



# Biofortification Approaches for Improving Nutritional Quality of Feed and Fodder

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Received: December 13, 2025

Revision Submitted: April 04, 2026

Accepted: April 07, 2026

**Abstract:** Fodder crops are an important component of livestock nutrition, serving as the primary source of food for dairy and meat-producing animals. However, the nutritional quality of fodder crops is lower, leading to suboptimal animal health and productivity. Long-term mineral shortages in animal diets cause nutritional disorders. Micronutrient deficiencies are more difficult to detect because they cause minor functional and structural changes in the animal body. Micronutrient requirements are essential, especially during the three to four weeks before and after parturition, as they affect the health of milch animals, breastfeeding, milk supply, and reproductive performance. Dietary supplementation of micronutrients helps to reduce the risk of infertility, foetal development, metabolic illnesses caused by negative energy balance, lowering somatic cell counts in milk, and reducing the risk of bacterial infections associated with mastitis. Micronutrients like iron, copper, manganese, zinc, selenium, cobalt and iodine are beneficial to high-yielding dairy cows, buffalo, goats, and sheep. Biofortification approaches address nutritional problems in animals worldwide by regularly introducing nutrient-enriched feed and fodder crops. Biofortification of fodder crops holds great promise as a sustainable solution to enhance the overall efficiency and productivity of livestock. Bolstering the nutritional content of fodder crops can contribute to the well-being of both animals directly and humans indirectly, fostering healthier diets, reducing malnutrition in livestock, and supporting the livelihoods of farmers worldwide.

**Keywords:** Biofortification, Deficiencies, Fodder crops, Micronutrients, Nutritional security.

## 1. INTRODUCTION

Indian agriculture relies heavily on livestock and agriculture. India has the largest livestock population in the world (Livestock Census, 2019). Micronutrients play a vital role in animal's body, but deficiencies lead to major problems, such as increased risk of disease, infections, and mortality. In dairy cows, micronutrients play a crucial role in regulating the reproductive tract, immune function, oxidative stress, and energy metabolism. Micronutrients act as antioxidants in the immune system, protecting cells from free radicals and maintaining the membrane integrity of cells involved in milk production (Lean et al., 2013). Zn, Fe, Cu, Co, I, Mn, and Se are essential elements for cattle and human health, and they play a significant role in internal and external development. Micronutrients are involved in several metalloenzymes, which include glutathione peroxidase (Se), catalase (Fe), and superoxide dismutase (Cu, Zn, Cr, and Mn). These enzymes protect the internal cellular structure from oxidative damage (Keshri et al., 2021). The micronutrients contribute as an important part of

the immune system's response to numerous illnesses (Dimkpa & Bindraban, 2016). In the absence of micronutrients, many proteins, enzymes, and other bioactive substances that regulate internal biochemical processes in livestock and humans are rendered ineffective (Grusak & Cakmak, 2009). Micronutrient deficiencies affect reproduction by depressing the activity of the rumen microflora, decreasing the activity of enzymes involved in energy and protein metabolism and hormone synthesis of hormones, and impairing the integrity of rapidly dividing cells. Similarly, mineral requirements for optimal growth and development in cattle are easily met by nutrient-rich green and dry fodder or concentrated feed. (Kubkomawa, 2019). The availability of high-quality feed and fodder for dairy and meat-producing animals, as well as poultry, increases yield and productivity. The mineral content, total calories, and, more importantly, nutrient bioavailability are essential aspects of the nutritional quality of feed and fodder. These factors highlighted the need of cultivate highly nutritious crops to achieve nutritional security (Dhaliwal et

Available online: May 04, 2026

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al., 2020). There are several options for providing nutrients through food fortification, dietary diversity, and medicinal supplements. In fact, biofortification is a promising method of reducing malnutrition easily. It enables the addition of certain nutrients in a crop's edible portion, so that crops consumed by both humans and animals (Sheoran et al., 2022; Rangasami et al., 2024). Breeding, agronomic, transgenic methods, and advanced genome-editing tools are the best approaches of biofortification (Whitem & Broadley, 2009). Agronomic biofortification is the process of employing micronutrients in fodder crops with different management practices to increase concentration in various plant sections, and it is one of the best choices for producing high-quality fodder (Alloway, 2008). Biofortified forage crops fed to animals will improve animal health and production (Capstaff & Miller, 2018). The supplementation of micronutrients in crops increased the concentration of micronutrients in fodder crops. Biofortified feed and fodder crops enriched with nutrients help overcome malnutrition-related health issues in animals. Biofortification of fodder crops improves the concentration of micronutrients such as Fe, Zn, Mn, Se, B, carotenoids, folates, protein, and vitamins. As a result, biofortification with micronutrients has been increasingly popular in recent years (Sheoran *et al.*, 2022). The current state of biofortification in food and fodder crops remains limited, so further improvement is needed to enhance the nutritional security of animals. This review scrutinises the efficacy of multiple and diverse biofortification techniques in fodder crops.

## 2. Essential Macro and Micronutrient Requirements for an Animal's Growth and Developments

Essential elements are required for the healthy growth of a plant, while the absence of any of these nutrients prevents plants from completing their life cycle. The seventeen major micro-elements were found to be essential for plant growth. C, H, O, N, P, K, Ca, Mg, and S are examples of basic, macronutrients, and Fe, Zn, Mn, Cu, Cl, Mo, B, and Ni are examples of micronutrients (Bhatla & Kathpalia, 2023). The absence of any single element or their excess availability can cause growth retardation and impair the regular functioning of a living body (Table 1). The requirements of minerals for the animal's daily basis vary according to animal type (cattle, buffalo, goat, sheep, etc.) and the basis for determining mineral demands in cattle differs from humans (Table 2). The intake of minerals is frequently chosen to increase growth (for example, in pigs, broiler chickens, and beef) and output (for example, in laying hens and dairy cattle) (Coleman & Moore, 2003). As a result, commercial feed often contains additional minerals to meet the mineral requirements of particular livestock (Pond et al., 2004). Conventional breeding and biotechnological interventions in animals' manipulated output potential and nutritional requirements. In certain aspects, the plant matter given to cattle varies from that ingested by humans. Although animals are fed forage, particularly for ruminants, cereals, legumes, and grasses are essential components of their diet (Pond et al., 2004; Reddy et al., 2003). The monocots (e.g.,

**Table 1.** Functions and the deficiency symptoms of micronutrients in animals

Micro mineral	Function	Deficiency symptom
Cobalt (Co)	Cobalt and rumen microbes are involved in the synthesis of vitamin B12	Poor appetite, anaemia, rough hair coat
Copper (Cu)	Enzyme activation, blood synthesis, nervous system	Change in colour of hair (grey or reddish), diarrhoea, rough hair coat, mastitis (grey or reddish), and an affected immune system
Iodine (I)	Synthesis of thyroxine (hormone)	Big neck in calves, reduced metabolic rate, poor reproductive performance, goiter
Iron (Fe)	Part of the blood haemoglobin, enzyme systems, and the immune system function	Anaemia with pale mucous membranes decreased milk supply.
Manganese (Mn)	Growth, bone formation, enzyme activation	Impaired growth, poor reproduction, skeletal abnormalities
Selenium (Se)	Involved in immune function, enzyme formation (glutathione peroxidase, and cell membrane protection.	Mastitis, reproductive disorders, immune system dysfunction, retained placenta, white-muscle disease
Zinc (Zn)	Repair of damaged tissue, immune system, enzyme activation, and keratin formation	Elevation in somatic cell count, parakeratosis in the skin, hoof dysfunction, elevation in somatic cell count, mastitis, stiff joints

Source: NRC, 2001

*Pennisetum spp.*, *Lolium spp.*) and dicots (e.g., *Trifolium spp.*, *Medicago sativa*) both serve as pasture; hence, most of the plant scientists should consider these plant species' nutrient-rich crops. Some strategies to improve nutrient concentration in beneficial forage crops, but ensuring an optimal mineral balance would be equally vital.

Elements such as Zn, Fe, Cu, Co, I, Mn, and Se are important for animals and humans and enter the plant system via non-selective pathways (roots). while micronutrients reach livestock and the human body through the food supply. Most of the forage crops are grasses belonging to the family Poaceae, legume crops of Leguminosae, and some trees like mulga (*Acacia aneura*) and subabul (*Leucaena leucocephala*) are grown in dryland areas (Muir et al., 2011). These crops can be consumed by cattle directly after partial or full drying. The concentrations of micronutrients, proteins, and lipids define the nutritional status and digestibility of fodder crops (Capstaff and Miller 2018). Crops are the main source of minerals in animal diets (Suttle, 2022). Several factors, including plant species and soil conditions, determine the elemental profile of forage crops. Plants absorb major and micronutrients from the soil because these nutrients are abundant in soil, but only a small amount of micronutrients is available to plants (Marijanušić et al., 2017).

### 3. Biofortification in Fodder Crops

Biofortification is the process of using agronomic treatments, conventional plant breeding, and genetic engineering to improve the nutritional profile of plant-based meals (Figure 1). An integrated approach of nutrient management in crops enhances the micronutrient concentration (Hussain, 2022). The biofortification of fodder crops depends on improved absorption of nutrients from the soil. However, if micronutrients are present in low concentrations in the soil, they must be supplied as fertilisers. The current need to focus on the bioavailability of these micronutrients in the rhizosphere, their absorption, and the uniform distribution into edible parts of the crop plants (Whitem & Broadley, 2009).

### 4. Agronomic Biofortification

To improve the concentration of micronutrients in edible plant tissues, agronomic biofortification uses mineral fertilisers to increase the mobilisation and solubility of micronutrients already present in the soil (Chugh et al., 2022). Soluble inorganic fertilisers are applied to the leaves and roots in a targeted manner when plants are grown in soil deficient in microelements. Soluble inorganic fertilisers are administered through the leaves when micronutrients are difficult to translocate into edible tissues. Agronomic biofortification increases the micronutrient concentration in

**Table 2.** Quantity of nutrients required for cattle at different ages

Category	Cows						Heifers (age in months)			
	Dry (far off)	Dry (close up)	Fresh	Early	Mid	Late	6	12	18	24 (close up)
<b>Macro-elements required in percent of dry matter</b>										
Calcium	0.44	0.48	0.79	0.60	0.61	0.62	0.47	0.41	0.44	0.40
Phosphorus	0.22	0.26	0.42	0.38	0.35	0.32	0.25	0.23	0.18	0.23
Magnesium	0.11	0.20	0.29	0.21	0.19	0.18	0.11	0.11	0.08	0.14
Chlorine	0.13	0.20	0.20	0.29	0.26	0.24	0.11	0.12	0.10	0.16
Sodium	1.10	0.14	0.34	0.22	0.23	0.22	0.08	0.07	0.12	0.10
Potassium	0.51	0.62	1.24	1.07	1.04	1.07	0.47	0.48	0.46	0.55
Sulfur	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
<b>Micro-elements in mg per kg dry matter (for cow and heifer's)</b>										
Iron	Cobalt	Copper	Manganese	Zinc	Iodine	Selenium	Fluorine	Molybdenum		
13-30	0.11	10-16	14-24	22-70	0.3-0.4	0.30	Upto 30	Upto 6		
<b>Vitamins in IU per day</b>										
Vit. A (IU)	58000	60600	75000	75000	75000	75000	16000	24000	36000	60100
Vit. D (IU)	11700	12100	21000	21000	21000	21000	6000	9000	13500	10000
Vit. E (IU)	1168	1211	545	545	545	545	160	240	360	1202

Source: NRC, 2001

the crops through agronomic practices (Mandi et al., 2022) (Table 3). Agronomic biofortification practice to increase Zn and Fe contents in edible plant portions is very useful for addressing malnutrition (Shukla & Mishra, 2018)

#### 4.1. Seed priming/coating

The application of nano-zinc oxide (nZnO) in the form of priming of the seed treatment increased the vegetative growth, yield, and quality of fibre fodder maize variety (J-1006). Additionally, nano-zinc oxide (nZnO) priming treatments were shown to be more successful at increasing zinc micronutrient availability in field-grown fodder maize. As a consequence, seed treatments with a small amount of nano-zinc oxide (nZnO) fertiliser can help minimise zinc fertiliser application dosages and waste. Zn-based fertilisers and nano-zinc oxide (nZnO) particles can also help improve Zn nutrient use efficiency in fodder crops and their content in crops, particularly fodder maize (Tondey et al., 2021). The seed treatments of cowpea with different levels of nano-copper oxide (nCuO; 25, 50, 100, 200 mg kg<sup>-1</sup>) and nano-zinc

oxide (nZnO; 250, 500, 750 mg kg<sup>-1</sup>) recorded the highest growth and micronutrient concentration. The concentration of copper (17.7 mg kg<sup>-1</sup>) increases up to the application of nCuO 100 mg kg<sup>-1</sup> but the highest zinc availability (45.4 mg kg<sup>-1</sup>) in plant dry matter was recorded with nCuO 25 mg kg<sup>-1</sup>. Nano-zinc treatments also recorded an increment of copper and zinc in plant dry matter. The maximum concentration of zinc (50.4 mg kg<sup>-1</sup>) was recorded with nZnO 700 mg kg<sup>-1</sup> (Srinivasan et al., 2017).

#### 4.2. Foliar application of micronutrients

In berseem crop applied boron (B) 2.0 mg kg<sup>-1</sup> to increase the dry matter yield by 6.3% and 8.5% in both first and second cuttings over the control, respectively Arora, (2007). Berseem crop mean boron content and absorption both depend on boron application rates significantly. The total B concentration in berseem plants increased by 10.7% and 20% over the control at first cutting when B was applied at 1.0 and 2.0 mg kg<sup>-1</sup>, respectively. At the first and second cuttings, the effect of B application of 2.0 mg kg<sup>-1</sup> in the

**Table 3.** Application of micronutrients in fodder crops for agronomic ferti-fortification

Micronutrient	Crop	Source
<b>Seed coating/priming</b>		
Nano-Zn	Maize	Tondey et al. (2021)
Nano-Zn and Cu	Cowpea	Srinivasan et al. 2017
<b>Foliar application</b>		
B	Berseem	Arora (2007)
Mo + B	Berseem	Dhaliwal et al. (2008)
Fe + Zn + Mn	Sorghum	Soleymani et. al. (2012)
Fe	Teosinte	Kumar et al. (2016)
Zn + Cu	Barley	Iahaq et al. (2018)
Cu	Oats	Sandhu et al. (2020)
Zn	Cowpea	Kumar and Dhaliwal (2021)
<b>Soil application</b>		
Cu	Oats	Kaur et al. (2015)
Zn	Berseem and lucerne	Kumari, (2017)
Zn + Fe + Se	Sorghum	Quereshi et al. (2021)
N + Zn + Se	Maize	Petković et al. (2022)
<b>Soil + foliar application</b>		
Fe + Zn and Mn + Cu	Barley	Booboori et al. (2012)
B + Mn	Lucerne	Kherikhah et al. (2016)
Zn	Maize	Kumar et al. (2017)
Zn	Pearlmillet	Shekhawat and Kumawat (2017)
Zn	Oats	Dhaliwal et al. (2020)
Zn	Sorghum	Kumar and Ram (2021)

berseem crop was a 23.1% and 24.4% increase in B uptake over the control, respectively. Seed production of berseem is strongly affected by B foliar spray, followed by Zn and Mo spray. (Dhaliwal et al., 2008). The maximum fresh forage yield of sorghum and quality forage was achieved with foliar application of Fe, Zn, and Mn together in comparison to the rest of the other treatments applied in sorghum fodder crops (Soleymani & Shahrajabian, 2012). Applying Fe to the teosinte fodder crop as a foliar increased yield, Fe content, and digestibility of teosinte (Kumar et al., 2016). Ishaq et al. (2018) found that foliar application of Zn and Cu in barley improves grain yield and quality. Sandhu et al., (2020) investigated the effect of Cu on oats fodder crops and recorded that Cu absorption, content, yield, and protein content were all considerably improved by foliar application of Cu (0.2%) at 60 and 90 DAS (days after sowing). The higher productivity and quality of dual-purpose cowpea were achieved with 16 kg ha<sup>-1</sup> of zinc sulfate applied at sowing, and after 0.3% zinc sulfate, two foliar sprays were applied at the early bloom and full bloom stages (Kumar & Dhaliwal, 2021).

**4.3. Soil application of micronutrients**

The application of Cu 6 kg ha<sup>-1</sup> increased oats fodder output, Cu content, crude protein (CP), and other nutrients.

Cu application increased the fodder quality of oats by lowering total ash content, NDF (Neutral Detergent Fibre), ADF (Acid Detergent Fibre), and cellulose content. The concentrations of Fe, Zn, and Mn in oats fodder were not affected by Cu treatment, but the bioavailability of nutrients in fodder oats increased due to the soil application of Cu 6 kg ha<sup>-1</sup> (Kaur et al., 2015). Soil application of chelated Zn in fodder berseem and lucerne enhances crop quality, including increased CP content and Zn uptake (Kumari, 2017). Zinc treatment in the soil is an efficient technique to increase Zn uptake by plants in zinc-deficient soils, and has been shown to inhibit phosphorus uptake and phytate-P buildup in plants. Sorghum crop biofortification with Fe, Zn, and Se had a positive effect on all the sorghum cultivars studied. Sorghum cultivars achieve maximum values for all growth and quality parameters with the application of Fe, Zn, and Se (Qureshi et al., 2021). The application of nitrogen with Zn and Se for biofortification of fodder maize increased yield and nutrient concentration (Zn and Se) in the crop (Petković et al., 2022).

**4.4. Soil and foliar application of micronutrients**

Soil and foliar Zn application improved Zn contents in fodder crops, CP contents, biomass, total biomass yield, and quality of fodder. Zn application in the soil and foliar spray

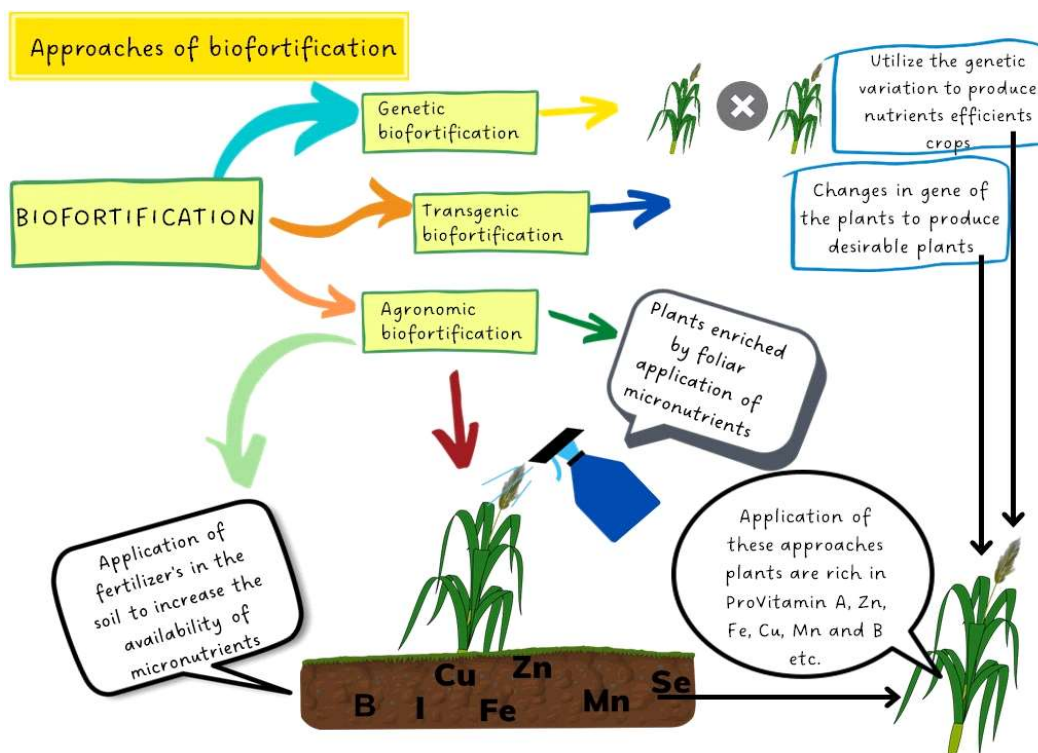


Figure 1. Different approaches to biofortification

increased nutrient absorption and the speed of transport to storage organs. Zinc enhanced the rate of protein synthesis by the buildup of amino acids. The application of zinc in the form of foliar and soil applications increased crude protein content and enhanced nitrogen metabolism in plants (Alloway, 2008). The soil application of Zn, after the zinc foliar spray in the cowpea crop, reported maximum grain yield and quality parameters. The highest CP, ash content and ether extract (EE), and yield were also reported with 20 kg ha<sup>-1</sup> ZnSO<sub>4</sub> application in maize fodder crop, followed by combined fertilisation soil application of 10 kg ha<sup>-1</sup> ZnSO<sub>4</sub> and one foliar spray of 0.5 per cent ZnSO<sub>4</sub> and two foliar sprays of 0.5 per cent ZnSO<sub>4</sub> (Kumar et al., 2017). Kheirkhah et al. (2016) investigated that the individual application of PSB, Mn, and B obtained the maximum fodder of lucerne and improved fodder quality when the foliar application of B was applied. Shekhawat & Kumawat (2017) found that using 20 kg ha<sup>-1</sup> ZnSO<sub>4</sub> in soil and four foliar sprays of 0.5 percent in pearl millet increased Zn and CP content, and overall quality. Zn is more readily available in the rhizosphere when applied to the soil, whereas foliar application increases absorption and fast translocation in plant systems. The elevated Zn level (foliar spray of zinc) was attributed to improved nitrogen metabolism, which increased the speed of protein synthesis and the formation of amino acids, increasing the CP content in fodder oats (Dhaliwal et al., 2020). In sorghum crop, soil and double foliar ZnSO<sub>4</sub> fertilization improved digestibility parameters such as total digestible nutrients, digestible crude protein, digestible dry matter, dry matter intake, net energy for lactation, relative feed value, digestible feed energy as well as relative fodder quality and decrease in fibre fraction (Kumar & Ram, 2021).

#### 4.5. Soil amendments application

The application of cattle dung with forest leaf litter and Zn-rich fertiliser in the soil resulted in significantly higher grain yield and Zn content in maize grain. Organic matter's long-term application in the soil increases the overall fraction of labile zinc and zinc content in the soil. Labile zinc is easily absorbed by plant roots and easily translocated in the plant system (Manzeke et al., 2017). Alkaline soil is often calcareous with a high concentration of carbonates. Deep ploughing increases the amount of carbonate in the top layers, raising the pH of the soil. Furthermore, higher soil pH reduces Fe and Mn solubility in the soil, the excess Ca and Mg in calcareous soils cause multiple nutrient deficiencies in the soil. To reduce the pH of sodic and saline-sodic soils, the use of acid-producing fertilisers and additives such as

elemental sulfur and gypsum has long been applied (Tavakkoli et al., 2022).

#### 5. Genetic Biofortification

Increasing the micronutrient content in plant tissue by the use of mineral fertilisers can help grow crops with a better ability to absorb and accumulate these elements in their edible portions. The identified genetic variation found in plant species defines Fe, Zn, Cu, and Se concentrations in edible tissues of crop plants. According to present and past findings, changes in micronutrient concentration in plant tissue are significantly less than those of the above-mentioned micronutrients (Yadava et al., 2017; Earagariyanna et al., 2017). The *Lolium spp.*, *Medicago spp.*, and *Festuca spp.* are some of the fodder crops improved through breeding. Individual plants have been discovered with high genotypic and phenotypic diversity, as well as polyploidy, which is increased by inbreeding in a variety of grasses and the association of a few agronomic factors with unique genes. (Collins et al., 2012; Blackmore et al., 2016). Pearl millet is the cheapest source of Fe and Zn; pearl millet has a wide range of genotypes for these minerals (Velu et al., 2007). ICRISAT and Harvestplus launched the biofortified variety of pearl millet, which is rich in Fe and Zn, "Dhanashakti" and a hybrid ICMH 1201 (Shakti-1201) in India in 2014. Several commercial cultivars with high Fe and Zn content in grain have been identified, along with their progenies and hybrids (Rai et al., 2012). Sorghum cultivars with high mineral, protein, lutein, zeaxanthin, and beta-carotene content have been examined. For Fe and Zn content, sorghum germplasm has demonstrated a lot of diversity and genetic heritability (Kumar et al., 2013). ICRISAT has developed and released biofortified Fe sorghum varieties ICSR 14001, ICSR 14002, and hybrids ICSA 318, ICSA 336, ICSA 661, ICSR 94, ICSR 196, and IS 3760. Cowpea has been biofortified through breeding to increase Fe content. G. B. Pant University of Agriculture and Technology, Pantnagar, in partnership with HarvestPlus, in India, has released the varieties of cowpea Pant Lobia-1, Pant Lobia-2, Pant Lobia-3, Pant Lobia-4, and Pant Lobia-7. These varieties are rich in Fe content. An experimental trial was conducted to feed Zn-biofortified sorghum stover of sorghum to sheep to ameliorate Zn deficiency (Giridhar et al., 2021). So, we can use biofortified crop varieties by-products and grain for animal feeding developed by conventional breeding.

#### 6. Transgenic Biofortification

Genetically modified alfalfa crops increase phytase activity that eliminates the needs of phosphorus

supplementation in animal feed used for livestock, fish, and poultry (Austin-Phillips et al., 2001). Barley has been targeted for improvement in nutritional quality because it is an ideal cereal and fodder crop. Its Zn level has increased due to the overexpression of zinc transporters. Activation of the phytase gene [HvPAPhy] has increased phytase activity in barley seeds, thereby increasing Fe and Zn bioavailability (Holme et al., 2017). Improvements in feed digestibility have also been studied since they are linked to animal performance. Three distinct cytochrome P450 enzymes were targeted for antisense-mediated expression reduction to establish modified alfalfa cultivars with substantially lower lignin concentrations (Reddy et al., 2005). Agronomic and genetic biofortification are combined in transgenic biofortification to promote micronutrient phytoavailability inside the soil rhizosphere and absorption translocation into smaller parts of the crop plant, then storage in consumable organs (Davies, 2007). Methionine is an amino acid that is used to make proteins and also plays a key role in many other biological functions. The Dzs10 cis-acting location was added to increase its concentration in maize. The amino acid equilibrium of maize has been improved to generate milk protein lactalbumin in the milch animals (Chen et al., 2008). In addition, the intention of transgenic biofortification seems to reduce antinutrient concentrations while raising the level of enhancer chemicals, which facilitate microelement assimilation inside the gut (Whitem & Broadley, 2009). Sorghum is one of the most important staple foods for millions of poor rural people. The improvement of provitamin A levels by releasing Homo188-A (beta-carotene). Sorghum's concentration of the essential amino acid lysine was raised after a high-lysine protein [HT12] was inserted (Zhao et al., 2003; Lipkie et al., 2013). Several stress-tolerant forage crop gene editing lines have been produced to aid biomass growth and nutritional quality. CRISPR/Cas9 was used to effectively alter the Squamaosa promoter binding (SPL9) gene in *Medicago sativa* (Gao et

al., 2018). The identification of genes or quantitative trait loci (QTL) connected to micro-elements like carotenoids, Fe and Zn and important amino acids in pearl millet germplasm lines is aided by molecular segmentation of germplasm types. Varietals having better nutrient quality have been generated thanks to the evolutionary divergence of these genes, also known as quantitative trait loci (QTL) (Boncompagni et al., 2018). In sorghum (*Sorghum bicolor*), recent advances in biotechnological technologies have allowed improving the important minerals, micronutrients, amino acids, and fatty acids, through genetic engineering (Reddy et al., 2005; Elkonin et al., 2018). Using genetic manipulation specifically increased the bioavailability of lysine, vitamin A, iron, and zinc in the sorghum crop (Zhao et al., 2019) (Table 4). Therefore, this method makes it possible to generate multiple nutrient-rich crop cultivars in a single phase and provides new opportunities. By developing methods to jointly target multiple micronutrients while accounting for their stability, metabolic engineering applications will make significant progress in this direction.

## 7. Conclusion

To solve the nutritional problem in animals, biofortification is a sustainable and cost-effective way to enrich feed and fodder crops. Biofortified material improves the health of malnourished animals. Different approaches of biofortification to increase the bioavailability of essential micronutrients in the feed and fodder crops eradicate all forms of nutritional problems in the animals. To overcome micronutrient insufficiency in the animal population, agronomic biofortification by fertilisation appears to be a viable and cost-effective strategy. The inorganic and organic sources of inputs might be used as direct sources of nutrients to help in the adequate availability of micronutrients to the animals. Multi-biofortified feed and fodder crops are given more weightage to produce quality feed and fodder. Feeding biofortified material to the animals increases the milk yield, growth, and overall performance. Optimising quality

**Table 4.** Application of transgenic biofortification techniques in fodder crops

Crop	Gene/protein/enzyme	Targeted nutrient	Gene/protein expression	Source
Alfalfa	phytase	Phosphorus	Eliminates the needs of phosphorus supplementation in animal feed	(Austin-Phillips et al., 2001)
Barley	phytase gene [HvPAPhy]	Zn	Increasing Fe and Zn bioavailability	(Holme et al., 2017)
Alfalfa	Cytochrome P450 enzymes	Lignin	Improvements in feed digestibility reduce lignin content	(Reddy et al., 2005)
Sorghum	Homo188-A, protein [HT12]	Provitamin-A amino acid lysine	Improvement of provitamin-A and lysine content	(Zhao et al., 2003; Lipkie et al., 2013)

enhances the capacity of fodder utilisation, reduces crop wastage, and helps to maintain a sustainable dairy industry. As a result, the knowledge presented here will help to address future nutritional security and to increase the bioavailability of micronutrients within forage crops to the animals.

#### CRedit Authorship Contribution Statement

Brijesh Kumar: Conceptualization, review collection, Writing-original draft, Supervision, Magan Singh: Reviewing and editing, Deepak Kumar: Reviewing and editing, Sandeep Kumar: Reviewing and editing, Rekha Rana: Visualization and tabulation.

#### Conflicts of Interest

There is no conflict of interest in personal and financial interests.

#### Declaration of Generative AI and AI-assisted technologies in the writing process

Article fully written manually without the use of AI.

#### Data Availability Statement

The published data will be available as per the user's request.

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