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Recent Advancement in Goat Nutrition

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Abstract

Nutrition or feeding is one of the most important components in livestock production and it's associated with high costs. In goat production, it can typically account for 60% or more of total production costs. As a result, there is much new research being conducted on goat feeding and nutrition in a variety of areas regarding production costs, sustainability, and quality of the product produced. Areas of research that are currently receiving much attention include feed additives such as prebiotics, probiotics, enzymes, antioxidants, plant secondary metabolites, etc. Their use in animal feed is expected to increase due to the abolition of synthetic antimicrobials in feed, although there is still limited information on their use and is accompanied by contradictory research reports. This study aims to highlight some of the recent and emerging studies on the different feed resources, feed additives and dietary feed composition for goats.

Keywords: Goat, Nutrition, Recent, Biochar, Glycerin

1. Introduction

Great importance is attached to nutrition in goat husbandry, as it is one of the factors of production on which the farmer can act quickly and easily. Moreover, it has the best known influence on the production cost while as affects the health and reproductive performance of goats [1]. Therefore, more attention should be given to the nutrition and feeding program for the profitability of the farm.

Currently, there is an increase in animal nutrition research carried out under a wide array of topics all over the world. This could be due to the differences in feed ingredients in different continents of the world, hence the wide variety of topics related to feeding and nutrition. The current research topics in feed and feed technology that are being studied are related to product quality, economic/financial perspectives and sustainability. Since there are very many topics currently being investigated in relation to goat feeding and nutrition, this study has reviewed and summarized some of the recently published research from around the world.

2. Methodology

For this study, a comprehensive review of various current scientific, technical and economic literature was used. This review study considered the most recent papers published between 2010 and 2021, with very few older studies published before 2010. Most of the information was obtained from original research articles

on goat nutrition published from different regions of the world and very few review articles, books and conference papers were used. The data and results within this study are based on directly reported values in the published literature and derivations from figures and tables.

Various databases from the internet were used to search for papers and different keywords and synonyms were used. In addition, the reference sections of the various papers obtained were scanned for other possible relevant publications. The authors selected the studies included in this review by evaluating the titles and abstracts to match the objectives of the review [2].

3. The different goat feeding resources, the new resources and their utilization

3.1 Fodder shrubs and trees

Goats are natural browsers and feed on shrubs, bushes and trees. This is common in tropical regions, especially in humid zones. Goats feed on these browses and feasibly utilize them more efficiently. Browsing is also common in arid and semi-arid zones, as most browse foliages are drought resistant. Therefore, they are the main forage resource during the long dry periods [3]. During grazing, goats have shown selective behavior towards different plants and plant parts [4]. In a study by Iussig et al., [5], goats showed a high conspicuous desire to consume most of the browse species compared to other plant species.

Browses are considered to have high nutritional value compared to pasture grasses and crop residues. Crude protein content is one of the great attributes of these trees used in ruminant feeding. Mokoboki et al., [6], demonstrated up to 227.9 g/kg (DM) crude protein in *Acacia* species. They also contain higher concentrations of ash (minerals), less fiber and remain nutritious during the dry season [7].

Despite their nutritional value, there are concerns about antinutritional factors such as tannins, nitrates, oxalates, sinogens, saponins, mimosine that limit their utilization [8]. On the other hand, tannins are said to bind with proteins in the rumen and lead to increased amino acid absorption in the intestine [9], increase nutrient utilization and feed efficiency, thus improving growth performance [10].

Patra and Saxena, [11], found that tannins are associated with stopping bloat, impede methanogenesis and increase the concentrations of certain fatty acids such as conjugated linoleic acid in ruminant products. Matovu et al., [12], in their study showed the potential of ethnomedicinal plants in the treatment of helminths. This could be due to the availability of phytochemicals such as condensed tannins, saponin and flavonoids which have been associated with anthelmintic activities [13].

There is also increasing popularity of a shrub called Cactus (*Opuntia spp.*) as a feed that is best adapted in arid areas [14]. However, it is associated with high fiber and ash content and thus low energy and protein density, which requires specific supplementation when cactus species are used in feeding [15]. The inclusion of cactus species in the diet had no adverse effects on the sensory properties of goat milk or on its lipid composition profile [16].

Eucalyptus leaves are also gaining importance in goat nutrition. Feeding with its leaves has shown antihelminthic activity against gastrointestinal nematodes in goats [17]. Sallam et al., [18], showed that Eucalyptus oil (*Eucalyptus citriodora*) can modify rumen fermentation and has the ability to reduce methane emissions. Further discussion on the importance of plant extracts such as essential oils as anthelmintics and their effects on methane emissions can be found in Section 4.2.

Items	Dietary treatments					
	A	B	C	D	E	SED
Total DMI (g/d)	648.00	696.00	694.00	678.00	723.00	16.35
DMI (g/kgw ^{0.75} /d)	94.00	99.00	96.00	97.00	101.00	3.34
ME intake (MJ/d)	6.68	7.74	7.39	7.51	7.88	0.50
DCP intake (g/d)	67.90	92.96	92.31	93.41	99.66	3.97
Initial weight (kg)	9.96	9.96	9.97	9.97	9.97	0.55
Final weight (kg)	14.83	16.42	16.60	16.20	16.70	0.76
Daily weight gain (g/d)	40.58	53.83	55.25	51.91	56.08	2.81
FCR	16.50	12.05	11.74	12.20	12.043	0.49

A: Control with no tree forage, B: *Erythrina orientalis*, C: *Leucaena leucocephala*, D: *Morus alba*, and E: *Sesbania grandiflora*.

Table 1.
Increased performance of goats supplemented with different tree forages (adapted from Rahman et al. [19]).

Due to the high protein content of shrubs/trees, their leaves act as supplements with other roughages and this has shown the increased performance of goats [19], which is seen in **Table 1**. In a study where small East African goats diet consisting of *Chloris gayana* hay which has a low protein content was supplemented with *Maerua angolensis*: *Zizyphus mucronata* foliages led to improved feed intake, digestibility and growth [20].

In the recent developments to further improve the nutritional value and forage tree utilization, they have been developed through the process of pelleting. Pellet products have been developed from these foliages and are seen to be important protein sources during ruminant feeding such as mulberry (*Morus alba*) leaf pellets and *Leucaena leucocephala* leaf pellets [21].

Currently, there are a variety of documented forage trees and shrubs used in goat feeding and these vary in different regions. Based on the above information, these feed types play an important role in the diets of goats in tropical and subtropical regions of the world.

3.2 Pastures, forbs and rangelands

In the humid and subhumid zones, the natural pastures consist of a variety of grasses and form an important food component for goats. One of the characteristics of the humid zones is the high amount of rainfall, which automatically leads to rapid growth of the forage. This is accompanied by lignification and consequent decrease in nutritional quality, which accentuates as the dry non-growing season progresses [22]. The reduction in nutritional value is due to the fact that mature plants have lower palatability and digestibility.

Also, the poor climatic factors in arid and semi-arid zones make these natural pastures and forbs nutritionally inadequate over a prolonged period [23]. To counter such and other situations like drought, soil and water salinity and water scarcity, the best activity has been promotion of cultivation of nutrient-rich leguminous and non-leguminous pastures/forages and fodder crops has been promoted.

On the other hand, due to global warming, the characteristics of various pastures have begun to change, these are being replaced by plants with shrubby characteristics such as cactus species, which have a great chance of surviving in such environments and have been used as fodder [24].

3.3 Crop residues and agro-industrial by-products

Growing population and urbanization automatically led to the need for food production to meet the needs of this population. During this process, new sources of feed have emerged, sometimes referred to as wastes or by-products. These by-products, such as: Soybean hulls, wheat middlings, corn gluten feed or dried distillers grains, corn cobs, potato peels, cassava peels, vegetables, fruit by-products, grape seed pulp, starch industry by-products, dairy industry by-products, olive by-products and many others have been incorporated into the diets of livestock in reasonable amounts and have been reported to have beneficial effects on health, performance and control of feed costs. Therefore, currently more and more by-products and residues are being investigated and evaluated as novel feeds in ruminant diets.

Studies by Teklebrhan et al., [25], reported an increase in dietary protein, fiber and sulfur content when corn was replaced by corn gluten in goat feeding. Reduction in methane emissions was also evidenced. Replacement of 61% of maize in the diet with dry citrus pulp and soybean hulls had no negative effect on milk yield in Murciano-Granadina goats during mid-lactation [26]. Cassava by-products [27, 28] are successfully utilized by goats with no effect on performance. In a recent study [29], silages of tomato and olive oil by-products replaced oat hay at a supplementation rate of 20% and there was no effect on goat performance. Tzamaloukas et al., [30], gave a comprehensive review on the use of olive oil by-products in the feeding of goats.

There is also an increasing use of biofuel or alcohol by-products in animal feed, mainly due to their high nutritional value. The corn-dried distillers grains with solubles (DDGS) is an example of alcohol by-products. A study in which DDGS (180 g) was mixed with dried citrus pulp (180 g) and exhausted olive cake (80 g) showed that this mixture can replace up to 44% of the cereal grains and protein feeds in the concentrate for lactating goats. No adverse effects on nutrient utilization and rumen fermentation characteristics were observed, as well as an increase in milk yield and unsaturated FA profile of milk [31].

Crude glycerin is another by-product of the biodiesel industry that is recently gaining more research coverage, especially in Asia. Crude glycerol is associated with high energy content ranging from 1.98 to 2.27 Mcal NEL/kg, which is close to that of maize (2.0 Mcal NEL/kg) as studied by Chanjula [32]. In a study

Item	Dietary crude glycerin, %				SEM
	0	5	10	20	
Initial BW, kg	17.08	17.52	16.76	16.76	0.42
Final BW, kg	25.20	27.40	27.44	26.96	1.17
Weight gain (kg)	8.20	10.08	10.88	10.16	1.16
DMI kg/day	0.653	0.674	0.738	0.654	0.02
OM, kg/day	0.611	0.632	0.691	0.611	0.03
CP, kg/day	0.101	0.103	0.113	0.101	0.01
NDF, kg/day	0.288	0.285	0.282	0.255	0.01
ADG, kg/day	0.090	0.112	0.120	0.112	0.01

Table 2.
Effects of different dietary crude glycerin percentage on performance and dry matter intake in goats (adapted from Chanjula, et al., [33]).

(Thai Native × Anglo Nubian) weaned goats were fed on diets containing 0, 5, 10, and 20% of Crude glycerin (87.61% pure), and it was concluded that Crude glycerin can be substituted with corn grain up to 20% of dry matter without any effect on performance **Table 2** [33].

4. Feed additives

Feed additives are one of the most topical and discussed issues in animal nutrition. Feed additives can be defined as animal feed supplements consisting of non-nutritive substances or microorganisms added to feed to improve growth, DM intake and feed conversion efficiency. This improves animal welfare and health, profitability and production performance [34]. Essential oils, organic acids, probiotics, prebiotics, coccidiostats, mycotoxin binders, methane inhibitors, etc. are some of the feed additives currently used.

In the past, antibiotic additives were widely used to modify the microbiota in the digestive tract and improve animal productivity and health. However, the long-term use of these agents has led to the development of drug-resistant microorganisms that pose a threat to consumer health and the environment [35]. Since the ban of antibiotic feed additives in Europe on January 1, 2006 [36], new research areas emerged in the search for better additives. In this current study, recent developments in feed additives used in goat nutrition, including their utilization, are discussed.

4.1 Probiotics and prebiotics

Probiotics are live microbial feed additives, which confer a health benefit when administered to the host animal. The most commonly used microorganisms are bacteria of the genera *Bifidobacterium*, *Lactobacillus* and *Streptococcus*, but yeasts (*Saccharomyces cerevisiae*), bacilli and fungi such as *Aspergillus niger* and *Aspergillus oryzae* are also commonly used in commercial probiotic production [37].

In particular, feeding probiotic bacteria has a lot of positive effects on goat health, such as reducing susceptibility to pathogen infections and their abundance [38], increasing average daily gain [39], improving nutrient digestibility coefficients [40], and increasing feed intake [38]. Supplementation of probiotics in the ration of lactating goats has also shown an increase in milk yield and positive effects on milk composition such as protein content, fat yield and lactose yield [41, 42].

The supplementation of probiotics in the dietary ration is of importance in the mitigation of methane reduction in goats [43]. A study in which common rice was replaced with red yeast rice resulted in a reduction of enteric CH₄ emissions in castrated Boer goats [44]. Chaucheyras-Durand et al., [45], in their review paper explained the mechanism of the ability of yeast cells to reduce enteric CH₄ by diverting hydrogen atoms from methanogens to acetogenic strains of rumen bacteria to increase the production of acetate.

Prebiotic can be defined as non-digestible feed ingredients which act by inducing the growth of one or a limited number of bacteria in the gut flora. Mannan-oligosaccharides, fructooligosaccharides, lactulose, lactitol, malto-oligosaccharides, xylo-oligosaccharides, stachyose, and raffinose are some of the commonly used prebiotics [35].

Despite their well-known significance in non-ruminants, the application of prebiotics in ruminant diets is limited because of the possibility that they are degraded by rumen microorganisms [46]. This could be the reason for the minimal modifying effect observed on rumen fermentation variables when the potential effects

of inulin (0, 2, and 4%) with different ratios of forage to concentrate (i.e., 20:80, 40:60, and 60:40) were examined in an in vitro experiment that lasted 48 hours [47]. However, it is hoped that enhancement in rumen-protective technologies may provide an opportunity for further use of prebiotics in ruminant diets [48, 49]. Therefore, this is another area that requires further research.

The effect of synbiotics in creep feed has a positive effect on the hematological characteristics of kid goats, resulting in improved production performance and fecal value. When synbiotics are added at 0.03% and 0.04% of DM, it has shown a positive influence on FCR, in addition to average daily gains and final body weight. They are also associated with a greater impact on microbial populations and nutrient digestibility, as well as volatile fatty acid content [50]. Mycotoxins and Shiga toxin-producing *Escherichia coli* infections are part of the disease complex for Haemorrhagic Enteritis during the winter months when animals consume moldy feed, and studies have shown that they can be controlled by the use of prebiotics and probiotics [51].

There is currently a growing study of biochar, a charred biomass that resembles charcoal. When added to feed, it is said to improve animal health, increase efficiency of nutrient uptake, and control methane emission [52], and it is said to act like a prebiotic [53]. Biochar has the ability to improve microbial growth in the rumen and is also associated with increasing amino acid absorption [53]. DM intake was increased by 5% and daily weight gain was improved by 27% as a result of biochar supplementation in the diet of goats **Table 3** [54].

Based on this study, there is limited research on feeding different probiotics and prebiotics in goat diets, especially there is a need for more research on prebiotics regarding their application and utilization in different goat breeds and growth stages.

4.2 Plant extracts and essential oils

Essential oils from plants are saturated hydrophobic liquids containing volatile aroma compounds of the plants from which they are extracted. They are a mixture of different compounds and differ from the so-called fixed oils in both their chemical and physical properties [55]. Currently, synthetic feed additives are increasingly used in feeding, and the study of phytogenic feed additives, which like essential oils are of plant origin, has shown the same efficacy [56]. However, it should be mentioned that the use of phytogenic feed additives and supplements is still surrounded by conflicting and contradictory research reports.

As discussed in Section 3.1, plants or plant extracts containing secondary metabolic compounds (i.e., condensed tannins and saponins) and plant oils have

Parameters	Diet type	
	Biochar	No Biochar
DMI, g/d	472	451
Initial BW, kg	12.6	12.3
Final BW, kg	17.1	15.8
Daily gain, (g)	49.4	39.0
FCR	11.0	12.8

Table 3.
Effects of biochar supplementation in the diets on the performance of goats (adapted from Silivong and Preston, [54]).

been studied for their significant effects in ruminant feeding. Some of their values include: Increase in feed intake, digestibility, feed efficiency, reduction in methane emissions [21], and antihelminthic ability [57].

In ruminants, essential oils are said to have inconsistent and dose-dependent effects on rumen microbial fermentation. They are said to inhibit methane production in the rumen, although this effect is associated with a reduction in diet digestibility [55]. However, most experiments related to essential oil studies such as their effect on rumen fermentation are mainly in vitro experiments and few in vivo experiments have been conducted. Therefore, there is a need for the assessment of in-vivo experiments.

In lactating goats, the addition of 17.6 g/kg sunflower oil, flavonoids and essential oils of *Piper betle* in the diet increased milk production and its composition [58]. Plant oils in the ration of lactating goats improved milk fat synthesis and altered the fatty acid composition of milk without negative effects on animal performance [59]. In another study, the supplementation of garlic oil (*Alilum sativum*), Cinnamon oil (*Cinnamomum cassia*), or Ginger oil (*Zingiber officinale*) to the diet of dairy goats had advantageous effects on the milk yield and milk protein. It was also associated with the enhancement of healthy fatty acids i.e. Omega 3 and CLA in the goats' milk [60].

Feeding goats with diets containing essential oils also improves meat quality. *Syzygium aromaticum* buds oil extracts addition to the goats' diet resulted in improved concentrations of beneficial FA in meat, without effects on digestibility and growth performance in Black Bengal goats [61]. Feeding soybean and sunflower oil to Black Bengal goats at a concentration of 45 g/kg of the total diet had no adverse effects on nutrient digestibility and performance. However, an increase in the content of polyunsaturated FA and conjugated linoleic acids was observed in the muscle and adipose tissue of goats [62].

Since the development of anthelmintic resistant populations [63], the use of new drugs such as essential oils has proved so important in maintaining the production of small ruminants. For example, *Eucalyptus staigeriana*, an essential oil from the *Eucalyptus* plant, showed anthelmintic activity against goat gastrointestinal nematodes in vitro and in vivo [64]. Furthermore, extracts of Garlic (*Allium sativum* L.) were found to reduce coccidial load and enhance goat performance [65]. Similar studies that have shown the anthelmintic effect of plant extracts and essential oils are [66, 67].

The studies on essential oils and plant extracts containing secondary metabolite compounds are likely to increase, but there is a need to provide detailed information on their mode of action and their use in goat production.

4.3 Exogenous enzymes

The idea of exogenous enzyme supplementation is not new, intensive research interests on this topic started in the 1990s. Basing on the particular substrate on which the exogenous enzyme activity can perform, leads to their three main groupings i.e. fibrolytic, amylolytic and proteolytic. Bacterial and fungal species plus some yeasts are the main sources of these enzymes. Solid-state and submerged fermentation are the main techniques for enzyme extraction, which have been combined with several other biotechnological aspects [68].

The considerable number of endogenous proteolytic enzymes produced by rumen microbes limit the supplementation of exogenous proteolytic enzymes in ruminants [69]. However, there are currently some major efforts to improve the application and efficacy of proteolytic enzyme supplements in ruminant diets. For example, some studies have shown that there are possibilities of forming a synergistic link between endogenous and exogenous enzymes [69, 70].

The addition of cellulolytic enzyme an exogenous fibrolytic enzyme to the diet of lactating goats improved nutrient digestibility in the diets and thus increased

Parameters	Diet type	
	Control	Cellulase enzyme
DMI, g/d	3.10	3.50
Digestibility (g digested/g ingested)		
Organic matter	0.76	0.80
Dry matter	0.74	0.77
Neutral detergent fiber	0.62	0.68
Ruminal fermentation		
CH ₄ (g/day)	20.10	19.90
pH	6.44	6.62
Acetate (A; mmol/l)	45	47
Propionate (P; mmol/l)	14.20	15.80
Milk yield (kg/day)	3.10	3.40
Milk composition (g/kg)		
Total solids	104	114
Fat	34	40
Protein	29	31
Lactose	41	44

Table 4.
Effect of cellulase enzyme supplementation to the basal diets of goats on feed intake, nutrient digestibility, rumen parameters, milk yield and composition (adapted from Rojo et al., [71]).

milk yield, although no effect on milk constituents was observed [70]. Rojo et al., [71], showed improved milk production and composition in French Alpine goats supplemented with exogenous fibrolytic cellulase at 2 ml/kg DM in the diet. In another study [72], an increased average daily live weight gain of 83.49 g was recorded in Beetal-Dwarf Crossbred Goat fed fibrolytic enzymes supplemented diet compared to the control group with 68.33 g. Song et al., [73], recorded an increase in average daily gains which can be explained by the enhanced Feed Conversion Ratio and nutrient utilization in black Lezhi goats after supplementation of exogenous fibrolytic enzymes in the diet (**Table 4**).

Feeding wheat straw with a concentrate containing exogenous fibrolytic and proteolytic enzymes improved nutrient digestibility in Baladi goats [74]. Yeast and exogenous enzymes improved intake, nutrient digestibility, rumen fermentation, milk yield and milk fat concentration in Nubian goats [75].

Although several researchers have studied supplementation with exogenous enzymes with positive results on growth performance, feed intake, nutrient efficiency, digestibility and other production parameters. There has also been some inconsistency and variability in the various results, so more research is needed on this topic in ruminant nutrition in areas such as mode of action and inclusion rates.

4.4 Organic acids

In recent years, the use of organic acids as substitutes for antibiotic feed additives has steadily increased due to the risks of antibiotic resistance in animals and the effects on human health [76].

Organic acids are known as weak acids used as drinking water additives or feed additives (acidifiers). Potassium, sodium or calcium salts are other forms in which organic acids also exist. The acids have the advantage over the salts that they are usually odorless, less corrosive, more soluble in water and are easier to handle in feed manufacturing because of their solid and less volatile form [76].

The addition of organic acids to animal feeds can increase feed flavor, body weight, FCR, and reduce colonization of pathogens in the gut, while beneficial bacteria such as lactic acid bacteria that support and resist the organism can dominate the gut environment. In silage production, organic acids are used to lower pH to produce high quality silage [77].

Citric acid (CA), which is an organic acid, when added to the ration of dairy goats, increased the rumen pH and thus reduced the possibility of rumen acidosis. It also improved milk yield and milk fat test as shown in **Table 5** [78].

4.5 Antioxidants

Antioxidants are natural or synthetic compounds added to commercial feeds to inhibit lipid peroxidation (polyunsaturated fatty acids) and oxidative rancidity

Item	Diet	
	Ground corn steeped in water	Ground corn steeped in 0.5% citric acid (CA) for 48 h
Intake		
DM (kg/day)	1.04	1.02
Organic matter (kg/day)	0.98	1.00
NDF (kg/day)	0.22	0.22
Starch (kg/day)	0.46	0.47
Metabolizable energy (MJ/da)	11.70	11.80
Milk yield (kg/day)		
Actual	0.48	0.52
4% FCM ²	0.52	0.67
Milk fat		
%	4.54	5.15
g/day	20.6	26.8
Milk protein		
%	4.45	4.37
g/day	20.5	22.1
Milk lactose		
%	4.25	4.24
g/day	20.30	22.1
Milk efficiency	0.46	0.49
Milk efficiency = kg actual/kg DM intake		
2FCM = 4% fat-corrected milk		

Table 5.
Effects of citric acid (CA) treatment of corn grain on feed intake, BW, milk yield and milk composition of dairy goats (adapted from Shen et al., [78]).

during manufacture, processing and transportation, and storage of the feed [79]. Antioxidants are important for maintaining sensory properties and prevent the degradation of critical nutrients such as pigments (oxy- and keto-carotenoids) and vitamins (A, D, E and B group vitamins) in commercial feeds. They also prevent the decrease of energy and protein in the feed [79].

There are natural and synthetic antioxidants. Vitamin E, C are the most abundant and common natural antioxidants. Vitamin A (retinol) and carotenoids are the other examples. Synthetic antioxidants are phenolic and nitrogen compounds. The major synthetic phenolic antioxidant compounds are; tert-butylhydroquinone, propyl galate, butylated hydroxyanisole and butylated hydroxytoluene. Details of the different types and their structures and sources are discussed in detail in this study [80].

Selenium as an antioxidant has become increasingly important in animal nutrition in the context of increasing production, fertility and disease prevention in animals. Although it is a more potent antioxidant compared to vitamins E, C, A and beta-carotene, it is said to be more toxic [81].

Antioxidants are important in animals specifically for the prevention of oxidative stress. Heat stress could be a consequence of the current climate change, which is characterized by a lot of sunshine, which may affect the performance and health of livestock. Vitamin E and selenium supplementation can improve the antioxidant status of sheep, therefore this could reduce some of the negative consequences as a result of heat stress [82].

In goats, supplementation of antioxidants (vitamin C and vitamin E with selenium) was studied on Acid–Base Balance during Heat Stress and had ameliorative effects on physiological parameters, endocrine responses and acid–base status during heat stress [83]. Reduction of endogenous heat by decreasing respiratory thermolysis in dairy goats was also reported with supplementation of organic selenium, in addition to increasing sensible and latent heat release and maintaining rectal temperature within normal limits [84].

Vit E and Se are shown to have improved the quality of milk, making it nutritionally safe for human consumption and increased milk production [85]. Dietary herbs and synthetic antioxidants are also seen in improving feed efficiency and increasing the quality of meat (by increasing lean meat and reduction of body internal fat in the carcass of goats [86]. Antioxidants supplementation improved the meat oxidative stability in Kacang goats [87].

Vit E and Se have been shown to improve the quality of milk, make it nutritionally safe for human consumption, and increase milk production [85]. Dietary herbs and synthetic antioxidants are also seen in improving feed efficiency and increasing meat quality (by increasing lean meat content and reducing internal body fat in goat carcasses) [86]. Supplementation of antioxidants improved oxidative stability of meat in Kacang goats [87].

Ingale et al., [88], in their study explained the role of inclusion of organic acids such as malate and fumarate in the ration in reducing methane emissions from ruminants. The addition of fumaric acid in goat diets decreased methane emissions and resulted in an increase in propionate [89]. Methane mitigation through the use of organic acids is further discussed by Hook et al., [90].

5. Goat dietary composition and feeding aspects

5.1 Practical aspects of feeding protein to goats

The main aim of feeding protein feeds to ruminants is to ensure that they are supplied with a minimum level of dietary crude protein. On the other hand, the

goal is to provide sufficient amounts of rumen degradable protein (RDP) for ideal rumen efficiency and microbial crude protein production by the rumen microorganisms [91].

The major sources of protein for ruminants are natural (or true) protein (consisting of amino acids), and Non-protein Nitrogen (NPN) (consisting of nucleic acids and ammonia). The commonly used sources of natural protein for ruminants worldwide include soybean meal and alfalfa hay, and other leguminous fodders [92]. NPN sources (including: urea and other ammonia compounds) are cheaper compared to true protein sources. A review by Tadele & Amha, [93], reports more on their use and their various sources.

Other, forms of protein utilization in ruminants are: (i) Ruminally Degraded Protein (RDP), which are broken down into different molecules in the rumen. Examples of these molecules are the amino acids, peptides, and ammonia that are utilized by rumen microbes for the production of microbial protein (MP). These MPs provide the bulk of amino acids in the small intestine, which is considered the main source of protein for ruminants. (ii) The other is the Ruminally Undegraded Protein (RUP), which is not broken down by the rumen and passes directly into the intestine [94].

There is a continuous supplementation of goats with proteins especially in goats consuming low-quality forages to maximize their intake and digestion. In most cases, increased intake and digestion leads to improved production such as increased milk, meat, and hair production. In most tropical countries CP can reach up to 12–15% for most grasses during the rainy season, but may drop below 5% during the dry season, necessitating protein supplementation [95]. On the other hand, nutrient requirements are always high during lactation so supplementation with feeds rich in nutrients such as proteins is necessary.

West African Dwarf goats fed *Panicum maximum* basal diet were supplemented with different protein sources: palm kernel cake (18.23% CP), soybean meal (41.46% CP), cottonseed cake (25.05% CP), and brewer's grain. The author found increased dry matter intake, digestibility, weight gain and feed conversion ratio [95]. Arigbede, [95] concluded that the higher CP content of the supplement may have led to the enhanced weight gain and feed utilization. Male Saanen kids fed wheat straw-based diets supplemented with concentrates containing 8.7, 11.7, 14.4 and 17.6% crude protein (CP) based on DM responded positively with increased feed intake and body weight gain [96].

Interestingly, a recent study found that supplementation of RUP in goats reduced the proliferation of parasite *Haemonchus contortus* [97] and positively affected periovulatory ovarian activity in goats [98]. These detailed reviews [99, 100] have already discussed that supplementation with protein-rich foods is essential for increasing host resistance to gastrointestinal nematodes, especially in small ruminants. Feeding rumen-protected tryptophan potentially improved growth performance, N utilization, and fiber growth in Liaoning Cashmere goats [101].

In another study, goats and sheep were fed isoenergetic diets (1.6% BW) with either addition of a high rumen degradable (RDP, 12.5% CP) or non-degradable (RUP, 12.5% CP) protein source or no added protein (control, 5% CP) to a seed juniper. Diets containing RDP and RUP showed an increased voluntary intake [102].

There is still a continuous supplementation of forages with NPN sources especially urea. However, when urea is supplemented in the feed, there is a need to supplement it with an energy source for utilization by rumen microbes as nitrogen is not efficiently utilized by rumen microbes [103]. This can be evidenced in a study where the addition of high N supplements to high energy diets (3.0 McalME/kg DM) enhanced the N balance and microbial protein synthesis in young dairy goats [104].

In a recent study by Lopes et al., [105], goats were fed diets containing buffel-grass hay and different levels of ruminal ammonia nitrogen (N-NH₃) (3.43, 9.95, 17.2, 23.0, and 33.7 mg/dl). Their results, showed that an increase in N-NH₃ concentrations had no effect on PH (6.43), and rumen Volatile fatty acids. Moreover, an increase in N-NH₃ resulted in a higher abundance of the rumen bacteria (Ruminococcaceae). They also recorded a positive linear effect ($P < 0.050$) on nutrient intake, nitrogen excretion and balance. Since excess inclusion of such NPN may cause toxicity, they concluded by recommending 3.43 mg/dl N-NH₃ as the lowest level for maintaining the activity of goat rumen microorganism and 14.5 mg/dl of N-NH₃ for optimization of the rumen microbial community.

A study, which involved the use of slow-release urea (SRU) as a supplement to groundnut straw (*Arachis hypogaea*), improved digestibility and weight gain of male goats and male sheep [106]. There was an increase in milk yield and milk fat and a reduction in blood urea nitrogen content when lactating goats were supplemented with slow-release non-protein nitrogen [107]. Other studies addressing to supplementation of NPN in goat diets include: [108, 109].

Therefore, this study it's shows us the increasing importance, use and need for research on NPN in ruminant nutrition. This can solve the current problems of scarcity of protein-rich legumes or the protein of plant origin and the high costs associated with other alternative protein sources.

Recently, single-cell proteins have been increasingly used in human and animal nutrition. Examples of these used in animal nutrition are: Blue-green algae, bacteria, yeast, fungi, etc. Even though the use of single-cells dates back to ancient times. Their commercial production and application in animal diets are new [110]. Microalgae are said to be rich in nutrients such as proteins, amino acids, pigments, vitamins/minerals, and polyunsaturated fatty acids [111]. There are promising novel feed additives, mainly because of their high protein content [112] and there are some studies that have shown that they are added to livestock feeds. In goat nutrition, the addition of dried algae resulted in an increase in the nutritional quality of goat milk due to changes in the fatty acid profile, as the content of oleic acid, linoleic acid, and linolenic acid increased [113].

However, it is important to note that excessive protein addition to the diet is lost through urine, which is not financially conducive to an efficient livestock production system.

5.2 Practical aspects of concentrate and forage feeding to goats

Diets for ruminants consist mainly of roughage, energy feeds, high-protein feeds, and additives such as vitamin-mineral salt. Among the feeds in the first three groups, roughages are the cheapest. The use of roughages, in ruminant rations at the highest possible level is the rule of thumb for a cheap ration. Therefore, in goat nutrition, correct estimation of the concentrate – roughage ratio is necessary to use for proper utilization of the feed and to minimize the costs [114]. One of the main consequences that can result from feeding high concentrate is subacute ruminal acidosis (SARA) [115]. SARA occurs when the rumen pH level becomes lower than 5.6 for a period greater than three hours per day [116].

Supplementation of forage with concentrates has been done mainly in dairy goats due to the high nutrient requirement during this stage. It has been observed that the nature of the diet does not only affects the amount of milk produced, but also its composition and the quality of the products made from it [9]. In this context, a study [117], was conducted on the effects of different levels of concentrate and supplementary hay feeding on the occurrence of rancid and tart flavors in Norwegian goat milk. It was concluded that increasing concentrate and hay feeding,

had the potential to reduce these off-flavors. In another similar study feeding concentrate resulted in the production of milk with less off-flavors and high in unsaturated fatty acids [118]. This supports the factor mentioned above that the type of the feed influences the composition of milk.

In most studies where concentrates were supplemented with roughage, an increase in production was reported. For example, one study [114] showed that an optimal ratio of 40% roughage to 60% concentrate resulted in increased milk secretion in goats. Feeding ad libitum green forage with a concentrate admixture of 300 gm had a positive effect on protein conversion rate (PCR), FCR and live weight gain of dairy goats. Increased milk yield, positive effect on birth weight and growth of kids were observed [119]. There was also increased milk yield when dairy goats were fed 50 g of concentrate daily in addition to ad libitum roughage [120]. In addition to the live weight gain of the kids in the first month, which could be due to the fact that they get enough nutrient-rich milk from the dams.

It was also found that feeding green grass (roughage) alone did not meet the appetite and nutritional requirements of Black Bengal goats [121]. Gradual increase in concentrate content in goat diet also resulted in gradual increase in live weight, nitrogen balance, carcass yield and net gain [121]. This undoubtedly explains the benefit of concentrate addition in meeting nutritional requirements.

Nevertheless, a study by Saijpal & Saini, [122], justifies the statement that roughage feeding can only meet the maintenance and part of the growth requirements of ruminants. In this study, [122] concentrate supplementation showed increased digestibilities of OM, CP, NDF, and total carbohydrates, and this explains the higher body weight gain in the Beetal kids. Tadesse et al., [123], in their study showed an increase in goat body weight gain upon concentrate supplementation.

Creep feeding is the supplementing of kids with a special feed designed to meet their nutritional needs. In most cases, this is either creep grazing or grazing with high quality, nutritious forage or concentrate supplements. A study where lactating kid goats were supplemented with creep feed showed improved rumen morphology where muscle layer thickness and rumen wall thickness were greater in the creep feed supplemented treatment group [124].

Increasing environmental concerns have led to the need to investigate the effects of concentrate supplementation on methane emissions. Although feeding grass and legumes showed lower performance in goats, there was a reduction in methane emissions [125]. In this context, the addition of concentrates may lead to higher emission of another environmentally unfriendly gas, namely ammonia. This is the case because most concentrates have a high protein content and they are rapidly degraded in the rumen of goats, releasing ammonia [126]. To solve such cases, more research is currently being done to find methods that can reduce ammonia and methane production in the rumen. The application of bioactive phytochemicals found in many different plant varieties is one of the identified potential mitigation methods.

Based on this study, the differences between feed ingredients in different continents, the wide variability in properties and their interaction with each other, and the effects on different animal groups automatically indicate that research on this topic will continue.

5.3 Practical aspects of feeding fats and oils to goats

The addition of fats in the feed is reported to increase the energy density of the feed [15] and the feed utilization [127] in goats. It improves palatability and reduces dustiness of the feed [116]. However, the addition of high levels of fat in the feed, especially at concentrations above 6–7% of the dietary DM, can reduce digestion DM especially of fiber, as described in [128].

Feeding soybean or flaxseed oils 20 mL/day to lactating Anglo-Nubian goats increased total VFA, propionate and blood glucose. There was also significant feed utilization, which may have resulted in increased milk production [127]. Oil supplementation has been reported to affect milk composition, especially increasing the concentration of fatty acids [129]. The study by Kholif et al., [127]] showed an increase in unsaturated fatty acids (FA) and conjugated linoleic acid (CLA) in milk, but a decrease in saturated fatty acids. An increase in CLA in goat milk was also previously found by Mir et al., [130], when goats were supplemented with canola oil. There are also many recent studies showing similar results on the effect of FA, such as [131] and [132]. The alteration of the milk fatty acid content is because when ruminants are fed with lipid sources, they alter the fatty acid profile of the lipid which enters the intestine of the rumen [133].

However, enrichment of essential fatty acids is also seen in other goat products such as meat. One study showed that the addition of linseed oil to goat feed enriched goat meat with essential fatty acids (i.e. n-3 FA) [134]. Other studies such as [135, 136] showed improvement in meat characteristics of goats by adding oil in the feed.

Another important factor related to fats is their ability to reduce methane emissions depending on the amount, a form of fat and fat source for supplementation [137]. The effects of fat supplementation on methane production may be due to its ability to inhibit the growth of methanogens and the number of protozoa. In addition to reducing rumen internal fermentation of organic matter and hydrogenation of unsaturated fatty acids (which act as an alternative H₂ sink) in the rumen [128].

Dietary supplementation with a mixture of 80% rapeseed oil and 20% palm oil altered VFAs in the rumen and reduced the acetate: propionate ratio and methane [138]. Methane reduction after oil supplementation was also observed in studies by (Martin et al., [139] and Puchala et al., [140]). It seems that proper supplementation of fats and oils is a promising technology to consistently mitigate CH₄ without affecting production as seen with our discussions. However, fat supplementation is associated with high costs which could not be economical for livestock producers.

6. Conclusion

Within our scope of the study, goat feed resources, feed additives, and the different dietary aspects are examined. Summarizing information on the effect of feeding on the intake, digestibility, utilization, health and performance. This updates our knowledge of these developments in the field of animal nutrition. This study has shown us the advances in animal nutrition that are being made in terms of financial criteria, sustainability and product quality. We have seen the importance of these advances in goat nutrition in terms of environmental protection, such as the reduction of methane emissions. The importance of some dietary ingredients (such as essential oils and plant extracts, probiotics, prebiotics and other additives) was highlighted and their use is likely to increase, but there is a need for more research on their mode of action and standard inclusion rates.

Abbreviations

DM	Dry Matter
Mcal	Megacalorie
NEL	Net Energy for lactation
CH ₄	Methane

N	Nitrogen
FA	Fatty acid
CLA	Conjugated Linoleic Acid
OM	Organic Matter
CP	Crude Protein
NDF	Neutral Detergent fiber
FCR	Feed Conversion Ratio
VFA	Volatile Fatty Acid

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