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An Overview of the Current Fodder Scenario and the Potential for Improving Fodder Productivity through Genetic Interventions in India

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ABSTRACT

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Fodder crops are cultivated to feed livestock in the form of forage, silage and hay. The total area under cultivated fodders in India is 8.4 mha on individual crop basis. India is maintaining about 15% of total livestock population of the world in 2.29% of the global land area. At present, the country faces a net deficit of 35.6% green fodder, 10.95% dry crop residues and 44% concentrate feeds. The deficit may further rise due to consistent growth of livestock population at the rate of 1.23% in near future. It is, therefore, imperative that forage production and its quality must be augmented to improve productivity of livestock. The expansion of fodder cultivation area seems to be very low and fodder yields have touched plateau in most of forage crops. Even then, there is a great scope to enhance the forage productivity through crop improvement activities focused on development of dual type grain and fodder crop varieties, stay green maize/sorghum varieties and application of biotechnological tools to evolve genetically engineered improved varieties which are tolerant to abiotic and biotic stresses. Forage crop improvement also needs to be focused on understanding of species relationships, genome structure and chromosomal constitution, extent of gene exchange/recombination, putative parentage and nature of polyploidy along with normal breeding programs.

Keywords: Biodiversity, Forage improvement, Genetic intervention, Quality fodder

INTRODUCTION

Agriculture and animal husbandry are always interlinked and interrelated in many ways *viz.*, economically, culturally and religious ways. In India mixed farming is an integral part of rural sustainable livelihood for the majority of small and marginal farmers (Maitra *et al.,* 2021). Although there is a decline in agriculture

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sector contribution to the Indian economy (from 51.81% in 1950-51 to 36.4% in 1982-83 to 14.4% in 2018-19), still 54.3% of the work force in our country are directly or indirectly dependent on agriculture (Anonymous, 2019a). The contribution of Indian livestock sector to the gross value output has been accelerating at a much faster rate (4.6%) than the crop sector, beside providing livelihood to two-third of rural community and employment to about 8.8% of the population in India. Livestock sector contributes 4.11% and 25.6% to the Indian and Agriculture GDP, respectively. Globally India ranks 1st in terms of total livestock (535.78 million) and buffalo population in the world (109.85 million), 2nd in cattle (192.49 million), goat (148.88 million) and 3rd in sheep population (74.26 million; Anonymous, 2019). This depicts that total livestock population has increased continuously with an increase of 15.8% in last two decades (1995-2015; Halli *et al.*, 2018). The livestock sector also contributes much to export earnings due to high export potential of its products like meat, leather, wools *etc*. However, livestock husbandry cannot be sustained without addressing the issues related to development of feed and fodder resources. It is, therefore, imperative that forage production and its quality need to be augmented to improve the productivity of livestock as India is maintaining about 15% of global livestock population.

Current status

Availability of adequate quantity and quality feed and fodder resources for livestock is essential for improving livestock productivity. Shortage of feed and fodder is mainly due to amplified stress and strain on land for growing food grains, oil seeds and pulses and inadequate attention towards fodder crops. Grazing lands and fodder cultivation areas are gradually dwindling either due to degradation or restriction for livestock grazing. Total area under fodder cultivation is around 8.4 mha (5.23%) which is almost static for the past two decades (Koli and Bhardwaj, 2018). Even though feed and fodder availability has improved in the last decade still gap exists with demand and availability of fodder during lean periods and abnormal weather conditions like droughts/floods (Anonymous, 2017). Moreover, the forages offered to animals are mostly of poor quality. At present, India faces a net deficit of 35.6% green fodder (GF), 10.95% dry crop residues and 44% concentrate feeds (Table 1; Anonymous, 2013). The data shows that green and dry fodder (DF) deficits have reduced significantly in recent years. Even though there is strong pressure to minimize the gap of supply and demand due to consistent growth of livestock population at the rate of 1.23% in coming years (Kumar, 2016). The situation worsens mostly in rainfall deficit states *viz*. Gujarat, Rajasthan, Karnataka, Madhya Pradesh, Andhra Pradesh, and Maharashtra.

Special measures are necessary to enhance fodder production during adverse and drought conditions (Anonymous, 2017). The objective of improving the forage productivity is complicated due to the varied agro-climatic conditions as well as farming situations (Kumari *et al.*, 2023). Production of GF has to grow at the rate of 3.2% to meet the expected demand. The surplus GF available during monsoon needs to be managed properly to ensure its availability during lean period. Post-harvest management of fodder *viz.* making silage, hay, blocks, pellets and value addition is another important aspect to reduce the losses by improving the shelf-life of feed resources and the quality of forages (Marsetyo *et al.,* 2013). The ensiling of water hyacinth on a larger scale can become viable alternative to farmers and could serve as a source of forage for ruminants in tropics. Silage of water hyacinth weed with maize bran in the ratio of 11:1 has been reported as nutritious (Thanhm *et al.*, 2013).

Table 1. Supply and demand scenario of green and dry forages (mt)

Year	Supply		Demand		Deficit (% of demand)	
	Green	Dry	Green	Dry	Green	Dry
2020	590.4	467.6	851.3	530.5	30.65	11.85
2030	687.4	500.0	911.6	568.1	24.59	11.98
2040	761.7	524.4	954.8	594.9	20.22	11.86
2050	826.0	547.7	1012.7	631.0	18.43	13.20

Source: Anonymous (2013)

Degraded forestland and wasteland restoration by various restoration techniques such as reseeding, legume seeding and other soil moisture conservation techniques have been taken up to enhance the fodder availability. In India, open forest cover is around 29 million hectares (mha), which can be further utilized for growing fodder trees without affecting standing trees, mostly as an under-storey on the partially shaded ground. Meena *et al.* (2017) recorded a higher herbage yield of 3.16 t/ha dry matter (DM), protein yield, grass seed yield and ber fruit yield under ber + *Cenchrus setigerus* plantation. Higher nutritional value and mean crude protein (CP) contents of feeds for legume (21.91%) trees were observed over non-legume (16.07%) tree species. Wide variation in CP, fibre, total tannin, condensed tannin (0.02-5.82%) and hydrolysable tannin (0.50-9.20%) contents were recorded in the leaves of eleven tree species commonly used for livestock foraging in northern India (Sahoo *et al.*, 2016).

Area under fodder production

The total area under cultivated fodders is 8.4 mha on individual crop basis. Sorghum and berseem grown in an area of 2.6 and 1.9 mha, respectively together occupy about 54% of the total cultivated fodder area (Kapoor *et al.*, 2018). Availability of data (2000-01) on grazing resources shows that forests contribute about 69.41 mha (22.70%) followed by fallow lands (8.1%), barren uncultivable wasteland (6.30%), cultivable wastelands (4.50%), permanent grazing lands (3.60%) and fallow land other than current fallows (3.30%) and total common property resources other than forests (17.70%) (Table 2). Thus, sizeable amount of fodder demand can be fulfilled through vast grasslands and rangelands.

Table 2. Grazing resources for livestock in India

Resources	Area (mha)	Percentage
Forests	69.41	22.70
Permanent pastures, grazing lands	10.90	3.60
Cultivable wasteland	13.66	4.50
Fallow land	24.99	8.10
Fallow land other than current fallows	10.19	3.30
Barren uncultivable wastelands	19.26	6.30
Total common property resources other than forests	54.01	17.70

Source: Anonymous (2011)

In India, grazing lands are about 40% of the total geographical area. About 157 mha area is classified under different types of degraded land category where cultivation of crops is economically unviable (Anonymous, 2019b). The grazing intensity of the country is very high (12.6 adult cattle units (ACU)/ha) as against 0.8 ACU/ha in developed countries. The total potential grazing lands in India is about 85.9 mha. By considering the contribution of 10% crops residue as fodder, total arable land contributes to 14.73 mha of grazing lands which brings up to total of 100.3 mha as grazing land. If the net primary productivity is taken as 500 g/m^2/year, then the total fodder production will come around 501.5 million tonnes (mt) per year. Healthy cattle if consumes 7 tons herbage per year, the normal annual consumption will arrive to 1,673 mt/year which shows that the net primary production of grasslands is much lower than the total requirements. The continuous degradation of grazing lands and overgrazing also decreases their productivity (Anonymous, 2011). Lower proportion of legume in the herbage is another serious concern which reduces the protein component of the ration subsequently reducing the livestock productivity (Lüscher *et al.,* 2014).

Pasturelands constitute the main grazing lands which is about 12 mha (3.94% of the geographical area) in India. However, it varies greatly among states. The grazing land availability is around 70% in Himachal Pradesh, Jammu and Kashmir, Meghalaya, Nagaland and Arunachal Pradesh. Most pasture lands are available in Himachal Pradesh (36.44%) followed by Sikkim (13.31%), Karnataka (6.54%), Madhya Pradesh (6.35%), Rajasthan (5.39%), Maharashtra (5.11%) and Gujarat (4.49%) (Anonymous, 2011). The northern region has a potential resource in the form of pasture in which the alpine meadow provides pasture to sheep and goats which is of economic importance. The available grazing land and permanent pasture is about 40% and 5.4% in Rajasthan and about 30% and 3.5% in Gujarat, respectively, which provides good quality fodder for livestock. Various soil conservation measures and management practices in grassland, pastureland and forest ecosystem can help to improve the fodder availability and can also address the issues like land degradation by soil and water erosion.

Importance of forage crops

The composition of livestock is changing with a shift towards small ruminants due to high growth in meat sector. Among the livestock, buffaloes and goats are attaining major importance (Thornton, 2010). Due to flexible growing durations, forage crops offer an ample scope in contingent crop planning as short duration, catch crop, inter crop or alley crop under different situations (Bybee and Ryan, 2018). Fodder crops are of shorter growth period and can be grown in dense stands to smother weeds and prevent soil erosion. Fodder crops also improve the soil health through addition of organic residues in the soil (Halli *et al.*, 2018). Fodder crops have wider adaptability with the capacity to grow under stress conditions and have multi-cut nature with capacity to provide regular income and employment, but storage, transport, processing and conservation are cumbersome. These crops are shy seed producers with poor harvest index and very low seed multiplication ratio. Wastelands like waterlogged areas, saline soils, sodic soils can also be utilized for cultivation of fodder varieties suitable for such areas (Anonymous, 2011). It is imperative to introduce nontraditional fodder crops which can be grown on wastelands. Fast growing shrubs and trees can be grown to be lopped regularly as fodder. The different fodder crops, which can be grown in the different tracts and crops suitable for water logging soil need to be considered to improve the availability of fodder (Table 3-4).

Regional imbalances in fodder availability

Fodder, which is quite uneconomical to transport over long distances, the regional deficits matter more than the national deficit (Anonymous, 2011). Fodder crops are also area, region and season specific. The GF as well as DF availability exceeds by more than 60% the actual requirement in western Himalayan, eastern plateau and upper Gangetic plains and hilly zones. In trans Gangetic plains, the feed availability is about 40 to 60% of the requirement and in the remaining areas, availability is below 40 (Ahmad *et al.*, 2018). By encouraging the cultivation of forage crops specific to each area and providing improved management practices to farmers, the availability of fodder can be improved, ensuring a more sustainable and efficient supply.

Role of coarse grain cereals in fodder as crop residues

In animal feed supply, coarse cereals play a major role and the four major cereals, *viz.* maize, barley, sorghum and pearl millet, accounted for about 44% of the total cereals. Of the total coarse cereals, maize and barley account for almost 75% and 15%, respectively while sorghum and other millets account for 11%. In India, productions of these cereals are stagnated at around 30 mt, which is less than 3% of the world's production (Anonymous, 2011). Most of these coarse cereals in developed countries are mainly used for cattle feed and some of the cereals like barley are used in breweries. Many minor millets *viz.,* finger millet/*ragi* (*Eleusine coracana*), little millet (*Panicum miliare*), kodo millet (*Paspalum scrobiculatum*), foxtail millet (*Setaria italica*), barnyard millet (*Echinochloa frumentacea*), proso millet (*Panicum miliaceum*) and *savan* millet (*Echinochloa colona*) are also important for fodder. Besides, the role of food grains, especially of the coarse cereals in providing balanced nutrition to the livestock for ensuring higher productivity needs no emphasis.

Table 3. Cultivated fodder species for different regions in India

Type of land	Rainfed	Irrigated
Arid tracts	Jowar (*Sorghum bicolor*), Bajra (*Pennisetum glaucum*), Moth grass (*Vigna aconitifolia)*, Guar (*Cyamopsis tetragonoloba*),	Lobia (*Vigna unguiculata*) Lucerne (*Medicago sativa*), Berseem (*Trifolium alexandrinum*), Oats (*Avena sativa*), Maize (*Zea mays*), Jowar, Bajra, Barley (*Hordeum vulgare)*
Semi-dry tracts	Jowar, Bajra, Moth grass, Guar, Lobia, Velvet bean (*Mucuna pruriens*), Field bean (*Vicia faba*), Guinea grass (Megathyrsus maximus), African bristle grass (*Setaria sphacelata*), Rhodes grass (*Chloris gayana)*	Jowar, Maize, Lobia, Teosinte (*Zea maxicana*), Lucerne, Berseem, Turnips (*Brassica rapa subsp. rapa*), Hybrid Napier, Oats, Sudan grass (*Sorghum sudanense*) Guinea grass
Semi-wet tracts	Dinanath grass (*Pennisteum Pedicellatum*), Jowar, Lobia, Rice bean (*Vigna umbellata*), Velvet bean,	Teosinte, Sun hemp (*Crotalaria juncea*) Berseem, Oats, Sudan grass, Hybrid Napier (*Pennisetum purpureum*), Guar, Jowar, Maize, Para grass (*Brachiaria mutica)*, Rhodes grass, African bristle grass
Wet regions	Jowar, Dinanath grass, Rice Bean, Coix (*Coix lacryma*)	Berseem, Oats (*Avena sativa*), Hybrid Napier, Guinea grass, Lucerne, Turnips, African bristlegrass, Para grass, Jowar
Lower hills	Jowar, Lobia (*Vigna unguiculata*), Bajra, Velvet Bean, Field Bean, Guar	Maize, Jowar, Oats, Berseem, Lucerne, Hybrid Napier, Sudan grass (*Sorghum sudanense*), African bristle grass, Rhodes

Source: Anonymous (2017b)

Biodiversity in forage resources

Indian sub-continent has very large biological diversity which makes it one of the world's mega centres of crop origin. The Indian gene centre occupies a very rich genetic diversity in native grasses and legumes too. It has been reported that around 245 genera and 1,256 species of Gramineae, among which 21 genera and 139 species are endemic and near about one-third holds fodder value. The tribes *Andropogoneae*

(30%), *Paniceae* (15%), and *Eragrosteae* (9%) constitute most of the grasses. Out of nearly 400 species of 60 genera of the *Leguminaceae* family, about 21 genera have been reported to have forage usage (Singh *et al*., 2018). The main centers of genetic diversity include peninsular India and north-eastern region along with some micro-centres for certain species. Major forage genera exhibiting forage biodiversity includes legumes like *Desmodium, Lablab, Vigna, Stylosanthes, Centrosema, Macroptelium, etc*.; grasses like *Dichanthium, Bothriochloa, Cynodon, Pennisetum, Panicum, Cenchrus, Lasiurus etc*. and browse plants such as *Sesbania, Bauhinia, Leucaena, Albizia, Grewia, Cassia, etc*. These genera along with many others constitute an integral part of feed and fodder wealth of the country.

Table 4. Forage crops suitable for waterlogged soils

Soil condition	Suitable crop
Standing water	Almond grass (*Echinochloa polyptachya*), Para grass, Coix, *Iseilemalaxum*, *Chloris gayana*, signal grass, karnal grass, congo signal grass
Shallow water table	Teosinte, shevary (*Sesbania sesban*)
Temporary waterlogged soil drained in rabi season	Sasuna (*Medicago denticulata*), Lathyrus (*Lathyrus sativus*), chatarimatri (*Vicia sativa*), Oats and Berseem
Riverine flood water logging	*Sorghum bicolor* (PC-6), *Euchaleana maxicana* (TL-6)
Saline waterlogged	Casuarinas and Populus

Source: Anonymous (2017b)

Forage crop improvement

The area under fodder cultivation seems to be not encouraging and fodder yields have reached a plateau in most forage crops. However, genetic improvement of fodder crops may significantly boost forage productivity. A lot of work has been done towards the development of high yielding nutritionally rich quality fodder varieties through the crop improvement programs (Table 5). The major breeding objectives focused in fodder improvement program includes high DM yield, better quality components *viz*. high *in-vitro* DM digestibility, high CP, low percentage of neutral detergent fiber (NDF) and toxic factors, tolerance to adverse soils and extreme weather conditions, resistance to diseases and pests, greater summer persistence and exploitable regeneration ability in multi-cut forages, fast growth and competing ability or complementation with the companion crops (Kumar *et al*., 2016). Forage crop improvement should also focus on understanding of species relationships, genome structure, and chromosomal constitution, extent of gene exchange/ recombination, putative parentage and nature of polyploidy along with normal breeding programme (Tulu *et al*., 2023; Kumar *et al*., 2020).

Table 5. Nutritional quality of different fodders

Fodder crops	Nutritional quality and specific characteristics
Sorghum	Nutritious and palatable fodder, 9-10% CP, 60-65% NDF, 37-42% acid detergent fibre (ADF), 32% cellulose and 21-23% hemi cellulose on DM basis
Pearl millet	Palatable, 7-10% CP, 56-64% NDF, 38-41% ADF, 33-34% cellulose and 18-23% hemi cellulose
Maize	Palatable, 9-10% CP, 60-64% NDF, 38-41% ADF, 28-30% cellulose and 23-25% hemi cellulose
Coix	Multi cut fodder High tillering capacity 10-11% DM, 7-8% CP, 65-70% NDF and 32-35% ADF
Dinanath grass	Profuse tillering, Fast growing, Suitable for silage and hay, 5-7% CP
Oats	Palatable fodder, 10.0 -11.5% CP, 55-63% NDF, 30-32% ADF, 22.0-23.5% cellulose and 17-20% hemicellulose
Napier-bajra hybrid *(Pennisetum glaucum x P. purpureum)*	Multicut, fast growing, palatable perennial grass, 8.7-10.2% CP, 28-30.5% CF and 10-11.5% ash
Guinea grass	Most palatable perennial grass, fast growing, high leaf stem ratio, 10% CP, 36% CF, 71% NDF and 42% ADF
Setaria grass	Palatable fodder, drought and heat tolerance, 6-8% CP
Para grass	Quality perennial grass, palatable, particularly suited to poorly drained and flooded soils, 7-10% CP and 70-75% NDF
Cowpea	Leguminous fodder, fast growing, 16-22% CP, 43-49% NDF, 34-37% ADF, 23-25% cellulose and 5-6% hemi-celluloses
Cluster bean	Leguminous fodder, drought resistant, 17-20% CP, 42-48% NDF, 37-42% ADF, 23.5-25.3% cellulose and 8-12% hemi-cellulose
Rice bean	Multipurpose leguminous fodder, Drought and heat tolerant, 17-22% CP, 55-60% NDF and 35-38%ADF
Lathyrus	Dual purpose legume fodder, Heat & Cold tolerant, 17-20% CP, 35-40% NDF and 25-28% ADF
Berseem	king of forage, multi cuts, 22% CP, 42-49% NDF, 35-38% ADF, 24-25% cellulose and 7-10% hemi-cellulose
Lucerne	Queen of forage, Perennial legume fodder, 17-25% CP, Dry matter digestibility 70%
Persian clover	Annual branched legume fodder, Palatable, 20-22% CP, 24-35% NDF and 18-25% ADF
Sweet clover	Erect annual legume fodder, 16-20 % CP, 45-51% NDF and 30-36% ADF

Source: Anonymous (2011; 2012)

Advanced biotechnological tools have provided enormous options to tailor the plants as per the need. Biotechnological approaches for forage improvement were started in 1980s making remarkable improvement. Hybrids in *Lolium-Festuca* complex, *Lolium-Dactylis* hybrids and many interspecific hybrids in *Trifolium* have been successfully produced through embryo-rescue techniques (Williams *et al.*, 2007). Progress in developing interspecific hybrids in berseem has also been made. Novel variations have been created in forages through somaclonal variation, genetic transformation and somatic hybridization. In grasses, successful genetic transformation so far is limited, and progress has been made only in few perennial grasses, *viz. Agrostis sp, Lolium sp, Festuca sp, Paspalum sp, Dactylis sp,* and *Dichanthium sp* (Krishna *et al.*, 2016). The molecular characterization of forage crops and weeds is also equally important. So there is a need to classify forage germplasm for developing DNA fingerprints and for identifying the duplicates in the germplasm through molecular characterization. The major problem encountered with the forage species is the existence of variability due to their synthetic populations. However, successful efforts have been made for characterizing the varieties based on molecular markers and discriminating between the varieties based on gene frequencies.

Genetic mapping and gene tagging in forage species have been attempted in a few crops. Gene tagging is somewhat difficult in case of forages due to multi-genic nature of most of the desirable agronomic traits. Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia, has successfully transferred gene for sulfur amino acid (sunflower) to lupin, which resulted in higher animal productivity with the use of transgenic lupin meal (Tabe and Droux, 2002). Stress tolerance, both biotic and abiotic, in fodder crops and range species can also be incorporated through gene pyramiding of identified QTLs. Selection of germplasm for salinity tolerance is of much importance for efficient utilization of degraded lands. *In-vitro* studies have revealed that significant interspecific and intraspecific variation exists among legume and clover species for salt tolerance. Intra-cultivar variation has also been reported in Lucerne and white clover (Roberts *et al.*, 2017).

In grass breeding, identification of genes controlling apomixis is of quite importance for fixation of heterosis. Identification of sexual lines in grasses is another important aspect to accelerate the breeding process (Hand and Koltunow, 2014).

There are lots of limitations involved in forage crop productivity. One major constraint is non-availability of quality fodder seeds and the other is non-availability of dual-purpose varieties. Availability of quality seeds is around 15-25% only. The main reasons for low seed production in forage crops includes non-availability of certified seeds and indeterminate growth habit along with non-synchronous maturity, seed dormancy, seed shattering and chaffy seeds. Few other constraints are abscission of spikelets after maturity and the presence of large number of sterile glumes in grasses, uneven pod setting in forage legumes and apomictic nature of most of the forage grasses which limits their genetic improvement (Hand and Koltunow, 2014).

Systematic forage crop breeding programmes at the research institutions under the Indian Council of Agricultural Research (ICAR) and the State Agricultural Universities (SAUs) have led to the development and release of a large number of improved varieties of different forage crops suitable for different agro-ecological zones. The cultivation of these improved varieties resulted in substantial increase in the productivity and production of forages in India (Anonymous, 2011; 2015; 2017; Pandey and Roy, 2011).

Future prospects to revitalize fodder production

It is high time to promote fodder crop production in scientific way by providing improved varieties and quality seeds of fodder crops. Forage genetic resources enrichment, pre-breeding efforts, pyramiding genes for multiple stress tolerance (biotic and abiotic) and desirable traits, ideotype development based on climate change parameters, identification and utilization of male sterility systems, fortification, enhancing fodder traits in otherwise grain crops, identification, cloning and characterization of key regulatory genes for fodder traits, biochemical engineering to improve quality components, studying pest genomics and disease etiology under changing climate scenario can lead to development of the improved varieties with the potential to minimize the supply demand gap.

Development of weevil tolerant Lucerne varieties (Chandra and Pandey, 2001), root rot and nematode resistant lines in cowpea (Dass *et al.*, 2008), root rot and stem rot resistance in berseem, low lignin lines in tropical perennial grasses (Duncan, 1996), exploitation of apomixis phenomenon (Hand and Koltunow, 2014), climate resilient varieties (drought/ acid/ salt/ cold/ shade) in fodder maize, pearl millet, sorghum are the major prioritized area of research to reduce the deficit of fodder (Kumar *et al.*, 2017b; Kumar *et al.*, 2017d). Evaluation, production and utilization of non-conventional fodder crops like *Cactus*, *Azolla*, *Spirulina etc.* may also lead to the enhancement of quality fodder availability.

Research on biochemical and molecular basis for quality seed formation in grasses, molecular mechanism on seed longevity, germination/dormancy, biotic and abiotic stress tolerance in seeds during germination and seedling growth, development of synthetic seeds in vegetatively propagated forages, developing climate resilient crops to cope up with the changing climatic condition for forage seed production can improve the fodder production to a significant level. Therefore, research has been mainly focused on cultivation of GF in irrigated areas, however dry land fodder or partially irrigated fodder crops can also be developed to promote its production in rainfed areas.

Research for the development of forage based cropping system/ silvi-hortipastoral system for extreme weather situations, utilization of problematic soils, silvipasture technologies for reclamation of wastelands, specific horti-pasture technologies for wide adoption, noncompetitive land use pattern for enhancing forage resources, augmenting production from a range of grasses and trees in watershed areas, grassland and pasture land are going on, but these need to be more focused (Ghosh *et al.,* 2016). Silvi-pastoral systems can be effectively utilized for gaining forage production from wastelands too. Sharma and Koranne (1988) reported that the production of 1800-2450 g/m^2/annum under modified silvipastoral system of *Digitaria decumbens*

+ *Quercus incana/ Bauhinia pupurea/ Celtis australis/ Grewia optiva* in comparison to maximum production of 300 g/m^2/annum under existing grasslands. Sharma and Jindal (1989) reported that 83.50% higher fodder yield after introduction of *Fescue* in apple orchard over local grasses in Shimla hills of Himachal Pradesh. Thus, the livelihood options for pastoral and nomadic communities can be increased by enhancing production of pasture lands/grasslands.

Finding suitable multi-cut forage legumes coinciding with the cutting schedule of Napier/Napier × bajra hybrid/guinea grass-based cropping systems under irrigated lands may lead to the availability of quality fodder (Kumar *et al.*, 2017a; Kumar *et al.*, 2017c). Efforts towards strengthening and diversification of the production potential of various non-conventional fodder crops prevalent in different areas of the country can improve fodder availability. Use of forest margins as forage resources through scientific management and sustainable use can help to bridge the supply demand gap.

Grassland development and improvement in forage cultivation can be made in non-forest waste lands, rangeland, grassland, non-arable land and forest land. Forage production can also be taken up in problematic soils like arid zones, especially sand dunes and areas with very less rainfall and degraded pasture land from cold desert like Leh/Ladakh by using ameliorating measures. It can help in improving the availability of suitable forage resources for temperate animals such as yak, mithun and migratory sheep and goats. For aquatic and waterlogged zones, exploitation of aquatic weeds such as Karmi, Para grass, Jalkumbhi, Coix for forage production after receding of floods can also be taken up (Acharya *et al.*, 2012).

Effective post-harvest mechanism should be in place for fodder conservation, compaction, transportation and storage (fodder bank) to mitigate the problem of fodder availability during lean period and also during natural calamities like flood and drought situations. Improvement of crop residues, largely of paddy straw (high silica, high lignin and anti-nutritional oxalate through various post-harvest technologies) can also contribute in fodder availability (Anonymous, 2013).

To boost animal productivity, improvement of feed nutritive value is an important aspect. Crop wastes that are diverted for industrial use or burned as agricultural refuge in fields pollute the environment, but they can be used as animal feed by enhancing its nutritional value and palatability with procedures like treating straw with urea and molasses or making silage. Treating straws and cellulosic waste like rice, sorghum, pearl millet, maize, and others with urea can improve their nutritional value. Processing, packing, distribution, and consumption of fruits and vegetables generate a huge amount of waste, which can be used as livestock feed along with straw during the lean period of GF production.

Availability of DF can be enhanced by installation of low-capacity fodder-block making machine to store surplus DF. Agricultural refuge can be condensed with or without mixing it with easily available materials like urea, butter milk and molasses for easy storage and to be used during the scarce period. *Azolla* fern, rich in micro-nutrients and *Spirulina* (*Althrospira* sp.), enriched with many essential amino acids, vitamins, minerals and also a source of carotenoids and fatty acids, especially γ-linolenic acid (GLA) can be used as an alternative to GF for many animal species to improve the productivity and health of livestock.

CONCLUSION

There is a rich biodiversity of forage resources in the Indian sub-continent, with a wide range of grasses, legumes, and browse plants that contribute to the feed and fodder wealth of the country. To increase the fodder availability, it is crucial to promote scientific fodder crop production by providing improved quality seeds and developing high-yielding varieties. Biotechnological tools offer opportunities for novel variations in forages through somaclonal variation, genetic transformation, and somatic hybridization. Research efforts should also focus on stress tolerance, gene mapping, and gene tagging in forage species. Additionally, the adoption of silvi-pastoral systems, agri-silvipastoral systems, and horti-pastoral systems, as well as the effective utilization of forest margins and non-conventional fodder crops, can contribute to enhancing forage production. Proper post-harvest mechanisms for fodder conservation and storage are also essential. By addressing these challenges and implementing research-based strategies, the production and productivity of quality fodder can be increased, bridging the demand supply gap and ensuring sustainable feed resources for livestock.

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