive performance.

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Conflict of interest

The authors declare that they have no conflict of interest.

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