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Quality Enhancement in Forage Crops of Cereals and Legumes

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

This article focus on quality improvement in forage crops, specifically grasses, cereals, and legumes. As milk and many other by-products obtained from dairy farms, poultry, etc are getting into demand, high-quality forage for livestock production is well recognized, and efforts to improve forage quality can have significant economic and environmental benefits. And an overview of current strategies for quality improvement, including breeding and genetic selection, management practices, and how these practices affect the quality of forage crops such as silica, lignin, and other phenolic components. Use of different breeding methods more over like synthetic cultivars, recurrent selection, etc. the use of biotechnology tools such as RNAi interference, tissue culture, and marker-assisted selection in the particular crop that has been developed for increasing the nutritional value, proteins that present in forage crops, and to decrease the harmful chemicals. Additionally, the paper discusses the challenges associated with quality improvement in forage crops and potential solutions. And about different types of grasses used for different types of cattle as supplements. Limitations that cause obstruction to improving the quality of forage crops.

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digestibility and how to increase the quality and protein content in milk and cattle. And nutrition that needs to be present in prescribed quantities in forage crops. Overall, this paper highlights the need for continued research and innovation in the field of forage crop quality improvement to support sustainable agriculture and meet the increasing demand for high-quality livestock feed.

Keywords: Factors affecting; limitations; digestibility; nutritional value.

1. INTRODUCTION

Forage crops are the plants or products of dry fodder used to feed ruminants for milk, dairy products, and meat production [1]. However, the area under forage agriculture in India was 13.8 million hectares in 2019, whereas the total area under forage cultivation worldwide was 1.11 billion hectares in 2020, according to the most recent information available from the Food and Agriculture Organization (FAO) of the United Nations. It's crucial to remember that these numbers might alter over time depending on changes in farming techniques, the weather, and other variables. Forage quality has a wide range of definitions. Agronomy experts and animal science researchers have recently learned to rely on ruminant animals' biological responses to make accurate assessments of the quality of fodder. High-grade forage is described to be leafy, fine-stemmed, green, sweet-smelling, rich in amino acids, low in fiber, and delicious Moore, 1980. Forage crops are a key source of feed for livestock; hence, forage crop, quality enhancement is important for the livestock business Moore, 1980. The health of the cattle that consume forage crops is intimately correlated with the quality of those crops. Forage crops were very recently domesticated, with major landrace and quality improvement in forage breeding beginning in the early 20th century [2]. Numerous research studies have looked at various methods, such as choosing high-quality plant varieties, applying fertilizer, and using growth regulators, to enhance the quality of fodder crops. Grasses (Poaceae), herbaceous legumes, or fodder cereals are used as forage crops (Fabaceae). Some tree legumes, like River tamarind (*Leucaena leucocephala*) and mulga (*Acacia aneura*), are also cultivated in desert areas and sward [3]. The predominant grasses in temperate regions include orchard grass (*Dactylis spp),* bent grass (*Agrostis spp*), fescue (*Festuca spp*), ryegrass (*Lolium spp*), and hybrids of this date back to the 1970s. Cereals are inexpensive and produce a lot of dry stuff, hence they are widely employed in livestock nutrition [4]. The variety of cereals cultivated for fodder, such as maize, oats, pearl millet, and rye, has gained relevance in the diets of ruminant animals [5]. The third-most significant cereal crop worldwide, maize (*Zea mays*), is used as food, animal feed, and forage. In contrast to sorghum or other fodder, feeding maize at any stage of growth is harmless and poses no risk from hydrocyanic or oxalic acid [6]. Oats (*Avena sativa L.*) have distinct benefits over other fodder species due to their high production potential, nutritional value, and great ability for regeneration, especially during the first few months of winter [7]. In the lower Midwest countries pastures with a combination of annual ryegrass (*Lolium multiflorum Lam*) and cereal rye (*Secale cereale L)* have become popular for grazing in the late winter and early spring[8]. The annual ryegrass and cereal rye pastures offer several alluring qualities. The two forage plants produce 70% of their yearly development while many tree species are either dormant or not experiencing severe environmental stress, which is perhaps the most significant [8-10]. During the low summer months of May to July and in conjunction with other fodder crops during the kharif and summer seasons, pearl millet is a potential crop for the provision of green fodder [11]. During the dry season, when there is a shortage of green fodder and grazing, cattle in marginal production areas are also fed with pearl millet's dry fodder and straw. As a result, it is typically cultivated in locations where the climate, particularly rainfall, temperature, and soil fertility, is too severe for the growth of other cereals [12].

Forage legumes such as alfalfa, clover, and soybean, are high in amino acids, whereas grasses are rich in energy from both structural and non-structural carbohydrates [13]. Because of its excellent nutritional content and productivity, alfalfa is the feed crop that is most often grown worldwide [14]. The fodder crop feed differs or changes depending on the country and soil conditions available. Similar patterns may be seen for pearl millet in Rajasthan, where the crop's straw is a significant source of animal feed[15]. Red clover is a popular feed legume in the United States, and it is often used as a cover crop to improve the soil environment [16].

Certain tropical locations combine tropical legumes, largely from Asia, with grass species, especially from Africa and the Americas, as demonstrated by pasture growth in tropical Queensland, Australia [17]. Have been thoroughly assessed and widely applied in cattle production systems. Forage legumes are ideal for use as roughage in the diet of animals because of their abundance of protein, vitamins, and minerals, whether they are fresh, dried, or stored [18]. They are distinguished as roughage because of their high fiber content (above 18% crude cellulose). In comparison to concentrate, these feeds have a smaller proportion of accessible (digestible) energy per unit weight or volume, and the majority of energy is present as cellulose or hemicellulose [19].

2. FACTORS AFFECTING AND IMPROVING FORAGE QUALITY

Environmental, genetic, and management factors: The quality of forage crops changes according to climate, soil quality, and water availability. Nearly all cool-season forage species are suitable for growing the humid regions, except perhaps for reed canary grass *Phalaris arundinacea L* [20].

Forage crops can achieve a certain percentage of their potential productivity in a given area depending on factors like temperature and rainfall, but the primary force that directly determines how much can be produced is solar radiation through photosynthesis[21]. Legume forage plants seek to reduce light penetration through the canopy by displaying their leaf area more horizontally than grasses. Similar to this, the leaf area index (LAI), which measures the number of leaf blades per unit area of the soil surface, is lower for legumes around 4-5 than for grasses about 6–8 and is necessary to maximum radiation interception [22]. Because of this, it is essential for the management of legume-grass combinations that the legume does not shadow the grass, even though the quality would be greater. Plants grow better forage when they are in the shadow [23]. Although this is not always true [21].

According to research conducted by Vough and Marten 1971, forage quality is often enhanced by water stress, while heat stress has little impact on it. According to Pembleton alfalfa grown under water stress had greater quality (IVDMD) than alfalfa grown in normal water circumstances, and better quality under stress was brought about by a delay in development [24]. According to a study by Reid, the level of oxalate in (*Atriplex halimus*) plants can be affected by soil moisture levels [25]. The research suggests that high soil moisture can lead to alterations in the oxalate level in these plants. One of the most important inputs for the production of crops is water. Not only does it directly affect crop performance, but it also indirectly does so by affecting the availability of nutrients, the timing of cultural activities, and other variables. With no irrigation, forage sorghum yields varied from 38.3 t per ha to 88.4 t per ha with 56 mm of irrigation [26]. According to Abdel, splitting the same amount of irrigation water into more frequent irrigation resulted in a greater benefit [27]. The absorption of N, P, and K as well as the production of dry matter were enhanced when three to four irrigations were applied to barley throughout the active tillering, flag leaf, and milk phases [28]. Soybean produced the driest matter when irrigated with a ratio of 0.6 IW: CPE [29]. The yields of grains, fodder, and straw are influenced by genomic and non-genetic factors, which vary between and within crop species. Crop varieties with higher grain and feed yields, as well as better straw quality, may be chosen or bred. According to research, wheat crop residue quality varies [30]. Rice,[31] Barley,[32] Oats,[33] Finger millet,[34] Sorghum,[35] and Maize,[36]. The proportion of variation in grain and fodder production, as well as straw digestibility that is attributable to genetic factors versus non-genetic components such as environmental conditions, crop management practices, and after-harvest methods, can vary depending on the crop species and the specific genotype within a given crop species[24].

Application of N up to 120 kg per ha resulted in higher levels of dry matter, CP, and green forage while lowering NDF levels [37,38]. As per the research conducted by Patel, the impact of phosphorus or potassium on the production and quality of fodder is not as significant as that of nitrogen. The study shows that the application of P_2O_5 did not affect the protein content or yield, indicating that the production and quality of fodder are not greatly influenced by the application of phosphorus [39]. Crude fiber decreased with increased N, while treatment of P had little effect [40]. Temperate forage legumes have also seen similar rates of genetic improvement as ryegrass. Research indicates that breeding advancements in yield and quality attributes for these legumes have also been estimated to be around 3.8 and 4.0% per WSC and annual dry matter yield maximized during that time period, respectively. These rates of improvement have been observed since the early 20th century [41,42].

According to research on various cropping systems, drought-tolerant crops like forage sorghums or pearl millet should be mono cropped during dry years as they are drought-tolerant varieties [43]. According to statistics on green forage yields, barley was the plant that tolerated soil salinity the best, followed by oats, sorghum, pearl millet, Egyptian clover, and maize [44]. Salinity reduced seed germination and early seedling development in sorghum. Pre-treatments with CaCl2 and ZnSO4 also boosted sorghum sowing rate and percentage [45]. Oats can withstand wet circumstances better than the majority of other cereals forage [46]. The quality of oats can be increased by inducing the water stress conditions and use of inorganic fertilizers than organic. the use of an N:P ratio of 112:45 with manure increases the quality of forage oats(*Avena sativa*). Enhancing the nutritional value of fodder crops requires certain agronomic and breeding techniques, some of which are mentioned in Table 1.

Limitations: The crop protein content, amino acid composition, and fiber content all affect how nutritious they are. There is genetic heterogeneity in the protein content and acid profile of cereals and legumes used as feed crops, according to several studies having limited genetic diversity, it is difficult for selecting desirable traits [52]. While being of excellent quality, alfalfa protein is not well used [20]. The rapid breakdown of soluble crude protein in alfalfa can lead to a disadvantage in terms of its quality, as it may result in the wastage of high-quality protein in the rumen. Furthermore, the breakdown of alfalfa amino acid can cause an increase in the solidity of the rumen fluid, which can put animals at risk of pasture bloat [53]. Another important aspect that has an impact on the quality of cereal and legume fodder crops is the environment. The nutritional value of various crops can be impacted by environmental conditions including temperature, light, and water availability. High temperatures, for instance, can lower the protein level of grains and legumes, and environmental factors that the forage crop are the same with every crop [54]. The quality of cereal and legume feed crops can also be impacted by management techniques, including fertilization, irrigation, and harvesting. While nitrogen fertilization can raise these crop protein content, overusing nitrogen can lower or increase the quality of their fodder crops [54]. The genetic diversity in maize is limited because of the narrow genetic base of commercial maize varieties. This limits the potential to improve quality traits in forage maize and reduces the quality traits, such as digestibility, which can lead to a reduction in yield and other agronomic traits [55]. Environmental factors such as Drought stress can lead to reduced yields and lower-quality forage maize and pearl millet [56]. Improper harvesting can result in increased levels of lignin and reduced digestibility [57]. While in pearl millet poor storage, conditions can result in mold and spoilage, leading to reduced quality forage [58]. Forage oats contain anti-nutritional factors, such as phytate, which can reduce the bioavailability of minerals, such as iron and zinc These factors can also have an impact on the digestibility of forage oats, reducing their nutritional value [59]. In rye such as ergot alkaloids, which can be toxic to livestock [60]. Pest and disease attack is common in forage clover. Common pests include clover root weevils, which can reduce yield and quality, and aphids, which can transmit viruses and reduce plant growth [61].

Breeding Methods for quality improvement of forage crop: Forage breeders must overcome obstacles in breeding fodder crops, like inherited and polymorphic variability, polyploid nature, and polygenic regulation of agronomic and nutritional qualities [62]. Traditional breeding methods have been successful in improving forage crops, but they are time-consuming [63]. Before producing a synthetic cultivar with a variable number of parents, some type of recurrent selection technique is frequently made use of because many forage species are perennial plants [64] believe that groups of half-sibling families chosen under space-planted and sward conditions will be important for Phalaris to make up recurrent selection. Breeding white clover and alfalfa mostly uses phenotype recurrent selection [65]. This has been accomplished using both traditional breeding methods and genetic engineering, in which fodder crops have had genes linked with enhanced nutritional quality put into them [66].

Future breeding will make use of the chances offered by new technology to accurately examine and alter genotype and phenotype. Using DNA profiling and marker-assisted selection, more focused breeding plans may be created for a larger variety of qualities. The raising of fodder crop nutritional quality is one area that has drawn a lot of interest. Forage crops with high quantities of protein, fiber, and energy have been the focus of research since these nutrients are crucial for the growth and well-being of cattle [67].

Breeding fodder crops to be more precisely adapted to animal demands is a difficult task. It found that advances in NIR near infrared reflectance technology enable breeders to assess a variety of feed quality criteria more quickly, particularly those related to the number and quality of animals [68].

In the majority of our breeding fodder crops, synthetic cultivars have been the primary breeding product. These only sparingly employ the heterosis that emerges from broad crossings across several gene pools [69]. A better-regulated application of hybrids might lead to major gains in many forages. This tactic is significantly affecting the rates of maize breeding advancement [70]. Some perennial fodder plants, such as Bermuda grass, have had their heterosis taken advantage of successfully by vegetative multiplication [71]. According to Dudley and Lambert, 1992 maize grain has undergone 90 cycles of selection for either high or low CP concentration, as well as high or low oil concentration, resulting in consistent progress over time [72]. Plant growth-promoting rhizobacteria (PGPR) improves plant growth and yield Panchagavya, which contains macro and micronutrients, growth-regulating chemicals, and useful microorganisms, might help provide appropriate plant nutrients, providing proper plant nutrients, hence boosting fodder quality and production [73]. Harrington, 1952 outlined certain procedures for the artificial hybridization of oats. Oat crosses can be developed outdoors, indoors, or in a greenhouse. Excellent plants to form crosses can be found in conditions that are ideal for plant development and growth. Although growth chamber crosses can be performed at any time, the majority of greenhouse crosses take place during the winter when it is simple to maintain the cooler temperatures needed for the best outcomes. Change the photoperiod and make the light more intense, specifically during the cloudy and brief winter days, when additional light is needed. Excellent outcomes have been attained in the greenhouse at Urbana, Illinois, using metal halide lighting and a 13-hour photoperiod [74]. According to Kumar *et al.,* 2012 the pedigree system has been especially effective for rust resistance in oat breeding [11]. By crossing the pearl millet x Napier hybrid, the dry matter potential of both plants can be combined. To create the inter-specific hybrid commercially, CMS pearl millet and Napier pollinators are planted in a 1:1 ratio [75]. Pandey *et al.,* 2019 examined 30 hybrids for the number

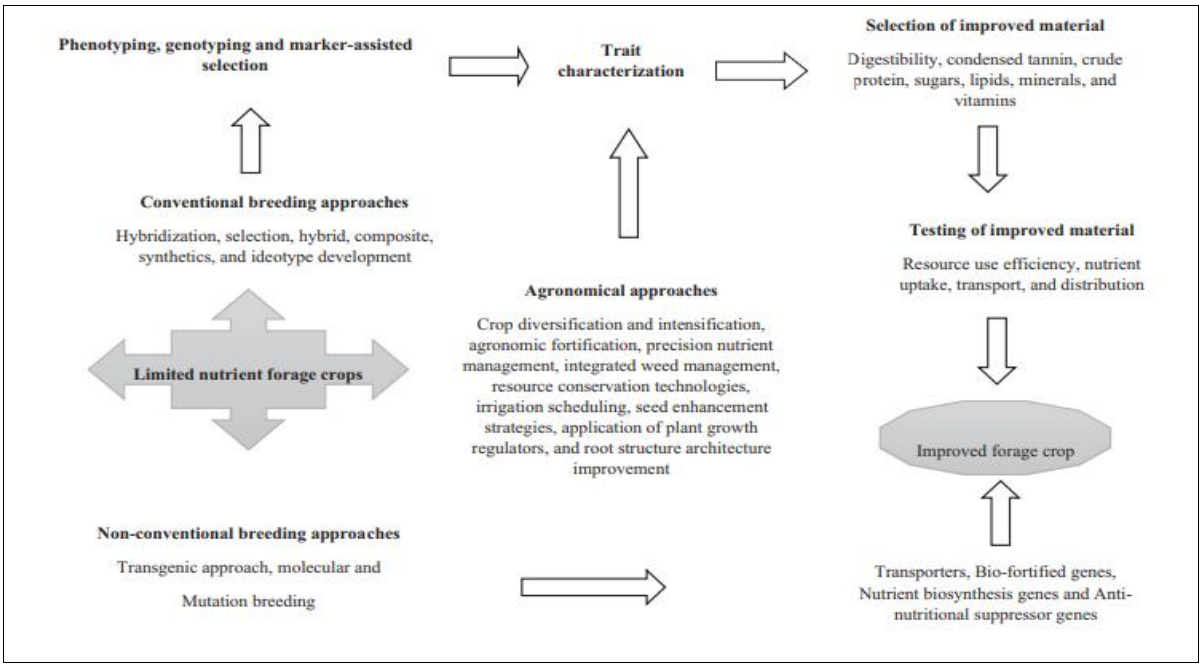

Fig. 1. Represents a blend of agronomic, conventional, and modern breeding methods to increase the nutrient content of fodder crops [76]

Table 1. Represents the soil and agronomic methods applied to enhance the nutritional value of fodder

Forage crop	Mineral nutrients status	Strategy used	Mechanism of action	References
White clover	Increased mineral uptake (shoots: Mg and Cu; roots: Ca, Mg, and Fe)	administration of sodium nitroprusside, a NO donor, exogenously	Increase the activity of the plasma membrane enzymes V-H+- ATPase and H+- ATPase in the root and shoot.	[47].
Fodder maize	enhanced se (36%), complete basic amino acids (40%), CP (47%), crude fibres (10%), and extract without nitrogen (10%).	Foliar Se supplementation	The osmoprotectants that se accumulates help to keep the turgor pressure constant. activate the antioxidant defense system to control physiological and biochemical processes.	[48].
Fodder maize, sorghum	a lower NDF and a higher net energy	Plant population decline and N fertilizer application	increase the effectiveness of resource use and reduce energy waste.	[49].
White sweet clover	higher amounts of N and P in the root zone and stem	the bacterium Rh meliloti and Arbuscular Mycorrhizal Fungi (AMF) inoculation	Inoculants increase physiological nitrogen fixing and phosphorus accessibility in a reciprocal manner.	[50].
Cereal Rye + Corn	decreased NDF (10%), elevated observed N recovery (84%), enhanced CP (29%), and decreased net lactation energy (10%).	pumping soil with liquid dairy cow excrement.	Enhance soil capacity to hold water and N and P restoration.	[51].

Table 2. Nutrients and quality parameters available in oats[104]

Crop	Phenol (mg/g)	Protein (mg/g)	Phytic (mg/g)	Beta-glucan (mg/g)	Zinc (mg/100g)	Iron (mg/100g)
Oats (*Avena sativa*)	11.90-31.3	138.70-160.50	3.70-8.00	31.00-53.50	4.96-6.50	2.48-4.89

of leaves per plant, their length, breadth, and relation to their stems, as well as their green fodder production by crossing three pearl millet genotypes and ten Napier genotypes. All the characters exhibited a lot of variety. Pearl millet (IP 6426) and Napier (FD 439), which were both effective general combiners, were outperformed by IP 6426 X FD 469 as a hybrid for green fodder yield and leafiness [76]. Although some rye species have had success with repeated phenotypic selection on spaced plants [64,69]. Improved agronomic management techniques and plant breeding techniques, both traditional and innovative techniques, can produce the required forage qualities (Fig. 1)[76].

Biotechnology tools for forage crop quality improvement: Turf and forage grasses are a broad collection of plants that exhibit clump-forming or sod-like growth patterns, annual or perennial life cycles, and cool- or warm-season growth preferences [77]. In North America, breeding for better fodder and turf grasses began seriously in the 1930s and 1940s, particularly with the initiatives of L. C. Newell in Nebraska and G. W. Burton in Georgia. Numerous forage types of grass coexist with other plant species. Grasses differ substantially in terms of chromosome count, reproductive deportment, incompatibility relationships, and practice of pollination [78]. Cultivars have been produced with verified improvements in attributes including fodder quality [60] and seedling strength [79].

The development of a callus culture technique the ability to rejuvenate plants cornerstone of genetic engineering in monoclonal grass species at the level of cells. To create a tissue culture system, the original explant must first be stimulated to generate calluses. Different explants, such as fescues have produced seeds and mature or undeveloped embryos, and ryegrass, have been used to start regenerable callus cultures in grasses [80-82]. leaf bases in orchard grass[83], and immature bud and shoot apices in pearl millet *Pennisetum Americanum*[84], and Scutch grass *Cynodon dactylon*[85]. Advancements in genomics research have led to the development of innovative tools like functional molecular markers, and a deeper understanding of inheritance patterns that can significantly enhance the accuracy and efficacy of crop improvement in alfalfa. This progress in genomics research can pave the way for better crop management and increase agricultural productivity. Pearl millet uses DNA markers to generate genetic linkage maps. Important characteristics like disease adaptability, insect resistance, and drought resistance, have DNA markers associated with them [86]. Marker-assisted selection (MAS) is a novel method that effectively raises the quality of fodder Hash *et al*., 2003 used Marker aided selection (MAS) and quantitative traits loci (QTL) mapping to increase stover yield, increase forage disease resistance, and figure out the nutritional value of different pearl millet residue portions for ruminants[87]. Only two forage species, perennial ryegrass [88], and white clover, have seen SNP - single nucleotide polymorphism - markers described for them. Based on single base pair alterations in a DNA order, these biological indicators [89]. Disease resistance and water-soluble carbohydrate content were discovered to be markers for traits in perennial ryegrass [90,14]. SNP markers are certain to be due to their enormous frequency and the swift technological advancements for high-throughput generation and identification, they will be crucial in the advancement of marker-assisted fodder crop breeding in the future. Another biotechnological tool for forage crop improvement is RNA interference (RNAi). RNAi is a process that enables the downregulation of specific genes by inducing the degradation of the corresponding messenger RNA (mRNA). RNAi has been used to reduce the expression of lignin biosynthesis genes in forage crops, leading to increased digestibility and improved nutritional quality [91]. Transgenic rye expressing the gene for rumen-stable amylase has been developed to increase the starch digestibility of rye silage [92].

3. NUTRITIONAL VALUE

Nutritional value in forage crops is not only beneficial to animals, but it also helps in overcoming pressure conditions during the grazing of animals. Every fodder crop has enough cellulose, quartz, and other phenolic substances to cut down on ruminant consumption [93]. These substances could serve as a general defensive strategy for plants to grow or multiply when challenged with grazing pressure [94].

One of a forage's key traits is its ability to nutritional value is digestibility. It serves as a measure of the ruminant's energy availability. It also has an impact on how soon forage particles exit the rumen since feed particles need to do so after being sufficiently broken down [95,96]. Legumes are a substantial source of protein and can make up for cereal deficiency in that regard [97]. Companion planting which involves growing crop mixtures next to legumes can boost the quantity of forage protein in diets. The forage crops' ability to serve as a source of feed for animals depends on maintaining their quality. Research has focused on developing techniques of long-term fodder crop quality preservation, such as ensiling and drying [98]. Researchers have also looked at the nutritional potential of conserved fodder crops, for instance, using inoculants that contain bacteria that hasten fermentation [99]. When fed more sugar ryegrass to graze on, Charolais steers devoured 20% more feed and put on 25% more live weight [100]. Maize often gets far less attention than it merits despite having more forage quality characteristics, such as being highly palatable, having high nutritional contents, lasting a longer time in storage, and being easily digestible [101]. inferior-quality chemicals like hydrocyanic acid (HCN) and oxalate, it has superior quality compared to Because it doesn't contain any sorghum and pearl millet [102]. Crude protein (CP) concentration is the most important factor compared to other factors which influence a crop's quality for use to be fodder [103,45]. According to research, oats have a higher crude protein concentration in the first cut (12.10–15.63%) than in the second cut (9.63–13.57%) Table 2[104].

Forage maize has a crude protein content of 7.5-8.5%, a crude fiber content of 32-34%, and a typical fat content of 1-2.5%. Approximately 32–34% of the material is dry, 7-9% is ash, and 50–50% is a nitrogen-free extract [105].

3.1 Digestibility

Studying the improvement of fodder crop digestibility has also been a priority. A feed crop's ability to be more successfully used by animals is encouraged by its higher digestibility, which improves animal performance [106]. A researcher reported that increasing the cell wall digestibility of fodder crop varieties and implementing relevant agronomic strategies have been effective in improving digestibility. Additionally, in vitro, the incubation of fodder in rumen fluid is a reliable method for predicting digestibility [107].

The percent of each component that has vanished in the animal digestive tract serves as a standard measurement of the digestibility of all forage components, including dry matter, organic matter, and cell walls. Indigestibility can alternatively be thought of as gm.kg^{-1} of metabolic weight, although it is often expressed as kg DM per animal and per day (live weight 0.75)[108]. According to Barrière,2003, the digestibility of various constituents of forage (such as dry matter, organic matter, or cell wall) is commonly calculated as the proportion of each component that is lost in the animal's digestive tract[108]. Indigestibility is typically measured in kilograms of dry matter per animal per day, but it can also be expressed as grams per kilogram of metabolic weight (live weight to the power of 0.75). It is crucial to enhance WSC in many fodder crops, especially grasses because protein digestion and absorption in cattle are strongly connected to power availability (ME) [94].

Marley *et al*.,2017 investigated how fertilization affects the nutritional content of grass-clover swards in one study. According to the results, adding more nitrogen (N) to the swards significantly boosted the amount of crude protein (CP) while simultaneously enhancing digestibility [100]. The Italian ryegrass cultivar "*Tribune*," which, when given as silage, produces 6% more milk, was developed as a result of raising the plant's stem digestibility [109]. Zhang *et.al*, 2020 conducted a second study to examine how growth regulators affect the quality of alfalfa. The scientists found that the addition of gibberellic acid (GA3) increased the height and green color of alfalfa plants, which resulted in a considerably larger content of total digestible nutrients (TDN) and crude protein (CP) [110]. Casler, 2001 reported that during the 20th century, advancements in breeding techniques resulted in an increase of 1.0, 14.7, and 6.5% per generation cycle for ryegrass characteristics related to digestibility, intake, and crude protein, respectively. In ruminants, some types of compounds, such as sugars and organic acids are entirely digested. Whereas lignin, cutin, silica, and tannins are nearly indigestible, proteins are fairly easily digested [111]. Forage-maize digestibility can be significantly increased if this variation is employed in breeding programs. The digestibility of cellulose and hemicellulose varies depending on whether they are encrusted with lignin [107]. Digestibility in forage crops can be calculated using several methods, including in vivo digestibility trials, in vitro techniques, and near-infrared reflectance spectroscopy (NIRS). Here are examples of how to calculate digestibility using two commonly used methods [93].

1. In vivo digestibility trials: In vivo, digestibility trials involve feeding animals a known amount of forage, collecting fecal samples, and analyzing them for nutrient content. The difference between the nutrient intake and the fecal nutrient content is used to calculate the digestibility of the forage. One commonly used formula for digestibility is:

Digestibility (%) = 100 - (fecal nutrient content/forage nutrient intake x 100) [112].

2. In vitro techniques: In vitro, techniques involve using laboratory equipment to simulate the digestive process and estimate nutrient digestibility. The most commonly used in vitro method is the two-stage in vitro digestibility (TIVD) method, which involves incubating the forage with rumen fluid and then with intestinal fluid. The difference between the nutrient content before and after incubation is used to calculate digestibility. One commonly used formula for TIVD digestibility is:

Digestibility (%) = (nutrient content before incubation - nutrient content after incubation) / nutrient content before incubation) x 100 [113].

4. CONCLUSION

In conclusion, the review targeted at enhancing the nutritional quality, and digestibility of forage crops has finally in substantial advancements in the field of forage crop quality enhancement. These initiatives have produced fodder crops that are more nutrient-dense, easily digested, and stable, all of which are advantageous to the livestock sector by using crop plants with less lignin, and silica content through the increase of protein content.

The use of biotic and abiotic factors, breeding methods, and biotechnological tools affects and improves the quality of feed crops. For livestock producers wanting to maximize the quality of their fodder crops to full fill the dietary needs of their animals, the knowledge from the research is invaluable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Halmemies-Beauchet-Filleau A, Rinne M, Lamminen M, Mapato C, Ampapon T, Wanapat M, Vanhatalo A. Alternative and novel feeds for ruminants: nutritive value, product quality and environmental aspects. Animal. 2018;12(s2):s295-s309.
2. Harlan JR. Origins and processes of evolution. Grass Evolution; 1992.
3. Muir JP, Pitman WD, Foster JL. Sustainable, low-input, warm-season, grass–legume grassland mixtures: Mission (nearly) impossible? Grass and Forage Science. 2011;66(3):301-315.
4. Ghanbari-Bonjar A, Lee HC. Intercropped wheat (*Triticum aestivum* L.) and bean (*Vicia faba* L.) as a whole-crop forage: effect of harvest time on forage yield and quality. Grass and Forage Science. 2003;58(1):28-36.
5. Eskandari H, Ghanbari A, Javanmard A. Intercropping of cereals and legumes for forage production. Notulae Scientia Biologicae. 2009;1(1):07-13.
6. Dahmardeh M, Ghanbari A, Syasar B, Ramroudi M. Effect of intercropping maize (*Zea maps* L.) vvith cow pea (*J'igna unguiculata* L.) on green forage yield and quality evaluation. Asian Journal of Plant Sciences. 2009;8(3):235-239.
7. Alipatra A, Kundu CK, Mandal MK, Banerjee H, Bandopadhyay P. Yield and quality improvement in fodder oats (*Avena sativa* L.) through the split application of fertilizer and cutting management. Journal of Crop and Weed. 2013;9(2):193-195.
8. Altom W, Rogers JL, Raun WR, Johnson GV, Taylor SL. Long-term rye-wheat-ryegrass forage yields as affected by rate and date of applied nitrogen. Journal of Production Agriculture. 1996;9(4):510-516.
9. Zhang S, Allen HL, Dougherty PM. Shoot and foliage growth phenology of loblolly pine trees as affected by nitrogen fertilization. Canadian Journal of Forest Research. 1997;27(9):1420-1426.
10. Balandier P, Lacointe A, Le Roux X, Sinoquet H, Cruiziat P, Le Dizès S. SIMWAL: A structural-functional model simulating single walnut tree growth in response to climate and pruning. Annals of Forest Science. 2000;57(5):571-585.
11. Kumar A, Arya RK, Kumar S, Kumar D, Kumar S, Panchta RAVISH. Advances in pearl millet fodder yield and quality improvement through breeding and management practices. Forage Res. 2012; 38(1):1-14.

12. Gulia SK, Wilson JP, Carter J, Singh BP. Progress in grain pearl millet research and market development. Issues in new crops and new uses. 2007;196-203.
13. Humphreys MO. The contribution of conventional plant breeding to forage crop improvement. In Proceedings of the 18th International Grassland Congress. Winnipeg and Saskatoon, Canada. 1997;8-17.
14. Skot L, Humphreys J, Humphreys MO, Thorogood D, Gallagher J, Sanderson R, Armstead IP, Thomas ID. Association of candidate genes with flowering time and water-soluble carbohydrate content in *Lolium perenne* (L.). Genetics. 2007;177:535–547.
15. Kelley TG, Rao PP, Purohit ML. Adoption of improved cultivars of pearl millet in an arid environment: straw yield and quality considerations in western Rajasthan. Experimental Agriculture. 1996;32(2):161-171.
16. Taylor NL. A century of clover breeding developments in the United States. Crop Science. 2008;48(1):1-13.
17. Walker B, Weston EJ. Pasture development in Queensland–a success story. Tropical Grasslands. 1990;24(4):257-268.
18. Vasiljević S, Milić D, Mikić A. Chemical attributes and quality improvement of forage legumes. Biotechnology in Animal Husbandry. 2009;25(5-6-1):493-504.
19. Jonker A, Gruber MY, McCaslin M, Wang Y, Coulman B, McKinnon JJ, Yu P. Nutrient composition and degradation profiles of anthocyanidin-accumulating L c-alfalfa populations. Canadian Journal of Animal Science. 2010;90(3):401-412.
20. Sheaffer CC, Miller DW, Marten GC. Grass dominance and mixture yield and quality in perennial grass-alfalfa mixtures. Journal of Production Agriculture. 1990;3(4):480-485.
21. Allard G, Nelson CJ, Pallardy SG. Shade effects on growth of tall fescue: I. Leaf anatomy and dry matter partitioning. Crop Science. 1991;31(1):163-167.
22. Nelson CJ, Moser LE. Plant factors affecting forage quality. Forage quality, evaluation, and utilization. 1994;115-154.
23. Buxton DR, Casler MD. Environmental and genetic effects on cell wall composition and digestibility. Forage cell wall structure and digestibility. 1993;685-714.
24. Pembleton KG, Volenec JJ, Rawnsley RP, Donaghy DJ. Partitioning of taproot constituents and crown bud development are affected by water deficit in regrowing alfalfa (*Medicago sativa* L.). Crop science. 2010;50(3):989-999.
25. Reid RL, Jung GA. Effects of elements other than nitrogen on the nutritive value of forage. Forage Fertilization. 1974;395-435.
26. Nabati J, Moghadam PR. Effect of irrigation intervals on the yield and morphological characteristics of forage millet, sorghum and corn. Iranian Journal of Field Crop Science. 2010;41(1):179-186.
27. Abdel Magid EA, Mustafa MA, Ayed L. Effects of irrigation interval, urea, and gypsum on N, P and K uptake by forage sorghum on highly saline-sodic clay. Experimental Agriculture; 1982.
28. Wahab K, Singh KN. Effect of irrigation on nutritional uptake and protein content of grain in two types of barley. Indian Journal of Agronomy; 1983.
29. Veeramani A, Palchamy A, Ramasamy S, Rangaraju G. Integrated weed management in soybean (Glycine max) under different moisture regimes and population densities. Indian Journal of Agronomy. 2000;45(4):740-745.
30. Doyle PT, Chanpongsang S, Wales WJ, Pearce GR. Variation in the nutritive value of wheat and rice straw. Ruminant Feeding Systems Utilizing Fibrous Agricultural Residues. IDP, Australia. 1987;75-86.
31. Walli TK, Ørskov ER, Bhargava PK. Rumen degradation of straw 3. Botanical fractions of two rice straw varieties and effects of ammonia treatment. Animal Science. 1988;46(3):347-352.
32. Ramanzin M, Ørskov ER, Tuah AK. Rumen degradation of straw 2. Botanical fractions of straw from two barley cultivars. Animal Science. 1986;43(2):271-278.
33. Shand WJ, Ørskov ER, Morrice LF. Rumen degradation of straw 5. Botanical fractions and degradability of different varieties of oat and wheat straws. Animal Science. 1988;47(3):387-392.
34. Subba Rao A, Prabhu UH, Oosting SJ. Genetic and managemental effects on variability of straw quality from ginermillet (*Eleusine coracana*); 1993.
35. Badve VC, Nisal PR, Joshi AL, Rangnekar DV. Variation in quality of sorghum stover. Feeding of ruminants on fibrous crop residues: Aspects of treatment, feeding, nutrient evaluation; 1993.

36. Harika AS, Sharma DD. Quality and yield differences in maize stover due to varieties and stage of harvesting. In Variation in the Quantity and Quality of Fibrous Crop Residues. Proc. National Seminar held at the BAIF Development Research Foundation. 1994;20-28.
37. Bebawi FF. Forage sorghum production on a witchweed-infested soil in relation to cutting height and nitrogen. Agronomy Journal. 1988;80(3):537-540.
38. Patil FB, Gadekar DA, Bhoite AG. Response of forage sorghum varieties to seed rates and nitrogen. J. Mah. Agric. Univ. 1992;17:150-151.
39. Patel KI, Ahlawat RPS, Trivedi SJ. Effect of nitrogen and phosphorus on nitrogen uptake and protein percentage of forage sorghum. Gujarat Agricultural University Research Journal (India); 1993.
40. Humphreys M, Feuerstein U, Vandewalle M, Baert J. Ryegrasses. Fodder crops and amenity grasses. 2010;211-260.
41. Woodfield DR, Brummer EC. Integrating molecular techniques to maximise the genetic potential of forage legumes. In Molecular Breeding of Forage Crops: Proceedings of the 2nd International Symposium, Molecular Breeding of Forage Crops, Lorne and Hamilton, Victoria, Australia, November 19–24, 2000. Springer Netherlands. 2001;51-65.
42. Ali M, Rawat CR. Production potential of different food fodder cropping systems under dryland conditions of Bundelkand. In Proceedings of the National Seminar on Advances in Forage Agronomy and Future Strategy for Increasing Biomass Production. Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, India. 1986;6-7.
43. Yadav RK, Kumar A. Feasibility of cultivating different forage crops on saline soil. CROP RESEARCH-HISAR. 1997;13:45-50.
44. Ismaeil SM, Khafagi OA, Kishk ET, Sohsah SM. Effect of some seed hardening treatments on germination, growth and yield of Sudan grass grown under saline conditions. The Desert Institute Bulletin (Egypt); 1993.
45. Assefa G, Ledin I. Effect of variety, soil type and fertiliser on the establishment, growth, forage yield, quality and voluntary intake by cattle of oats and vetches cultivated in pure stands and mixtures. Animal Feed Science and Technology. 2001;92(1-2):95-111.
46. Liu SL, Yang RJ, Ma MD, Dan F, Zhao Y, Jiang P, Wang MH. Effects of exogenous NO on the growth, mineral nutrient content, antioxidant system, and ATPase activities of Trifolium repens L. plants under cadmium stress. Acta Physiologiae Plantarum. 2015;37(1):1721.
47. Nawaz F, Naeem M, Ashraf MY, Tahir MN, Zulfiqar B, Salahuddin M, Shabbir RN, Aslam M. Selenium supplementation affects physiological and biochemical processes to improve fodder yield and quality of maize (*Zea mays* L.) under water deficit conditions. Frontiers in Plant Science. 2016;7:1438.
48. Contreras-Govea FE, Marsalis MA, Lauriault LM, Bean BW. Forage sorghum nutritive value: A review. Forage and Grazinglands. 2010;8(1):1-6.
49. Hack CM, Porta M, Schäufele R, Grimoldi AA. Arbuscular mycorrhiza mediated effects on growth, mineral nutrition and biological nitrogen fixation of Melilotus alba Med. in a subtropical grassland soil. Applied Soil Ecology. 2019;134:38-44. DOI:https://doi. org/10.1016/j.apsoil.2018.10.008
50. Binder JM, Karsten HD, Beegle DB, Dell CJ. Manure injection and rye double cropping increased nutrient recovery and forage production. Agronomy Journal. 2020;112(4):2968–2977. DOI:https:// doi.org/10.1002/agj2.20181
51. Gallego-Giraldo L, Shadle G, Shen H, Barros-Rios J, Fresquet Corrales S, Wang H, Dixon RA. Combining enhanced biomass density with reduced lignin level for improved forage quality. Plant Biotechnology Journal. 2016;14(3):895-904.
52. Wang Y, Majak W, McAllister TA. Frothy bloat in ruminants: Cause, occurrence, and mitigation strategies. Animal Feed Science and Technology. 2012;172(1-2):103-114.
53. Kaur G, Asthir B, Bains NS. Modulation of proline metabolism under drought and salt stress conditions in wheat seedlings; 2018.
54. Hou P, Liu Y, Liu W, Liu G, Xie R, Wang K, Li S. How to increase maize production without extra nitrogen input. Resources, Conservation and Recycling. 2020;160:104913.
55. Osman KT, Osman KT. Poorly fertile soils. Management of Soil Problems. 2018;219-254.

56. Hetényi G, Molinari I, Clinton J, Bokelmann G, Bondár I, Crawford WC. AlpArray Working Group. The AlpArray seismic network: A large-scale European experiment to image the Alpine Orogen. Surveys in Geophysics. 2018;39:1009-1033.
57. Divya G, Vani KP, Babu PS, Devi KS. Yield attributes and yield of summer pearl millet as influenced by cultivars and integrated nutrient management. International Journal of Current Microbiology and Applied Sciences. 2017;6(10):1491-1495.
58. Dhaliwal SS, Sandhu AS, Shukla AK, Sharma V, Kumar B, Singh R. Bio-fortification of oats fodder through zinc enrichment to reduce animal malnutrition. J. Agric. Sci. Technol. A. 2020;10:98-108.
59. Zhu Y, Dong K, Liu Z, Wang J, Wei S, Shi Y, Zheng Y. Ergot alkaloids in endophyte-infected grasses are toxic to livestock animals. Toxins. 2016;8(5):144.
60. Asay KH, Dewey DR, Gomm FB, Johnson DA, Carlson JR. Registration of 'Bozoisky-select' Russian wildrye. Crop Science. 1985;25(3):575-576.
61. Vogel KP, Pedersen JF. Breeding systems for cross-pollinated perennial grasses; 1993.
62. Katoch R. Techniques in forage quality analysis. Springer Nature; 2022.
63. Oram RN, Culvenor RA. Phalaris improvement in Australia. New Zealand Journal of Agricultural Research. 1994;37(3):329-339.
64. Gates RN, Hill GM, Burton GW. Response of selected and unselected bahiagrass populations to defoliation. Agronomy Journal. 1999;91(5):787-795.
65. Collard BC, Mackill DJ. Marker-assisted selection: An approach for precision plant breeding in the twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences. 2008;363(1491):557-572.
66. Hanna WW. Improving forage quality by breeding. International Crop Science I. 1993;671-675.
67. Beever DE, Reynolds CK. Forage quality, feeding value and animal performance. In Grassland and Society. Proceedings of the 15th General Meeting of the European Grassland Federation. 1994;48-60.
68. Marshall AH, Collins RP, Humphreys MW, Scullion J. A new emphasis on root traits for perennial grass and legume varieties with environmental and ecological benefits. Food and Energy Security. 2016;5(1):26–39.
69. Burton GW, Mullinix BG. Yield distributions of spaced plants within Pensacola bahiagrass populations developed by recurrent restricted phenotypic selection. Crop Science. 1998;38(2):333-336.
70. Ortiz-Monasterio JI, Palacios-Rojas N, Meng E, Pixley K, Trethowan R, Pena RJ. Enhancing the mineral and vitamin content of wheat and maize through plant breeding. Journal of Cereal Science. 2007;46(3):293-307.
71. Kumar D, Singh M, Kumar S, Meena RK, Kumar R. Fodder quality and nitrate estimation of oats grown under different nutrient management options. Indian Journal of Dairy Science. 2021;74(4).
72. Dudley JW. Ninety generations of selection for oil and protein in maize. Maydica. 1992;37:81-87.
73. Brown PD, McKenzie RIH, Mikaelsen K. Agronomic, genetic, and cytologic evaluation of a vigorous new semidwarf oat 1. Crop Science. 1980;20(3):303-306.
74. Harrington JB. Cereal breeding procedures. FAO Develop. Paper 28. FAO of UN, Rome; 1952.
75. Sukanya DH, Ramamurthy V, Ramesh CR. Forage Res. 2001;27:115-118.
76. Pandey AK, Pusuluri M, Bhat BV. Down-regulation of CYP79A1 gene through antisense approach reduced the cyanogenic glycoside dhurrin in [*Sorghum bicolor* L.) Moench.] to improve fodder quality. Frontiers in Nutrition. 2019;6:122.
77. Wang ZY, Ge Y. Recent advances in genetic transformation of forage and turf grasses. *In Vitro* Cellular & Developmental Biology-Plant. 2006;42:1-18.
78. Vogel KP, Haskins FA, Gorz HJ, Anderson BA, Ward JK. Registration of' Trailblazer's witchgrass; 1991.
79. Lowe KW, Conger BV. Root and shoot formation from callus cultures of tall fescue 1. Crop Science. 1979;19(3):397-400.
80. Dale PJ. Embryoids from cultured immature embryos of *Lolium multiflorum*. Zeitschrift für Pflanzenphysiologie. 1980;100(1):73-77.
81. Torello WA, Symington AG. Regeneration from perennial ryegrass callus tissue. HortScience. 1984;19(1):56-57.
82. Hanning GE, Conger BV. Factors influencing somatic embryogenesis from

cultured leaf segments of Dactylis glomerata. Journal of Plant Physiology. 1986;123(1):23-29.

83. Vasil V, Vasil IK. Somatic embryogenesis and plant regeneration from suspension cultures of pearl millet (*Pennisetum americanum*). Annals of Botany. 1981;47(5):669-678.
84. Artunduaga IR, Taliaferro CM, Johnson BL. Effects of auxin concentration on induction and growth of embryogenic callus from young inflorescence explants of Old World bluestem (Bothriochloa spp.) and bermuda (Cynodon spp.) grasses. Plant cell, tissue and organ culture. 1988;12:13-19.
85. Zhang Y, Mian JR. Functional genomics in forage and turf-present status and future prospects. African Journal of Biotechnology. 2003;2(12):521-527.
86. Boora KS, Boora P, Urvashi, Sonika. In: Forage symposium on “Emerging trends in Forage research and livestock production. Feb.16-17,2009 at CAZRI, RRS, Jaisalmer (Rajasthan) India. 2009;17-28.
87. Hash CT, Raj AB, Lindup S, Sharma A, Beniwal CR, Folkertsma RT, Blümmel M. Opportunities for marker-assisted selection (MAS) to improve the feed quality of crop residues in pearl millet and sorghum. Field Crops Research. 2003;84(1-2):79-88.
88. Cogan NO, Ponting RC, Vecchies AC, Drayton MC, George J, Dracatos PM, Forster JW. Gene-associated single nucleotide polymorphism discovery in perennial ryegrass (*Lolium perenne* L.). Molecular Genetics and Genomics. 2006;276(2):101-112.
89. Cogan N. OI, Drayton MC, Ponting RC, Vecchies AC, Bannan R, Sawbridge TI, Forster JW. Validation of in silico-predicted genic SNPs in white clover (*Trifolium repens* L.), an outbreeding allopolyploid species. Molecular Genetics and Genomics. 2007;277(4):413-425.
90. Dracatos PM, Cogan NOI, Dobrowolski MP, Sawbridge TI, Spangenberg GC, Smith KF, Forster JW. Discovery and genetic mapping of single nucleotide polymorphisms in candidate genes for pathogen defence response in perennial ryegrass (*Lolium perenne* L.). Theoretical and Applied Genetics. 2008;117(2):203-219.
91. Gallego-Giraldo L, Shadle G, Shen H, Barros-Rios J, Fresquet Corrales S, Wang H, Dixon RA. Combining enhanced biomass density with reduced lignin level for improved forage quality. Plant Biotechnology Journal. 2016;14(3):895-904.
92. Selinger LB, Forsberg CW, Cheng KJ. The rumen: A unique source of enzymes for enhancing livestock production. Anaerobe. 1996;2(5):263-284.
93. Van Soest PJ. Nutritional ecology of the ruminant. Cornell University Press; 2018.
94. McCarthy Jr RD, Klusmeyer TH, Vicini JL, Clark JH, Nelson DR. Effects of source of protein and carbohydrate on ruminal fermentation and passage of nutrients to the small intestine of lactating cows. Journal of Dairy Science. 1989;72(8):2002-2016.
95. Poppi DP, Hendricksen RE, Minson DJ. The relative resistance to escape of leaf and stem particles from the rumen of cattle and sheep. The Journal of Agricultural Science. 1985;105(1):9-14.
96. Waghorn GC, Shelton ID, Thomas VJ. Particle breakdown and rumen digestion of fresh ryegrass (*Lolium perenne* L.) and lucerne (*Medicago sativa* L.) fed to cows during a restricted feeding period. British Journal of Nutrition. 1989;61(2):409-423.
97. Gebrehiwot L, McGraw RL, Assefa G. Forage yield and quality profile of three annual legumes in the tropical highlands of Ethiopia. Tropical agriculture; 1996.
98. Barker AR, Muck RE, Mertens DR. Preservation and quality of forage crops. In Forage Quality, Nutrition and Feeding. John Wiley and Sons, Ltd. 2019;563-582.
99. Thomas SL, Thomas UC. Innovative techniques in fodder production-a review. Forage Res. 2019;44:217-223.
100. Marley CL, Bruce DB, Arthaud J, Teixeira da Silva JA. Fertilizer effects on the quality of grass-clover swards: A review. Agronomy. 2017;7(11):133.
101. Iqbal A, Ayub M, Zaman H, Ahmad R. Impact of nutrient management and legume association on agro-qualitative traits of maize forage. Pakistan Journal of Botany. 2006;38(4):1079.
102. Gupta BK, Bhardwaj BL, Ahuja AK. Nutritional value of forage crops of Punjab. Punjab Agricultural University Publication, Ludhiana; 2004.
103. Caballero R, Goicoechea EL, Hernaiz PJ. Forage yields and quality of common vetch and oat sown at varying seeding ratios and seeding rates of vetch. Field Crops Research. 1995;41(2):135-140.

104. Poonia, Atman, Phogat DS. Genetic divergence in fodder Oat (*Avena sativa* L.) for yield and quality traits. Forage Research. 2017;43:101-105.
105. Iqbal MA, Iqbal A, Akbar N, Khan HZ, Abbas RN. A study on feed stuffs role in enhancing the productivity of milch animals in Pakistan-Existing scenario and future prospect. Global Veterinaria. 2015;14(1):23-33.
106. Chaabane M, Bejaoui S, Trabelsi W, Telahigue K, Chetoui I, Chalghaf M, Soudani N. The potential toxic effects of hexavalent chromium on oxidative stress biomarkers and fatty acids profile in soft tissues of Venus verrucosa. Ecotoxicology and Environmental Safety. 2020;196:110562.
107. Deinum B, Struik PC, Dolstra O. Improving the nutritive value of forage maize. Breed Silage Maize. Proc 13th Cong Maize Sorghum Sect EUCARPIA. Pudoc, Wageningen. 1986;77-90.
108. Barrière Y, Guillet C, Goffner D, Pichon M. Genetic variation and breeding strategies for improved cell wall digestibility in annual forage crops. A review. Animal Research. 2003;52(3):193-228.
109. Wilman D, AHMAD N. In vitro digestibility, neutral detergent fibre, lignin, and cell wall thickness in plant parts of three forage species. The Journal of Agricultural Science. 1999;133(1):103.
110. Ma XY, Sui XQ, Li JM, Zhang B. Effects of spraying ga3 on flower and pod endogenous hormones and yield component factors of alfalfa. Acta Agrestia Sinica. 2020;28(5):1294.
111. Casler MD. Breeding forage crops for increased nutritional value; 2001.
112. Katoch R. Approaches for nutritional quality improvement in forages. In nutritional quality management of forages in the himalayan region. Singapore: Springer Singapore. 2022;167-192.
113. Gosselink JMJ, Dulphy JP, Poncet C, Jailler M, Tamminga S, Cone JW. Prediction of forage digestibility in ruminants using in situ and in vitro techniques. Animal Feed Science and Technology. 2004;115(3-4):227-246.

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