REVIEW OF SELECTED TRACE ELEMENTS CONTAINED IN TROPICAL MEDICINAL PLANTS UTILISED IN ANIMAL PRODUCTION

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Abstract. The use of different parts of plants as nutraceuticals to boost animal productivity is on the rise because of the ban on the use of antibiotic growth promoters in animal diets, and the presumption that medicinal plants have no adverse effects on animals. Analytical studies have shown that tropical plants are rich sources of beneficial phytochemicals and essential nutrients with minimal concentrations of anti-nutrients. However, most of the research on tropical medicinal plants is focused on their phytochemical with less attention given to their trace element composition and concentration. Therefore, detailed knowledge of the trace element content of tropical medicinal plants is essential in maximising their use in livestock production. Moreso, published data on trace mineral values of tropical medicinal plants used in animal production are fragmented in the literature, making it difficult to use this important information in the decision-making process. Thus, the purpose of this paper was to condense evidence on the manganese, zinc, copper, and iron content of some tropical plants used in animal production as feedstuffs or to treat a variety of ailments, as well as factors that affect their uptake and absorption in the gastrointestinal tract. This paper will also review the roles of trace minerals in enzyme systems and performance indicators of animals on dietary trace element salt supplementation.

Keywords: *tropics, medicinal plants, microminerals, farm animal, micromineral requirements*

Introduction

Livestock production fulfils important socio-economic roles in the livelihood of rural people through the supply of milk, eggs, and meat (Becker, 2015; Nkonki-Mandleleni, 2019). The growing awareness of consumers on the benefits of healthy animal products, the demand for increased animal products, rising feed cost, and restrictions on the utilisation of antibiotics growth promoters (AGPs) in livestock production have boosted investigation into the use of medicinal plants to enhance animal productivity and product quality (Dibner and Richards, 2005; Shaib et al., 2022; Ogbuewu et al., 2023). Medicinal plants are rich in minerals, fibre, vitamins, and proteins (Ukorebi, 2011; Okoli et al., 2019), as well as in beneficial bioactive compounds (Ukorebi, 2011; Ogbuewu et al., 2023). They are used in traditional medicine to treat a variety of diseases (Eleyinmi, 2007; Ogbuewu et al., 2023). The therapeutic properties of tropical plants are found in some of their organic and inorganic components, which elicit a specific physiological effect in the animal body (Ukorebi, 2011; Okoli et al., 2019; Ogbuewu et al., 2023).

Minerals, one of the inorganic components found in tropical medicinal plants are categorised into macro and trace elements based on the concentration needed in the animal body (Underwood and Suttle, 1999). Macro-minerals such as potassium, sodium, calcium, phosphorus, magnesium, and several others are required in relatively large amounts in the animal body and are measured in g/kg. On the other hand, trace elements such as selenium, copper, zinc, iron, and manganese are needed in small amounts in the body (Underwood and Suttle, 1999; USDA, 2018) and are measured in mg/100 g or mg/kg. Trace elements are crucial for optimal growth and development in animals (Richards et al., 2010), depending on their balance (Esonu, 2006). They are also required for bone development, feathering, growth, and appetite in broiler chickens (Nollet et al., 2007). Moreso, trace minerals support the antioxidant system and hormone production in animals (Esonu, 2006; Ogbuewu et al., 2015). Thus, increasing our knowledge and understating of trace element contents of tropical medicinal plants is critical for maximising their use as feedstuffs and additives in the animal production industry (Serror-Armah et al., 2002; Baljinnyam et al., 2014).

While a quite number of studies have focused on the nutritional and medicinal values of tropical medicinal plants, as well as their positive impact on animal performance, little attention has been paid to the trace mineral contents of this important biological resource (Okoli et al., 2003, 2019; Ogbuewu et al., 2023). Published data available on the micro-mineral content of medicinal plants used in animal production as feedstuffs or to treat a variety of ailments is limited and fragmented in the literature, making it hard to use this important information in evidence-based decision-making. To the best of our knowledge, no review on the trace element contents of tropical medicinal plants used in animal production, especially in the tropics has been published. Therefore, this review aimed to condense evidence on the manganese, zinc, copper, and iron content of tropical plants used in animal production, as well as the factors that influence the bioavailability of these trace elements in the gastrointestinal tract. This review will also discuss the role of trace minerals in enzyme systems as well as the performance indices of livestock and chickens on dietary trace element supplementation.

Methodology

The thrust of this review was to aggregate published evidence on beneficial trace mineral elements present in tropical plants utilised in livestock and chicken production. In light of this, it was pertinent to condense evidence on the trace mineral contents of tropical plants to maximise their use in animal production. Publications utilised for the study were retrieved from PubMed, ScienceDirect, Scopus, Web of Science, and Google Scholar databases using the combinations of the following search terms: trace elements, tropical plants, trace element supplementation, and animal performance. The reference sections of retrieved papers were also screened for other related studies. The search was not restricted by language and date. In the first phase of screening, the search performed on the Google Scholar search engine using the search terms ‘tropical medicinal plants’ and ‘trace elements’ yielded 32,300,000 articles. Most of the studies were not in our area of interest and were not included in the review. As a result, the search term ‘animal production’ was included in the search to exclude articles that were not relevant to the review. As a result, 5,340,000 articles were identified. These publications were evaluated based on their title, abstract, and keywords. Based on this, several publications were excluded after reading the titles and abstract, or because the study was not done in tropical medicinal plants, parameters of interest were not on trace elements, and they were duplicates across two or more databases. Two hundred and eighty (280) full-text studies were assessed for eligibility of which 98 were used for the review.

Trace elements in the animal enzyme system

Trace mineral elements are considered essential for normal body functions (Okoli et al., 2019). Trace minerals are involved in several biological functions including the transport of oxygen in the blood and the maintenance of cell membrane integrity (Murray et al., 2000). They also act as cofactors to several metalloenzymes. Trace elements are components of hormones and mediate nutrients (i.e., carbohydrates, fat, and protein) and nucleic acid metabolism. Specifically, zinc is involved in acid-base balance, carbohydrate metabolism, and protein synthesis (Krupanidhi et al., 2008; Plum et al., 2010). It also plays an important part in nucleic acid metabolism, cell replication, tissue repair, and growth. Furthermore, zinc is needed for organogenesis, proper functioning of neurotransmitters, development of thymus, epithelialization in wound healing, taste sensation, and secretion of pancreas and gastric enzymes (Murray et al., 2000). Zinc is excreted from the body via the pancreas, intestine, and kidney (Todd et al., 1980). In animals, zinc deficiency results in loss of appetite, decreased growth rates, and lowered immunity. The trace minerals involved in animal enzyme systems and their functions are illustrated in *Table 1*.

Table 1. *Some important metalloenzymes and metalloproteins in animals*

Elements	Metalloenzymes/proteins	Functions
Copper	Superoxide dismutase	Dismutation of superoxide radical
Copper	Ceruloplasmin	Copper transport
Copper	Hephaestin	Iron absorption
Copper	Lysyl oxidase	Lysine oxidation
Copper	Cytochrome oxidase	Terminal oxidase
Iron	Hepcidin	Iron regulating hormones
Iron	Haemoglobin	Oxygen transport in the blood
Iron	Catalase	Protection against H_20_2
Iron	Succinate dehydrogenase	Oxidation of carbohydrates
Manganese	Pyruvate carboxylase	Pyruvate metabolism
Manganese	Superoxide dismutase	Removal of superoxide radical
Manganese	Glycosyl aminotransferases	Proteoglycan synthesis
Zinc	Alkaline phosphatase	Hydrolysis of phosphate esters
Zinc	Phospholipase A2	Hydrolysis of phosphatidylcholine
Zinc	Carbonic anhydrase	Formation of carbon (iv) oxide

Source: Georgievskii (1982)

Copper is an essential part of numerous metalloenzymes as mentioned in *Table 1* (Crapo et al., 1992; Harris, 2001; Manto, 2014). Furthermore, copper plays an essential part in electron and oxygen transport, oxidation-reduction reactions, and shields the cells from oxidative stress (Manto, 2014). Copper has been reported to play a role in haemoglobin formation, tissue pigmentation, and cellular respiration (Turnlund, 1998; Gaetke and Chow, 2003). Unlike monogastric animals, ruminants have a low ability to regulate copper, making them prone to secondary copper deficiency caused by antagonism between sulphur, molybdenum, copper, and sulphur in the forestomach (NRC, 2005). Excessive intake of copper has been found to cause liver damage (NIH, 2017). Copper deficiency in animals can result in lowered immunity, anaemia, decreased growth rates, and reduced conception rates.

Manganese is a trace element that all animals require in trace amounts. In the body, manganese is widespread but is concentrated in bone and liver. Manganese acts as a cofactor in lipid metabolism by assisting in cholesterol and fatty acid synthesis (Rehnberg et al., 1982). It also plays an active role in the urea cycle, oxidative phosphorylation, and mucopolysaccharide metabolism (Rehnberg et al., 1982). Manganese serves as a cofactor for many enzymes that catalyse carbohydrate, fat, and protein metabolism. Excess calcium or phosphorus in the diet inhibits manganese absorption in the digestive system. Manganese is absorbed from the digestive as Mn^{2+}, oxidized to form Mn^{3+}, and transported to tissues via transferrin. Excess manganese in the diet can cause iron deficiency (EFSA, 2013).

Iron is a constituent of haemoglobin and myoglobin and is found in a variety of enzymes. The total concentration of iron in the body is about 3-5 g, with 75% found in erythrocytes, while the rest is found in the liver, bone marrow, and muscles (Vasudevan and Sreekumari, 2007). Iron also forms important complexes with peroxidase, succinate-ubiquinone reductase, cytochrome P-450, cytochrome C, cytochrome oxidase, ubiquinol-cytochrome C reductase, nicotinamide adenine dinucleotide (NADH)-ubiquinone reductase, tryptophan pyrrolase, and catalase, which are involved in electron transfer mechanisms, oxidative metabolism, and energy production in the mitochondria (Vasudevan and Sreekumari, 2007). Inadequate iron intake in the animal body causes iron-related anaemia, since bone marrow requires iron to produce haemoglobin (Fu et al., 2004).

Dietary trace minerals versus chicken performance

The NRC (1994) data summarised in *Table 2* suggest that trace element requirements of immature white and brown-egg-laying strains maintained the following order: iron > manganese > zinc > copper at the first 6 weeks of age. The high need for iron in immature laying hens could be due to the role of iron in regulating hormones, electron transport, handling of molecular oxygen, and oxygen transport and storage (McDowell, 2003). Abbasi et al. (2015) found that increasing the level of iron in the diet of layers increases egg weight. Copper, manganese, and zinc are also required for the formation of eggshell (McDowell, 2003). Copper deficiency in layers has been shown to affect the formation of lysine-derived cross-links, which are implicated in the biochemical and mechanical properties of eggshell membranes (Chowdhury, 1990), leading to egg-shape abnormalities. Manganese is a part of Galβ1,3-glucuronosyltransferase, which plays a vital role in proteoglycan synthesis. Available evidence revealed that dietary manganese supplementation improves the formation of glycosaminoglycan in eggshell and may modify its microstructure and breaking strength (Xiao et al., 2014, 2015). Zinc is a component of carbonic anhydrase, an enzyme that assists rapid inter-conversion of carbon dioxide and water into carbonic acid, protons, and bicarbonate ions required for eggshell formation. Inhibition of anhydrase synthesis results in lowered bicarbonate ion secretion and greatly reduces eggshell weight (Nys et al., 1999). Data in *Table 2* indicated that trace mineral requirements of broiler chickens at starter and finisher phases followed the same pattern with immature white and brown egg-laying strains aged 1-6 weeks. Layers fed zinc-deficient diets (<10 mg/kg diet) produced fewer eggs and consumed less feed (Naz et al., 2016). Improved bone quality and higher body weight and lower feed conversion ratio were also observed in broiler chickens fed diets supplemented with trace elements (copper, iron, manganese, and zinc) than those without trace element supplementation

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(Zhao et al., 2010; M'Sadeq et al., 2018). This observation was consistent with the results of Rao et al. (2013) showing a lower feed conversion ratio in chickens with trace element supplementation. Low dietary zinc intake in breeder broilers results in poor hatchability, impaired growth, and abnormal organ development with embryo death in extreme cases (Amen and Al-Daraji, 2011; Zhu et al., 2017).

Table 2. *Trace mineral requirements of immature layers (mg/kg diet)*

Item	**Trace elements**			
	Copper	Zinc	Iron	Manganese
White-egg-laying strains				
0 - 6 wks	5.0	40.0	80.0	60.0
6 - 12 wks	4.0	35.0	60.0	30.0
12 - 18 wks	4.0	35.0	60.0	30.0
18 weeks to first egg	4.0	35.0	60.0	30.0
Brown-egg-laying strains				
0 - 6 wks	5.0	38.0	75.00	56.0
6 - 12 wks	4.0	33.0	56.0	28.0
12 - 18 wks	4.0	33.0	56.0	28.0
18 weeks to first egg	4.0	33.0	56.0	28.0
Broiler chickens				
0-3 weeks	8.0	40.0	80.0	60.0
3-6 weeks	8.0	40.0	80.0	60.0
6-8 weeks	8.0	40.0	80.0	60.0

Source: NRC (1994)

Dietary trace minerals versus swine productivity

Table 3 summarised trace mineral requirements of pigs at different phases of growth and physiological state (NRC, 2012). Trace minerals control many metabolic pathways for energy efficiency, health, and immunity in pigs. They are also required by pigs for the various processes of life, including maintenance, growth, reproduction, and lactation. Deficiencies of trace elements in a swine diet will limit their performance and welfare, and diets with excessive trace elements are expensive and contribute to environmental pollution. The piglet is born with depleted iron reserves and requires iron supplementation after birth to avoid anaemia. Absorption of trace minerals is often a major limitation of their utilization in the ration (Acda and Chae, 2002). Smits and Henman (2000) fed diets containing either no added copper (control: 20 mg/kg), inorganic copper (150 mg/kg), or organic copper (40 mg/kg) had similar body weight gain at both growing (30-60 kg) and finishing (60-90 kg) phases. However, the feed conversion ratio only improved at the finishing phase and not at the growing phase. Trace elements supplementation, especially iron has been shown to improve reproductive efficiency in pigs (Fehse and Close, 2000; Acda and Chae, 2002). Studies have shown that supplementation of dietary manganese above the rate recommended by the NRC (2012) for piglets (5-11 kg) as shown in *Table 3* improved average daily gain, feed intake, and feed conversion ratio in piglets (Edmunds et al., 2022). In addition, they reported that dietary manganese supplementation improved the antioxidant status of weaned piglets by enhancing the activity level of manganese superoxide dismutase (MnSOD) in the red blood cells.

Table 3. *Trace mineral requirements of pigs (mg/kg diet)*

Body weights (kg)	**Trace elements**			
	Copper	Zinc	Iron	Manganese
Requirement (amount per day)				
5-7	1.60	26.6	26.6	1.06
7-11	2.81	46.8	46.8	1.87
11-25	4.53	72.4	90.5	2.72
25-50	6.01	90.2	90.2	3.01
50-75	7.41	105.9	105.9	4.24
75-100	7.52	125.3	100.2	5.01
100-125	8.36	139.4	111.5	5.57
Dietary requirement (per kg diet)				
Gestation	10.0	100	80.0	25.0
Lactation	20.0	100	80.0	25.0
Daily requirement (per kg diet)				
Gestation	21.0	210	168	52.49
Lactation	119.32	596.6	477.3	149.15

Source: NRC (2012)

Dietary trace minerals versus ruminant performance

Numerous authors have found beneficial impacts of trace minerals in ruminant nutrition (Griffiths et al., 2007; Ogbuewu et al., 2015). Supplementation of ruminant diets with essential trace elements improved their productive indices and health status (Griffiths et al., 2007). The high content of copper and zinc in the rumen has been reported to impair fibre degradation and modify ruminal fermentation (Durand and Kawashima, 1980; Daniel et al., 2020; Guimaraes et al., 2021). Copper deficiency in small ruminants leads to delayed estrus, abortion, congenital ataxia, and infertility (Minatel and Carfagnini, 2000; Smith and Akinbamijo, 2000). Excessive intake of copper, manganese, and zinc by ruminants decreased fertility before breeding (Nayeri et al., 2014). In calves, zinc deficiency causes slow wound healing which can lead to secondary infections (Van Emon et al., 2020). Ewes fed zinc-free rations during pregnancy had lambs with lower birth and liver weights, as well as lower zinc levels in their carcass, liver, and pancreas (Masters et al., 1988). In contrast, Nayeri et al. (2014) found that zinc supplementation did not affect calf birth weight in ruminants. This variability in results could be ascribed to zinc form, dosage, and ruminant type (Norton, 1994). In vitro studies have indicated that the inclusion of an inorganic form of manganese in the diet at a rate higher than 100 μg/ml reduced rumen cellulose degradation, whereas the reverse was the case when inorganic manganese was added at the rate of 5–30 μg/ml (Martinez and Church, 1970). In a similar study, Kisidayova et al. (2018) noticed that supplementation of high doses of organic and inorganic manganese (184 and 182.7 mg total Mn/kg dry matter, respectively) in lamb diets did not influence the number and species composition of ciliates and the number of bacteria in the rumen. The supplementation of 30 mg/kg of iron from an iron-amino acid complex to rations offered to cows at dry cows, transition cows, and early lactation phase did not influence milk production and milk composition (Weiss et al., 2010). The trace mineral requirements of ruminants are presented in *Table 4*.

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Table 4. *Trace mineral requirements of dairy cattle (mg/kg dry matter intake)*

Minerals	Growing heifer	Dry cow	Lactating cow	Young goat*	Young sheep*
Cu	10	13	11	-	-
Zn	43	18	15	>10--50	20-33
Fe	22	18	14	30-100	30-50
Mn	32	22	48	20-40	20-40

Source: Spears and Engle (2016); *NRC (1985)

Tropical plants as a source of trace minerals

Trace minerals are considered vital due to the role they play in the body to maintain animal and human health (Esonu, 2006). Mineral analysis of tropical trees and shrubs is considered vital due to its beneficial effect on livestock and chicken production (Ogbuewu and Mbajiorgu, 2019; Okoli et al., 2019). Nutritional analysis of tropical medicinal plants suggests that most tropical medicinal plants are moderate sources of important trace elements (Ogbuewu et al., 2014; Modisaojang-Mojanaja et al., 2019; Okoli et al., 2019). Heavy metals were found in a few tropical plants, but their concentrations were lower than the safe level (Ogbuewu and Mbajiorgu, 2019; Okoli et al., 2019; Oteng et al., 2022). The high iron content of the yellow pawpaw leaf as reported by Ayoola and Adeyeye (2010) suggests that it could be used as an anti-anaemic agent in animals consuming this leaf meal. This finding corroborates the trend of trace element concentrations in *Ficus microcarpa* leaf meal (Iron > Manganese > Zinc > Copper) reported by Achonwa et al. (2019), and (Iron > Zinc > Copper > Manganese) and (Iron > Manganese > Copper > Zinc) documented by Okoli et al. (2019) for leaf meals of *Mucuna pruriens* and *Garcinia kola*, respectively. This suggests that iron is the highest trace element in most plants in southeastern Nigeria. Available data suggest that *Tetrapleura tetraptera* plant contains an appreciable amount of trace minerals, especially iron and manganese (Oteng et al., 2022). However, there is limited published information on the extractabilities of trace elements in tropical medical plants in the literature. A study by Oteng et al. (2022) observed the low extractability of manganese in the *T. tetraptera* seeds as compared with the high extractability in its pulp and whole fruit. This difference could be attributed to the high concentrations of fibre and tannins in the *T. tetraptera* seeds, which have been shown to inhibit the bioavailability of minerals contained in feedstuffs (Parada and Aguilera, 2007).

The pulp, leaf, and stem bark of *Dialum guineense* are moderate in selenium, manganese, and zinc and low in anti-nutrients (Ogbuewu et al., 2023). *D. guineense* pulp is also moderate in iron (14.75 mg/100g), (Osanaiye et al., 2013; Gnansounou et al., 2014). The iron content of *D. guineense* plant is higher than the value found in raw lean beef (1.8 mg/100g) reported to be a rich source of iron (Williams, 2007; Gnansounou et al., 2014). The appreciable levels of iron and vitamin C in *D. guineense* together with the low levels of anti-nutrients (Niyi, 2015) suggest that *D. guineense* pulp can be given to piglets to ameliorate the problem of iron deficiency anaemia. In a similar study, Sahito et al. (2003) found considerable amounts of zinc, copper, and iron in the leaves, stem, and fruit of *Azadirachta indica* which were comparable to the values obtained by Otache and Agbajor (2017) in the same plant. There is evidence that neem leaves contain an appreciable amount of iron that can be supplemented in livestock diets to meet their daily iron requirement (Sahito et al., 2003; Otache and Agbajor, 2017; Alade et al., 2018).

Microdesmis puberula, a preferred browse plant contains zinc (0.20 - 0.24 mg/kg) and iron (13.83 - 24.50 mg/kg) in amounts that can help prevent the problem of mineral deficiency in animals (Esonu et al., 2003; Fu et al., 2014; Gbadamosi and Oloyede, 2014). *Moringa oleifera* leaves and seeds are also moderate in iron (316.98 mg/kg) as reported by others (Olugbemi et al., 2010; Modisaojang-Mojanaja et al., 2019). This was consistent with the findings of Alikwe and Omotosho (2013); Annongu et al. (2014); Limmatvapirat et al. (2015) who reported that *M. oleifera* leaves and seeds are moderate in trace minerals. The iron content of *M. puberula* and *M. oleifera* leaves as reported by others (Gbadamosi and Oloyede, 2014; Udo et al., 2017) was higher than the value of 0.38 mg/kg reported for pumpkin leaves, which are used to boost blood for anaemic patients (Ibironke and Owotomo, 2019). This implies that leaf meals of *M. puberula* and *M. oleifera* trees could be used as an iron-based supplement to enhance livestock and chicken productivity. In addition, *M. oleifera* and *M. puberula* leaf extracts could be used to improve blood iron levels in farm animals, especially piglets that don’t have enough iron to maintain satisfactory blood levels of haemoglobin, as sows' milk is low in iron (Nath et al., 2015). Mineral analysis of ginger rhizomes indicates their moderate source of essential trace elements (Ogbuewu et al., 2014). However, the concentrations of trace elements in two varieties of ginger as reported in the literature (Ajayi et al., 2013) were lower than the values reported by Ogbuewu et al. (2014). This disparity in the trace mineral content of ginger could be attributed to species differences, soil type, and age (Norton, 1994). *Table 5* summarised the trace mineral composition and concentration of several parts of tropical medicinal plants used in animal production.

Factors limiting the intake of trace elements in tropical plants

Even though plants are high in essential nutrients, including beneficial trace elements, it is important to take into account the existence of toxic and deleterious anti-nutrients found in several parts of tropical medicinal plants, which may limit their availability in gastrointestinal tract. These anti-nutrient agents include indigestible fibre, cyanogenic glycosides, saponins, tannins, and others (Shih et al., 2011). It has been reported that some anti-nutrients found in plants such as oxalates, phytates, and saponins inhibit the uptake of trace elements from the gastrointestinal tracts (Parada and Aguilera, 2007). There are also absorptive interactions between iron, zinc, and copper (Hund-Rinke and Kordel, 2003), which may affect their uptake from the digestive system. The absorption of selenium and copper is much lower in ruminants than in non-ruminants, which is due to modifications that occur in the rumen environment (Spears, 2003). Regardless of various published evidence on the mineral composition and concentration of various tropical medicinal plants used in animal diets (Ogbuewu et al., 2014; Modisaojang-Mojanaja et al., 2019; Okoli et al., 2019), data on the bioavailability and digestibility of minerals from tropical plants used in livestock and chicken diets are lacking in the literature.

Limitations and strengths of the study

Some of the limitations in this review are: the plants used by the authors whose studies were reviewed vary in the age the analyses were performed, variations in soil, plant part, and climatic variables may have an impact on the validity of the findings. Furthermore, variations in analytical protocols may constitute a limitation.

Table 5. *Composition and concentrations of essential trace elements in tropical medicinal plants*

Items	Study country	Common name	Plant part	Composition (mg/kg)				Authors
				Copper	Zinc	Mn	Iron	
Zingiber officinale	Nigeria	Ginger	Rhizome	4.19	18.90	0.86	1.59	Ogbuewu et al. (2014)
Zingiber officinale	Pakistan	Ginger	Rhizome	12.50	12.23	7.33	80.00	Shahid and Hussain (2012)
Zingiber officinale	Nigeria	Ginger	Rhizome	94.9	43.8	367.9	1219.2	Obiajunwa et al. (2002)
Moringa oleifera	South Africa	Moringa	Leaf	-	-	12.52	316.98	Modisaojang-Mojanaja et al. (2019)
Moringa oleifera	Nigeria/India	Moringa	Leaf	12.0	47.0	122.0	415.0	Annongu et al. 2014, Limmatvapirat et al. (2015)
Moringa oleifera	Nigeria/India	Moringa	Seed	6.0	41.0	125.0	142.0	Alikwe and Omotosho (2013), Annongu et al. (2014), Limmatvapirat et al. (2015)
Carica papaya	Nigeria	Paw paw	Green leaf	-	-	9.50	90.50	Ayoola and Adeyeye (2010)
Carica papaya	Nigeria	Paw paw	Yellow leaf	-	-	5.50	147.50	Ayoola and Adeyeye (2010)
Carica papaya	Nigeria	Paw paw	Brown leaf	-	-	4.50	79.50	Ayoola and Adeyeye (2010)
Mangifera indica	Nigeria	Mango	Leaf	188.1	127.6	796.3	404.4	Obiajunwa et al. (2002)
Azadirachta indica	Kenya	Neem	Leaf		45.18			Njenga (2017)
Azadirachta indica	Kenya	Neem	Bark		37.51			Njenga (2017)
Azadirachta indica	Kenya	Neem	Fruits		33.27			Njenga (2017)
Azadirachta indica	Nigeria	Neem	Bark	BDL	BDL	0.19	7.22	Alade et al. (2018)
Ocimum gratissimum	Nigeria	Scent leaf	Leaf	138.1	88.9	66.2	305.4	Obiajunwa et al. (2002)
Tetrapleura tetraptera	Ghana	Gum tree	Pulp	16.10	31.60	55.30	162.00	Oteng et al. (2022)
Tetrapleura tetraptera	Ghana	Gum tree	Seed	11.90	43.40	156.00	115.00	Oteng et al. (2022)
Spondias monbin	Nigeria	Hog plum	Leaf	142.4	69.3	137.7	354.6	Obiajunwa et al. (2002)
Vernonia amygdalina	Nigeria	Bitter leaf	Leaf	BDL	0.25	0.35	5.75	Alade et al. (2018)
Garcinia kola	Nigeria	Bitter kola	Seed	188.6	105.3	53.5	148.7	Obiajunwa et al. (2002)
Microdesmis puberula	Nigeria	Microdesmis	-	-	0.20	0.20	24.50	Gbadamosi and Oloyede (2014)
Microdesmis puberula	Nigeria	Microdesmis	Leaf	-	4.08	-	18.87	Udo et al. (2017)
Ficus exasperata	Nigeria	White fig		99.3	51.5	126.2	187.0	Obiajunwa et al. (2002)
Ficus microcarpa	Nigeria	Curtain fig	Leaf	32.74	32.74	57.10	708.00	Achonwa et al. (2019)
Aframomum melegueta	Nigeria	Wild cardamom	seed	247.8	120.0	232.3	333.2	Obiajunwa et al. (2002)
Alchornea cordifolia	Nigeria	Christmas bush	Leaf	124.0	71.3	274.1	161.1	Obiajunwa et al. (2002)
Azadirachta indica	Nigeria	Neem	Leaf	141.5	58.2	40.8	245.3	Obiajunwa et al. (2002)
Chromolaena odorata	Nigeria	Siam weed	Leaf	148.3	95.0	187.7	261.2	Obiajunwa et al. (2002)
Euphorbia hirta	Nigeria	Asthma-plant	Aerial part	234.8	191.1	52.0	535.7	Obiajunwa et al. (2002)

Mn - Manganese

Notwithstanding these limitations, the findings of this review have contributed significantly to our understanding of the composition and concentration of copper, zinc, manganese, and iron in tropical plants utilised in animal production. To the best of our knowledge, this is the first study to condense evidence on trace element profiles of tropical plants used in animal production, thus making it easy to use this important information in decision-making.

Conclusion and future perceptive

This review suggests that several parts of tropical plants contain appreciable amounts of iron, manganese, zinc, and copper, implying that the inclusion of tropical plants in feed as a nutraceutical will improve the mineral status and well-being of farm animals. However, extensive research on the toxicity of tropical plants used in animal production is needed before they can be used as nutraceuticals as such data is lacking in the literature. Despite promising results on the potential of tropical plant products to improve livestock performance, there is yet a problem with anti-nutritional elements that may limit the digestion and absorption of these elements when consumed in large amounts. In view of this, research into the use of biotechnology to eliminate the challenge of anti-nutritional elements in tropical plants should be considered. Moreso, research focusing on the bioavailability and digestibility of trace minerals present in tropical plants would be required for enhanced utilisation of these trace elements as feed supplements in animal production, as little or no investigation has been done and reported in this area.

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