



Indigenous ethno-nutraceutical plants: Potential game-changers for the dual management of ruminant helminths and undernutrition in sub-saharan africa

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ARTICLE INFO

Handling editor: D M Leonti

Keywords:

Anthelmintic activity
Ethno-nutraceutical plants
helminth infections
Nutritional potency
Phytochemicals
Ruminant productivity

ABSTRACT

Ethnopharmacological relevance: Ruminant productivity in sub-Saharan Africa (SSA) remains low largely due to helminth infections coupled with undernutrition. To jointly boost ruminant health and nutritional status, rural farmers in SSA often resort to indigenous ethno-nutraceutical plants (iENPs), which form part of folkloric practices perceived to be more accessible, affordable and effective compared with chemotherapy which is challenged by helminth resistance. However, these perceived advantages are largely unsubstantiated.

Aim of the study: The current review aimed to 1) identify iENPs used as ruminant anthelmintic and undernutrition remedies in SSA, 2) document their bio-efficiency, mode of action, safety, and optimal application conditions and 3) highlight priority areas for further research.

Materials and methods: A PRISMA approach-based search of literature from the past three decades was performed in several electronic academic research databases and accredited scholarly repositories.

Results: The review identified 15 iENPs from 88 scientific articles. The *Vachellia* and *Vernonia* species possessing polyphenols, saponins and essential oils as the dominant phytochemicals demonstrated the highest anthelmintic and nutritional potency. However, for most iENPs, nutrients and phytochemicals have not been fully profiled, optimal conditions of application are not yet ascertained, bio-efficiency is highly variable, mode of action remains unclear, and safety limits are unknown.

Conclusion: To exploit the full potential of SSA's iENPs as anthelmintic and undernutrition remedies for ruminants, the review advocates for a holistic, transdisciplinary regional approach focusing on identifying key phytochemicals in indigenous plants, validating their bio-efficacy and mechanisms of action, determining safety limits, and optimizing application conditions using least-cost technologies.

1. Introduction

Grazing ruminants (i.e., cattle, sheep and goats) are a predominant source of proteinaceous food, income, draught power, and sociocultural wealth for smallholder farmers who constitute about 60 % of sub-Saharan Africa (SSA)'s total human population of 1.24 billion (Ayantunde et al., 2018; WorldPopulationReview.com, 2024 a, b, c, d). However, grazing ruminant productivity in SSA remains unsustainable largely due to high prevalence of helminth infections coupled with

undernutrition (Ayantunde et al., 2018; Erdaw, 2023). Helminth infections adversely affect animals' nutritional status through reductions in nutrient intake, digestion, absorption and metabolism, while undernutrition elevates animals' vulnerability to infections by weakening the immune system leading to a vicious cycle of infection and undernutrition (Hoste et al., 2016; Cei et al., 2018). Globally, the economic loss due to reduced ruminant productivity caused by gastrointestinal nematodes is estimated at US \$ 25 billion (Strydom et al., 2023). To dually manage helminth infections and undernutrition in ruminants, more than 80 % of

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<https://doi.org/10.1016/j.jep.2025.120077>

Received 18 November 2024; Received in revised form 20 May 2025; Accepted 31 May 2025

Available online 4 June 2025

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the smallholder farmers in SSA often resort to indigenous ethno-nutraceutical plants (iENPs) also referred to as traditional nutri-medicinal plants or dietary ethno-phytomedicine (Nwafor and Nwafor, 2022; Mhlongo et al., 2024; Yusuf et al., 2024). Use of iENPs is part of folkloric practices perceived to be natural, accessible, simple, affordable, effective and safe (Nikelo et al., 2022; Mhlongo et al., 2024; Yusuf et al., 2024) relative to the other methods. These include rotational grazing, vaccination, genetic selection, and conventional synthetic chemicals like anthelmintics and nutritional supplements (Hoste and Torres-Acosta, 2011; Nikelo et al., 2022). Despite their perceived advantages and widespread use in SSA, there is still inadequate research

and documentation on iENPs specifically used to manage helminths and undernutrition in ruminants.

SSA is richly endowed with a diverse range of indigenous plants, including the *Combretum*, *Dichrostachys*, *Ocimum*, *Vachellia* and *Vernonia* species that have been exploited for centuries by smallholder farmers to deworm and nourish ruminants (Mapiye et al., 2011; Nwafor and Nwafor, 2022). In addition to supplying nutrients in ruminant diets, some iENPs embody a broad spectrum of chemical compounds such as polyphenols, alkaloids, saponins and essential oils (i.e., terpenes and terpenoids) that possess anthelmintic and nutrient-binding properties (Alem, 2024). Some of these phytochemicals exhibit synergistic and

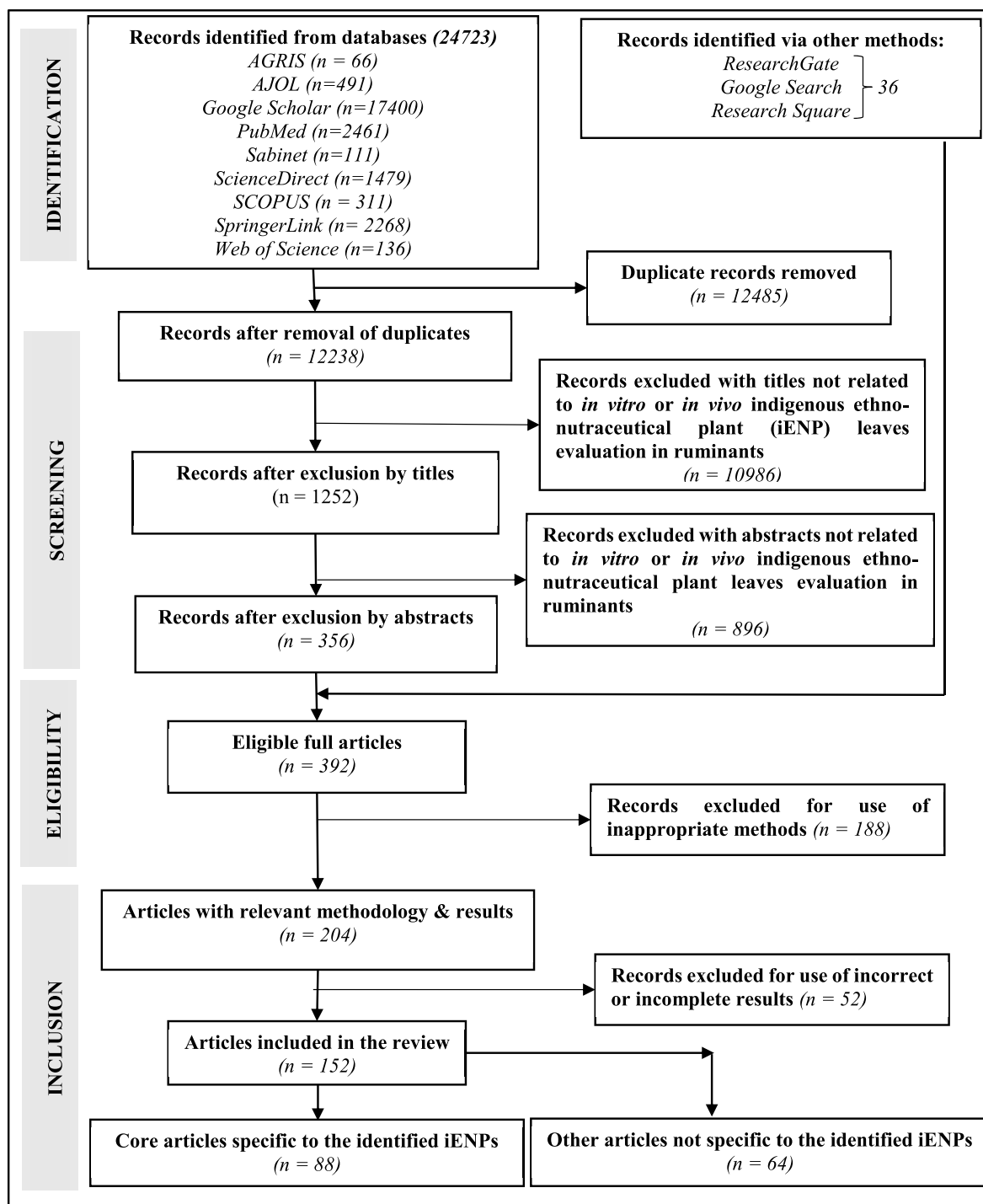


Fig. 1. PRISMA Flow diagram.

pleiotropic effects including anticoccidial, antibacterial, immunostimulatory and antioxidant effects. Such properties may modify rumen metabolism, improve nutrient utilisation, lower ruminal methane emissions, and enhance animal health and production as well as health value and shelf life of edible ruminant products (Mapiye et al., 2011; Besharati et al., 2022). Nevertheless, for most indigenous plants, phytochemical content and composition have not been profiled, optimisation of application conditions and *in vivo* efficacy trials are lacking while safety limits and mechanisms of action are largely unknown (Nikelo et al., 2022; Yusuf et al., 2024). Filling such knowledge gaps is important for the discovery and development of new anthelmintic and undernutrition remedies for ruminants. Additionally, it is critical for the preservation of biodiversity and traditional indigenous knowledge about iENPs used to manage ruminant parasitic diseases and malnutrition. The objectives of the current review were to identify iENPs used as feed by SSA's smallholder ruminant farmers in the management of helminths and undernutrition, document their optimal application conditions, bio-efficiency, mode of action, and safety limits and highlight priority areas for future research, innovation and development.

2. Methodology

Scientific articles used in this review were obtained from large scientific scholarly electronic databases which included AGRICOLA, AGRIS, AJOL, Google Scholar, PubMed, Sabinet, ScienceDirect, SCOPUS, and SpringerLink using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach (Page et al., 2021). According to the PRISMA guidelines, a broad Boolean search string “ethno-nutraceutical plants/nutri-medicinal plants” AND “sub-Saharan Africa” were used. A combination of multiple phrases such as “indigenous”, “ruminants”, “beef cattle” OR “steers” OR “dairy cattle” OR “cow” OR “calf”, “goat” OR “kid”, “sheep” OR “lamb”, “helminth” OR “nematode”, OR “worm”, “rumen”, “digestibility”, “intake” OR “dry matter intake”, “animal performance”, “feed”, “additive”, “extracts”, “nutrient” AND/OR “chemical composition”, “polyphenols” AND/“antinutrients”, “*in-vitro*” AND/OR “*in-vivo*” were added to the broad string. Google Search, ResearchGate, and Research Square were also used to obtain published articles relevant to the review. All the published literature not in English was translated using Google Translate before being added to the literature database, and only literature from 1994 to 2024 was considered for the review. All the gathered literature was screened for bias according to Fig. 1. Articles that were not precise to the topics, duplicates, theses, books, non-scientific reports, and those with unclear methodology and results were excluded. The inclusion criteria were strictly limited to primary *in vitro* or *in vivo* studies that evaluated the potential of iENPs leaves as ruminant feed to control helminths and/or enhance animal production. The acquired literature was analysed, described, summarised, and critiqued using a structured approach (Fig. 1). A total of 152 research articles were included in the review. Of these, 88 articles were specific to the 15 iENPs identified forming the core of the review.

3. Ruminant population, distribution and production efficiency in SSA

SSA is home to approximately 372 million cattle, 295 million sheep, and 465 million goats, with East Africa having the largest numbers followed by West, Central and Southern Africa, respectively (FAO, 2024; WorldPopulationReview.com, 2024 a, b, c). At country level, Ethiopia and Nigeria have the highest numbers of cattle and small ruminants, respectively (FAO, 2024). The variation in the distribution of ruminant populations in SSA is largely driven by geographical and socio-economic conditions, which subsequently influence the production systems. Specifically, pastoral (i.e., extensive) systems are predominant in the arid and semi-arid agro-ecozones. In contrast, agro-pastoral (i.e., mixed crop-livestock or semi-extensive) systems dominate the humid,

sub-humid, and tropical highland agro-ecozones (Anim-Jnr et al., 2023). In SSA, resource-poor smallholder farmers in rural areas often keep and manage ruminants communally.

Ruminant production efficiency in the SSA region remains low and unsustainable (Erdaw, 2023; Cooke et al., 2024). For example, natural pasture production systems in the smallholder sector are typically characterised by low animal growth and reproductive rates (low conception rates and long birth intervals), small herd sizes (5–30), high mortality rates (<30 %) and low off-take rates ranging from 2 to 12 % (Mapiye et al., 2009a; Cooke et al., 2024). This has been attributed to parasitic diseases and malnutrition among other challenges (Ayantunde et al., 2018; Anim-Jnr et al., 2023; Erdaw, 2023). Biffa et al. (2006) emphasised that parasitic infections and undernutrition not only lead to direct health issues in ruminants and humans but also contribute to significant economic losses due to decreased production and product quality, highlighting the importance of determining their prevalence and devising sustainable control measures.

4. Helminth infections and undernutrition in SSA's ruminants

Helminth infections are a critical challenge in ruminant livestock production across SSA, significantly contributing to disease burden and undernutrition. On the one hand, gastrointestinal tract (GIT) helminths prevalent in ruminants such as nematodes (roundworms), trematodes (flukes), and cestodes (tapeworms) are associated with reduced productivity and increased health issues, leading to undernutrition in affected animals (Karshima et al., 2018). On the other hand, undernutrition increases the risk of infections due to immune deficiency, resulting in the persistence of infection and undernutrition (Hoste et al., 2016; Cei et al., 2018).

4.1. Prevalence of GIT helminths and undernutrition in SSA's ruminants

Nematodes have been reported to be the most prevalent GIT helminths in ruminants, followed by trematodes and cestodes (Mpofu et al., 2022). Table 1 summarises the helminth species infecting ruminants in SSA and their characteristics. The prevalence of helminth infections in ruminants across SSA exhibits significant variability (Fig. 2), with Ethiopia and Nigeria having the highest (100 %) and lowest (10 %) prevalence, respectively. The prevalence variability is influenced by factors including regional environmental conditions, seasonal changes, and specific types of helminths present in different areas.

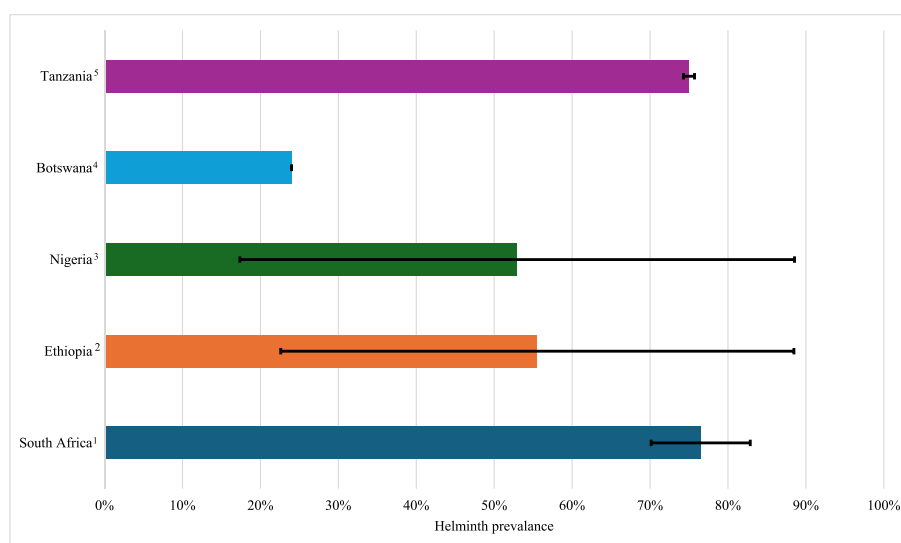
Variability in the prevalence of helminths is accentuated by seasonal climatic changes (Shearer and Ezenwa, 2020), with helminth prevalence exceeding 80 % during the wet season due to increased moisture, which facilitates the development and spread of larvae on pastures (Zvinorova et al., 2016). Some research has shown that increased precipitation negatively correlates with lower parasite loads due to enhanced nutrition-mediated host immunity (Shearer and Ezenwa, 2020). In contrast, arid and semi-arid regions generally experience a lower prevalence of helminth infections especially during the dry season, due to dry conditions that inhibit larval development and survival (Mpofu et al., 2022). The contrasting effects of season on helminth infections suggest a more complex relationship between rainfall, nutrition and parasite prevalence. In SSA, ruminants primarily rely on natural grazing, whose biomass quantity and quality deteriorate due to seasonal effects (Mapiye et al., 2009a). Most nutrients are generally sufficient in the mid-end of the wet season (Cooke et al., 2024). However, natural pastures are generally deficient in energy and minerals in the early-to mid-wet season, while protein is limited in the dry season (Mapiye et al., 2011). The variation in forage quality and quantity causes inadequate or imbalanced supply of nutrients, which results in undernutrition (Hoste et al., 2016; Cei et al., 2018). This will in turn weaken animal immunity and negatively influence weight gain, fertility and lactation. Nevertheless, it is important to further explore the influence of rainfall seasonality and nutrition on helminth prevalence in ruminants in SSA.

Table 1

Summary of main helminth species infecting ruminants in Sub Saharan Africa.

Helminth Type	Helminth species	Host	Predilection site	Brief description	Prevalence
Nematode	<i>Haemonchus contortus</i>	^a Ruminants	Abomasum (stomach)	Causes severe anaemia and protein loss, leading to weight loss and death.	High (up to 90 % in some areas during wet seasons)
Nematode	<i>Trichostrongylus</i> spp.	Ruminants	Small intestine	Causes subclinical infections leading to reduced weight gain and poor feed conversion, and in severe cases, diarrhoea.	Moderate to high (50–80 % depending on season and region)
Nematode	<i>Cooperia</i> spp.	Ruminants	Small intestine	Affects feed efficiency and weight gain.	Low to moderate prevalence in grazing cattle
Nematode	<i>Oesophagostomum</i> spp.	Cattle, Ruminants	Large intestine	Causes nodular disease; associated with significant weight loss and diarrhoea.	Moderate to high (varies with season and region, up to 80 %)
Nematode	<i>Ostertagia ostertagi</i>	Ruminants	Abomasum (stomach)	Causes ostertagiosis, leading to reduced appetite, diarrhoea, and poor growth.	Moderate (varies with climate, up to 70 %)
Nematode	<i>Strongyloides papillosus</i>	Ruminants	Small intestine	Common in young and naïve animals. Causes diarrhoea and weight loss.	Low to moderate
Trematode	<i>Calicophoron microbothrium</i>	Cattle	Rumen	Causes mild digestive disturbances.	Moderate to high (varies with presence of snail hosts)
Trematode	<i>Fasciola</i> spp.	Ruminants and humans	Bile ducts	Cause fascioliasis, leading to liver damage, weight loss, and reduced production of meat and milk.	Moderate to high (varies with presence of snail hosts)
Trematode	<i>Schistosoma</i> spp	Ruminants and humans	Bile ducts, gut, bladder	Cause schistosomiasis resulting reduced fertility and productivity, liver condemnation, stunted growth and premature death.	Low to moderate (up to 35 %)
Cestode	<i>Moniezia</i> spp.	Ruminants	Small intestine	Generally, less pathogenic; affects nutrient absorption.	1.4–50 % in various hosts

^a Ruminants = Cattle sheep and goats. References: Alkadir et al. (2024); Ayana and Ifa (2015); Dabasa et al. (2017); Fentahun (2020); Hassan and Jibrin (2022); Jansen et al. (2020); Kalu et al. (2018); Karshima et al. (2018); Kouadio et al. (2020); Mhoma et al. (2014); Sharma and Busang (2013); Shime, 2018; Tsotetsi et al. (2013).

**Fig. 2.** Prevalence of helminths (means $\pm$ standard deviation) in the Sub-Saharan African region

Generated from a summary of the literature reports on the prevalence of helminths in ruminants in SSA's sub-regions.

Sources: 1Jansen et al., 2020, Tsotetsi et al., 2013; 2Fentahun, 2020, Dabasa et al., 2017, Shime, 2018, Ayana and Ifa, 2015, Alkadir et al., 2024; 3Kalu et al., 2018, Hassan and Jibrin, 2022, Karshima et al., 2018; and 4Sharma and Busang 2013; and 5Mhoma et al., 2014.

High temperatures and solar radiation are the other environmental factors that influence undernutrition and behaviour of nematode larvae on pastures (Heckler and Borges, 2016). High temperatures or solar exposure can increase evapotranspiration, lowering soil and forage moisture and leading to reduced plant and animal productivity. They also desiccate larvae, reducing their infectivity, while moderate temperatures and sunlight may promote larval activity, increasing the risk of infection (Heckler and Borges, 2016). High humidity and moderate temperatures provide ideal conditions for parasite transmission, particularly for species such as *Haemonchus contortus* and *Trichostrongylus* spp., which thrive in warm, moist environments (Caminade et al., 2019). In addition, high stocking rates can increase pasture contamination with helminth eggs and larvae, raising the risk of infection (Maqbool et al., 2017). Moreover, the presence of intermediate

hosts, such as snails in the case of trematodes, significantly affect infection rates, as these hosts are essential components in the life cycle of certain helminths (Megersa et al., 2024). Their abundance is often influenced by environmental factors like moisture, temperature and vegetation. Thus, climate changes in temperature and rainfall patterns in SSA are anticipated to increase the spread of helminths in previously low-risk areas, lengthen the transmission season and extend geographical range to formerly unaffected areas (Morgan et al., 2013; Caminade et al., 2019). Thus, understanding the interplay between various factors influencing prevalence is essential in projecting potential impact and timeously development of effective strategies to manage helminth infections and undernutrition in ruminants.

4.2. Effects of helminths and undernutrition on animal health, production, product quality, human welfare and economy

4.2.1. Effects on ruminant health and welfare

Helminth infections and undernutrition pose a serious threat to ruminant animal health and welfare, leading to reduced productivity and diminished quality of life (Hempstead et al., 2023). Infected animals frequently exhibit signs of anaemia, depressed appetite, poor feed utilisation and assimilation, weight loss, diarrhoea, and general weakness, symptoms that are particularly severe in young and pregnant ruminants (Hoste et al., 2016; Cei et al., 2018). Helminth infections and undernutrition result in physiological stress and discomfort, which alters animal behavioural patterns characterized by reduced feeding duration and increased recumbency, thus compromising animal welfare (Hempstead et al., 2023). They also weaken immune responses, making animals more vulnerable to secondary infections and inflammatory diseases (Cortés et al., 2020). The cumulative physiological and psychological stress induced by parasitism and undernutrition results in negative affective states, signifying suffering in ruminants (Bricarello et al., 2023), accentuating the critical importance of managing helminths and undernutrition to improve welfare of grazing ruminants.

4.2.2. Effects on ruminant production and product quality

Helminth infections and undernutrition significantly impact ruminant production and product quality, affecting meat, milk, hides, and manure. They particularly affect meat production as infected and undernourished animals have lower reproductive rates, body weight gain and condition (Charlier et al., 2023). This leads to reduced meat yield and quality, with animals producing extremely lean and less tender meat, which diminishes consumer acceptability (Mapiye et al., 2011; Ola-Fadunsin et al., 2020). Similarly, infected cows produce low milk yield and quality due to the energy drain imposed by parasites (Shrestha et al., 2020). High parasite loads are correlated with lower milk output, while inadequate energy and protein intake further exacerbate these losses (Cei et al., 2018; Charlier et al., 2023).

Infected and undernourished sheep and goats tend to produce lower-quality wool and mohair characterised by reduced length and strength, which diminishes market prices, negatively affecting the livelihoods of farmers reliant on these products (Khan et al., 2012; Charlier et al., 2023). Notably, reduced intake of digestible energy, essential amino acids and macro-minerals has a negative effect on fibre growth and strength (Khan et al., 2012). The stress caused by helminth infections and undernourishment also results in lower fleece weight and poorer fibre quality (Sharma et al., 2020). In addition, helminth infections and undernutrition tend to reduce the skin's defences against external parasites, leading to an increase in external infestations and subsequent hide degradation (Kahsay et al., 2015). Poor body condition in an infected and undernourished animal further impacts hide quality, exacerbating the economic challenges for livestock producers (Karshima et al., 2018; Sharma et al., 2020). Moreover, undernourished and infected animals produce dung with lower nutrient content, which reduces its efficiency as fertiliser (Karshima et al., 2018; Sharma et al., 2020). The presence of helminth eggs in manure also increases contamination of natural pasture, perpetuating the cycle of infection among grazing ruminants (Maqbool et al., 2017; Charlier et al., 2023). This re-emphasises the importance of managing both helminth infections and undernutrition to sustain ruminant livestock health and agricultural productivity in SSA.

4.2.3. Effects on human health and welfare

Ruminant helminths and undernutrition negatively impact human health and welfare by disrupting livestock's vital contributions to food, nutrition and income security. Specifically, they reduce meat and milk output, key dietary components for smallholder subsistence farmers (Van Wyk and Bath, 2010; Umair et al., 2024). Equally important, helminth infection and undernutrition related livestock losses diminish

household income, thereby affecting the ability of families to purchase other foodstuffs necessary for human health and welfare (Mapiye et al., 2020). Apart from food supply, ruminants serve a plethora of diverse roles including provision of fertiliser and draught power, and generation of cash income through sales of live animals, meat, milk, fibre, skins and hides. The cash income generated is often used to purchase farming inputs, additional stock and other food items, improving overall diet and contributing to better nutrition, health and welfare for rural households (Varjakshapanicker et al., 2019; Banda and Tanganyika, 2021).

The reduction in livestock productivity due to helminths infections and undernutrition may promote higher stocking densities or increased grazing pressure, which can lead to overgrazing, land degradation, disruption of nutrient cycles and loss of biodiversity (Ayantunde et al., 2018; Du et al., 2022). Karshima et al. (2018) examined how these environmental impacts, coupled with increased climate-warming emissions from less efficient natural pasture-based ruminant production systems, add to the ecological footprint of agriculture in the region. Furthermore, less efficient natural pasture-based ruminant production systems may lead to increased transmission of zoonotic diseases, particularly trichostrongylosis (Bhat et al., 2023), schistosomiasis (Díaz et al., 2023) and fascioliasis (Mehmood et al., 2017). The health burden of helminth infections on humans often goes undetected due to their asymptomatic nature (WHO, 1987). The worms consume nutrients from their human host, leading to or exacerbating malnutrition, which in turn causes stunted growth, impaired physical development or even death (Umair et al., 2024). Helminths effects are exacerbated by the emergence of anthelmintic-resistant parasites, which not only affect ruminants but can also spread to humans (Charlier et al., 2023). The situation is particularly severe in developing countries, where the misuse of anthelmintics, combined with poor sanitary conditions and shared land and water resources between livestock and humans, create an environment ripe for spreading these parasites (Zvinorova et al., 2016; Nwafor and Nwafor, 2022).

4.2.4. Effects on human sociocultural values

The socio-cultural implications of helminth infections and undernutrition are particularly significant in communities where livestock play a central role in social and cultural practices. In many SSA communities, ruminants are a symbol of wealth, social status, and cultural heritage and key source of youth and women empowerment (Mapiye et al., 2020; Galiè et al., 2022). The health and nutritional status of these animals directly influence traditional practices, such as ceremonies and community gatherings, where livestock is often used as a form of currency or sacrifice and serve as offerings or symbols of wealth (Mapiye et al., 2020; Banda and Tanganyika, 2021). However, declining livestock health and nutritional status due to helminth infections and undernutrition can disrupt these cultural practices and erode community values. This negatively impacts community cohesion and cultural continuity because the inability to fulfil cultural obligations can lead to social stigmatisation, loss of cultural identity and weakened cultural fabric of communities (King et al., 2015; Mhlongo et al., 2024).

4.2.5. Effects on the economy and trade

The economic impact of helminth infections and undernutrition on ruminant production in SSA is profound, negatively affecting the economy and trade, especially in rural communities reliant on livestock production. Also, it contributes to significant losses in productivity metrics such as milk production and quality, fertility, weight gain, carcass yield, meat quality and draught power (Umair et al., 2024). For example, helminthosis alone has been reported in Ethiopia to contribute up to 30 % of mortalities in lambs and 20 % in adults (Biffa et al., 2006). Helminths can significantly diminish the daily income potential for livestock producers by reducing the overall output of their animals, in terms of meat, milk and non-edible products (Umair et al., 2024). The same authors reported that productivity losses attributable to helminth parasites amount to US\$ 81.8 million annually. For small-scale farmers,

who often operate on thin margins, even a temporary loss of productivity due to helminth-induced morbidity can have long-lasting financial consequences. Literature stresses the detrimental effects of helminths and undernutrition on these critical aspects of livestock production (Charlier et al., 2023).

Helminth infections and undernutrition in ruminants seriously threaten the economic stability of farming communities, reducing farmers' immediate income and the long-term sustainability of their operations. This, in turn, affects local and regional trade, as decreased livestock productivity leads to reduced supply and potential increases in prices of ruminant products, which can ripple through the economy. The economic repercussions are not confined to reduced productivity alone, but extend to increased extension and veterinary costs, driven by the need for more frequent interventions to combat infections and infestation, especially in the context of growing anthelmintic resistance (AR; Van Wyk and Bath, 2010). Addressing the problem of helminth infections is thus not only a matter of improving animal health but also of safeguarding the economic well-being of agricultural communities and ensuring the stability of trade in livestock and related products.

5. Helminths and undernutrition control methods in ruminants

5.1. Conventional management

Helminth control in ruminants in SSA primarily relies on synthetic anthelmintic drugs, including benzimidazoles, macrocyclic lactones, imidazothiazoles, and tetrahydropyrimidines (Gray et al., 2012; Charlier et al., 2023). These drugs effectively reduce parasite burdens, improving animal health and productivity. However, the overuse and inappropriate administration of anthelmintic drugs in ruminant production have escalated AR and resulted in drug residues in ruminant-derived food products and the environment (Gray et al., 2012; Charlier et al., 2023). In SSA, AR has been reported in 14 countries, with Kenya and South Africa showing pronounced cases predominantly for *H. contortus* (Vatta & Lindberg, 2006). In Kajiado County, Kenya, for example, high resistance to ivermectin has been confirmed, while in Limpopo, South Africa, irregular dosing practices among 67.5 % of farmers have further increased AR risk (Mphahlele et al., 2021). Southern Mozambique and West Cameroon also exhibit significant resistance to albendazole and ivermectin (Atanásio-Nhacumbe et al., 2017; Stephanie et al., 2022). Resistance is prevalent in Ethiopia, with low efficacy of common drugs, especially in gastro-intestinal nematodes (Solomon et al., 2024). The economic consequences of AR are severe. For example, in sheep, resistance levels to benzimidazoles have reached 86 %, leading to substantial financial losses and costly alternative treatments (Rose Vineer et al., 2020; Makmur et al., 2022). The major contributors to AR development are inconsistent dosing and inaccurate weight estimation, which results in under- or over-dosing (Leathwick and Luo, 2017).

Alongside chemical treatments, nutritional supplementation plays a vital role in boosting ruminant immunity and recovery from infections as well as addressing undernutrition. Protein and energy rich diets significantly reduce parasite loads, increase nutrient utilisation and improve overall health, directly enhancing resistance to infections (Cei et al., 2018; Bricarello et al., 2023). In addition, supplementation with a complex of minerals and vitamins is important in improving recovery and productive performance of helminth-infected animals (Hughes et al., 2023; Farias et al., 2021). The interaction between nutrition and immunity is well-documented, with malnutrition exacerbating infection severity (Hoste et al., 2016; Cei et al., 2018). Chemical and nutritional synergism has, however, not been adequate in minimizing AR and controlling helminths and undernutrition. In this context, it has been suggested that a holistic strategy, integrating chemical and biological methods could manage helminths and undernutrition and sustainably improve ruminant health and productivity in SSA.

5.2. Integrated management

Integrated parasite management combines chemical and nutritional therapies with target selective treatment, vaccinations, grazing management, selective breeding, predation, and phytotherapy in managing parasites and undernutrition (Cei et al., 2018; Gray et al., 2012). The integrated approach aims to complement or replace chemical interventions, reducing dependence on synthetic drugs while addressing nutritional deficiencies to optimise animal health and production. Targeted selective treatment treats only animals exhibiting clinical signs or elevated parasite burdens, reducing anthelmintic use and slowing resistance development by maintaining drug-susceptible parasite strains (Walker et al., 2015). Anthelmintic vaccines induce immunologic defence against helminth infection in ruminant hosts (Claerebout and Geldhof, 2020). Improved grazing management, including rotational grazing and mixed species grazing, limits helminth transmission and improves health and productivity of pastures and animals (Gray et al., 2012; Bambou et al., 2021). Selective breeding of resistant and resilient animals enhances host immunity against helminths (Zvinorova et al., 2016). Predacious fungi like *Duddingtonia flagrans*, trap and destroy parasite larvae in faeces, reducing pasture contamination without chemicals (Worku et al., 2017). Adoption of most of these non-chemical methods is limited by several factors including affordability, availability, appropriateness, applicability, consistency and reliability under smallholder farming conditions (Hoste and Torres-Acosta, 2011; Zvinorova et al., 2016; Gray et al., 2012).

Smallholder farmers in SSA mostly use phytotherapy, especially iENPs, to treat both helminth infections and undernutrition in ruminants as an alternative to chemotherapy (Nwafor and Nwafor, 2022; Yusuf et al., 2024). Various iENP parts, such as leaves, stems, roots, and bark have successfully been utilized to control helminth infections in ruminants among local SSA communities (Yusuf et al., 2024; Selogatwe et al., 2021). The use of iENPs leaf meals is more popular than the other non-chemical methods because it is part of culturally embedded indigenous knowledge and practices for managing ruminant health and production among many ethnic groups in SSA (Maqbool et al., 2017; Selogatwe et al., 2021). The leaves of iENPs, provide a more locally available, practical and potentially sustainable alternative in resource-limited settings (Jato et al., 2022; Mhlongo et al., 2024; Yusuf et al., 2024), and warrant further exploration.

5.3. iENPs as helminth and undernutrition remedies

5.3.1. Nutrient and phytochemical composition of leaves from iENPs in SSA

The nutrient and phytochemical contents of leaves from iENPs widely used by rural farmers in SSA to jointly manage helminth infections and undernutrition in ruminants are summarised in Table 2. *Vachellia* species were the most studied iENPs cited 35 times, maybe because of their abundance, wide distribution, and use by ruminants in the region. The dry matter (DM) of leaves from iENPs (80–99 %) displayed species and spatial variation typical of tropical browse tree leaves (Belachew et al., 2013; Aruwayo and Adeleke, 2019). An increase in dietary DM content linearly results in high DM intake (DMI) which translates to improved animal production (Freer et al., 2007). Overall, the crude protein (CP) content of the iENPs (8–30 %) is above the minimum for ruminant maintenance and normal rumen function (>7 % CP/DM) and within ranges required by growing, finishing and lactating ruminants (10–17 % CP/DM; NRC, 2007; NASEM, 2016, 2021). Of importance, the neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents of iENPs are above the ruminant requirements of 25–33 % and 17–21 %, respectively (NRC, 2007; NASEM, 2016, 2021). These high fibre contents may reduce DMI and nutrient digestibility when higher dietary inclusion levels of iENPs are used. However, at moderate inclusion levels, most iENPs, particularly *Vachellia* and *Vernonia* species may substitute low quality forages in ruminant diets because of their high protein and moderate fibre contents.

Table 2Nutrient (%) content, *in vitro* DM digestibility (%) and phytochemical composition (mg/g DM) of leaves from indigenous ethno-nutraceutical plants in Sub-Saharan Africa.

Plant	Origin	DM ^a	CP ^b	NDF ^c	ADF ^d	Ash	EE ^e	CT ^f	TT ^g	TP ^h	Anthelmintic phytochemicals	IVDMD ⁱ	References
<i>Combretum molle</i> R. Br. ex G. Don (Velvet bushwillow)	SSA	89–95	8–16	33–63	19–43	4–8	1–5	312–382	–	53–97	- Alkaloids -Saponins -Steroids -Essential oils	21–65	Debela et al. (2017); Desalegn et al. (2016); Lukhele and Van Ryssen (2003); Megersa et al. (2017); Ndlovu and Nherera (1997); Ntshanka et al. (2020); Parusnath et al. (2023);
<i>Dichrostachys cinerea</i> (L.) Wight & Arn. (Sicklebush)	SSA	89–92	11–18	33–45	14–27	6–14	–	3–11	17–38	41	-Alkaloids -Saponins -Steroids -Essential oils -Glycosides	70	Mengistu et al., 2017a; Rubanza et al. (2003); Mudau et al. (2021), 2022; Vijayalakshmi et al. (2013)
<i>Ocimum gratissimum</i> L. (Clove basil/Scent leaf)	East and west Africa	81–94	10–19	–	–	4–14	2–28	8–13	14–34	15–23	-Essential oils (i.e., oleanolic acid) -Saponin -Alkaloids -Steroids -Glycosides	–	Adebayo et al. (2019); Idris et al. (2011); Igbinosa et al. (2013); Ikpeazu et al. (2019); Okoye et al. (2023); Ugboju et al. (2021)
<i>Peltophorum africanum</i> Sond. (African/ Weeping wattle)	Tropical and Southern Africa	99	8–12	38–40	22–34	3–5	–	–	–	23–34	Saponins Essential oils	57–66	Aganga et al. (2001); Dambe et al. (2015); Lukhele and Van Ryssen (2000); Mudau et al. (2021), 2022; Mazimba (2014); Bizimenyera et al. (2005); Aruwayo and Adeleke (2019)
<i>Rhus natalensis</i> Bernh. ex C. Krauss (Natal rhus)	South Africa	78–91	8–24	36–45	18–30	4–9.5	0.4–7.1	17	35	8.5–44	-Alkaloids -Saponins -Essential oils	52–62	Ghebremeskel et al. (1991); Mengistu et al., 2017a
* <i>Senegalia senegal</i> (L.) Britton (Gum Arabic tree)	Desert region of SSA	91–94	14–28	22–67	12–57	7–10	4	54	217	236	-Saponins -Essential oils -Alkaloids	–	Rubanza et al. (2005), 2007a; Sisay et al. (2022); Musa et al. (2020)
** <i>Vachellia etbaica</i> (Schweinf.) Kyal. & Boatwr.	East Africa	91–93	13–18	40–54	36–44	6–15	–	11.0	2–68	70	-Saponins -Essential oils -Steroids -Alkaloids	60	Abdalla and Ahmed (2023a,b); Mengistu et al., 2017a; Yayneshet et al. (2008)
<i>Vachellia karroo</i> (Hayne) Banfi & Galasso (Sweet thorn)	Southern Africa	87–97	10–23	27–50	12–37	5–7	2–3	2–7	–	0.5–38	-Saponins -Glycosides -Steroids -Essential oils	31–68	Brown et al. (2016), 2018; Kugedera et al. (2021); Mapiye et al. (2009b); Marume et al. (2012); Mokoboki et al. (2005), 2011; Ndagurwa and Dube (2013); Ravhuhali et al. (2022) Mudau et al. (2021), 2022
<i>Vachellia nilotica</i> (L.) P.J. H. Hurter & Mabb. (Scented Thorn)	Southern Africa	89–96	12–17	18–42	5–35	3–15	2–4	1–60	54.2	10–76	-Saponins -Essential oils -Alkaloids -Steroids -Glycosides	50–81	Al-Soqeer (2008); Bekele et al. (2022); Mokoboki et al. (2011); Ndagurwa and Dube (2013); Rubanza et al. (2007a), 2007b; Zabré et al. (2017); Ravhuhali et al. (2022); Mudau et al. (2021), 2022
<i>Vachellia polyacantha</i> (Wight & Arn.) P.J.H. Hurter. (White thorn)	Tropical Africa	88–90	13–21	31–50	13–28	8–12	28–35	18–46	41–95	45–98	-Saponins -Essential oils -Steroids	53	Chilanga et al. (2022); Max et al. (2007); Rubanza et al. (2003), 2005, 2007a, 2007b; Yaya Alain et al. (2015)
<i>Vachellia seyal</i> Delile (Shittimwood)	West and East Africa	91–95	13–20	14–68	12–58	5–13	1–4	10–39	–	9.5–10.2	-Saponins -Essential oils -Steroids -Alkaloids	–	Al-Soqeer (2008); Gebreselassie et al. (2014); Sisay et al., 2022; Abdel-Farid et al. (2014)
*** <i>Vachellia tortilis</i> subsp. <i>raddiana</i> (Savi) Kyal. & Boatwr. (Umbrella thorn)	SSA	87–94	9–27	15–50	11–30	6–12	3.0	3–51	121–392	95–401	-Saponins -Essential oils -Glycosides	35–54	Dambe et al. (2015); Kujoana et al. (2023); Madibela et al. (2004); Max et al. (2007); Mokoboki et al. (2011); Rubanza et al. (2003), 2007a; Sisay et al., 2022; Zabré et al. (2017); Mudau et al. (2021), 2022; Abdel-Farid et al. (2014); Aruwayo and Adeleke (2019)
<i>Vernonia amygdalina</i> Delile (Bitter leaf)	East and West Africa	80–97	14–30	23–64	13–43	4.0–15	2–10	–	0.6–1	1.5–15.6	-Alkaloids -Saponins -Steroids	76	Adebayo et al. (2022); Adem and Misbah (2021); Adugna et al. (2023); Bonsi et al. (1995); Degu et al. (2024)

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Table 2 (continued)

Plant	Origin	DM ^a	CP ^b	NDF ^c	ADF ^d	Ash	EE ^e	CT ^f	TT ^g	TP ^h	Anthelmintic phytochemicals	IVDMD ⁱ	References
<i>Viscum verrucosum</i> Harv. (Mistletoe)	Southern Africa	85–95	10–16	27–56	14–36	18–24	–	3.0–10.2	53–60	23	-Essential oils -Glycosides -Alkaloids	33–57	Hawu et al. (2022); Madibela et al. (2002), 2003, 2004; Ndagurwa and Dube (2013); Ramantsi et al. (2019)
<i>Ziziphus mucronata</i> Willd. (Buffalo-thorn)	Southern Africa	92.3	19–26	32–58	17–31	7.0–15	5.3	0.72–2.8	–	27–75	-Saponins -Alkaloids -Essential oils	72	Hassen et al. (2009); Kujoana et al. (2023); Njidda and Nasiru (2010); Mongalo et al. (2020); Ibrahim et al., 2012

^a DM, Dry matter.^b CP, Crude protein.^c NDF, Neutral detergent fibre.^d ADF, Acid detergent fibre.^e EE, Ether extract.^f CT, Condensed tannins.^g TT, Total tannins.^h TP, total polyphenolics.ⁱ IVDMD, *In vitro* dry matter digestibility. *Senegalia and **Vachellia were formerly known as *Vachellia tortilis* subsp. *raddiana* was formerly known as *Vachellia raddiana* (Savi) or *Acacia raddiana* (Savi).

Compared to other species, *Viscum verrucosum* (Mistletoe; 6 citations) has the highest ash contents (18–24 %; Table 2), confirming earlier reports that it is a rich source of minerals, including calcium, phosphorous, iron, magnesium, zinc and copper (Hawu et al., 2022). The levels of these minerals exceed the minimum requirements for productive ruminants (NRC, 2007; NASEM, 2016, 2021), suggesting that their supplementation is not essential when feeding *V. verrucosum*. The ash content (3–15 %) for the rest of the iENPs is also high indicating potential to supply the required mineral concentrations for the productive ruminants (NRC, 2007; NASEM, 2016, 2021). With exception of *Ocimum gratissimum* (Clover basil; 6 citations) and *Vernonia amygdalina* (bitter leaf; 5 citations), the rest of the iENPs had ether extract (EE) values less than 5 % recommended for optimal rumen function and above which DMI and nutrient digestibility could potentially be reduced (Chikwanha et al., 2018). Condensed tannin levels for the majority of the iENPs are within the range of 2–6 % of dietary DM known to improve feed intake, nutrient digestibility, animal health and production (Uushona et al., 2021; Besharati et al., 2022). The dominant bioactive compounds include polyphenols, alkaloids, saponins, steroids and essential oils (i.e., terpenes and terpenoids; Table 2).

Apart from the leaves, the seeds, pods and fruits from iENPs in SSA have high contents of diverse nutrients and phytochemicals but are underutilised due to limited information regarding their *in vitro* and *in vivo* feeding and anthelmintic potencies (Rubanza et al., 2003; Yaneshet et al., 2008; Kugedera et al., 2021). Thus, evaluation of these iENPs' nutrient and phytochemical composition and *in vitro* and *in vivo* nutritional and anthelmintic efficacy could provide promising avenues for improving the nutrition and health status of ruminants in the region.

5.3.2. *In vitro* nutritional and anthelmintic efficacy of leaves from iENPs to SSA

Screening of iENPs for nutritional and anthelmintic efficacy often begins with the use of *in vitro* models (Oliveira Santos et al., 2019). *In vitro* assays are a rapid and cost-effective approach to evaluating the nutritive value of ruminant feeds (e.g., *in vitro* dry matter digestibility, IVDMD; Mabeesh et al., 2000) and anthelmintic efficacy of synthetic and phytochemical drugs (Oliveira Santos et al., 2019; Sisay et al., 2021). For anthelmintic efficacy, *in vitro* assays target the free-living stages (eggs, first- and third-stage larvae) and/or adult helminths, focusing on the ability of drug candidates to inhibit egg hatch, larval development, migration, motility or exsheathment, and survival (Oliveira Santos et al., 2019). However, these anthelmintic *in vitro* assays have a limitation of not considering the interaction between the drug active compounds and the host animal, which affects efficacy (Bizimenyera et al., 2006; Oliveira Santos et al., 2019).

Plants that demonstrated high IVDMD and broad-spectrum activity against helminth eggs, larvae, and adult worms are presented as promising candidates for use as nutraceuticals *in vivo*. The 15 identified iENPs have IVDMD values (21–81 %; Table 2) comparable to those reported earlier for tropical browse tree leaves (26–83 %; Belachew et al., 2013; Ravhuhali et al., 2022). Most of the IVDMD values are above the 45 % threshold required to meet maintenance requirements for ruminants (Madibela et al., 2000) and between 50 and 70 % sufficient for medium production levels (Mokoboki et al., 2005).

Fourteen of the 15 identified iENPs have been screened for anthelmintic potency (Table 3). Most of the screened iENPs bear anthelmintic properties against various intestinal nematodes but their efficacy varies with source, concentration and type of phytochemicals, extractant, exposure time, species and stage of development of the target helminth. For example, *in vitro* anthelmintic activity variation was observed across iENPs evaluated in the same study (Table 3). Efficacy was in the order of *D. cinerea* > *R. natalensis* > *V. etbaica* (Mengistu et al., 2017b), *V. tortilis* > *V. nilotica* (Zabré et al., 2017), *V. amygdalina* > *Z. mucronata* (Fomum et al., 2017) and *V. amygdalina* > *V. tortilis* > *Senegalia senegal* > *V. seyal* (Sisay et al., 2021). This variability in anthelmintic efficacy could be largely due to differences in the concentration

Table 3*In vitro* anthelmintic efficacy of leaves from Sub-Saharan Africa's indigenous ethno-nutraceutical plants on ruminant helminths.

Plant	<i>In vitro</i> assay	Test organism	Extractant	Concentration (mg/mL)	Efficacy	References
<i>Combretum molle</i> R. Br. ex G. Don (Velvet bushwillow)	Egg hatch inhibition and larval development inhibition	<i>Haemonchus contortus</i>	Acetone and fractions of hexane, chloroform, and 35% water in methanol	10	-Extract and fractions inhibited egg hatching, larval development and killed larvae in a concentration-dependent manner -35% water in methanol fraction was the most active for egg hatch inhibition ($^{1}LC_{50}$ = 0.065 mg/mL) -Chloroform fraction was the most active for larval development inhibition (LC_{50} = 0.131 mg/mL)	Ademola & Eloff, 2010
<i>Dichrostachys cinerea</i> (L.) Wight & Arn. (Sicklebush)	Larval exsheathment inhibition	<i>H. contortus</i>	Acetone-water (70/30)	0, 0.15, 0.3, 0.6 and 1.2	-Larvae exsheathment increased with concentration - $^{2}EC_{50}$ achieved at 0.13 mg/mL	Mengistu et al., 2017b
<i>Ocimum gratissimum</i> L. (Clove basil/ Scent leaf)	Adult worm motility inhibition	<i>Haemonchus placei</i>	Aqueous acetone	5-60	-Extracts inhibited motility with low potency (LC_{50} = 56.0 mg/mL)	Aderibigbe & Idowu, 2020
<i>Combretum molle</i> R. Br. ex G. Don (Velvet bushwillow)	Larval development inhibition	<i>H. contortus</i>	Ethanol	0.5, 1.0, 2.0, 4.0, and 8.0	-Produced 15% paralysis	Njoku and Asuzu, 1998
	Adult worm motility inhibition	<i>Paramphistomum cervi</i> and <i>Fasciola hepatica</i>	Water	2, 4, 6, 8 and 10	-100% mortality was recorded in 4 h at 10 mg/mL for both trematodes, and in 5h at 6 and 8 mg/mL for <i>F. hepatica</i> and <i>P. cervi</i> , respectively - <i>F. hepatica</i> (LC_{50} = 2.02 mg/mL) was more susceptible than <i>P. cervi</i> (LC_{50} = 2.63 mg/mL)	Ibekwe & Bikom 2019
<i>Dichrostachys cinerea</i> (L.) Wight & Arn. (Sicklebush)	Egg hatch inhibition and larval development inhibition	<i>Trichostrongylus colubriformis</i>	Acetone	25, 5, 1, 0.2, 0.04 or 0.008	-Ovicidal and larvicidal activity increased with concentration - $^{2}EC_{50}$ for egg hatch inhibition was 0.63 mg/mL - $^{2}EC_{50}$ for larval inhibition was 0.72 mg/mL	Bizimenyera et al., 2006a
	Egg hatch inhibition and larval development inhibition	<i>H. contortus</i>	Acetone	25, 5, 1, 0.2, 0.04 or 0.008	-Extracts inhibited egg hatching and larval development concentration-dependently	Bizimenyera et al., 2006b
<i>Rhus natalensis</i> Bernh. ex C. Krauss (Natal rhus)	Larval exsheathment inhibition assay	<i>H. contortus</i>	Acetone-water (70/30)	0, 0.15, 0.3, 0.6 and 1.2	- Extracts inhibited larval exsheathment in a concentration-dependent manner - $^{2}EC_{50}$ achieved at 168.6 g/mL	Mengistu et al., 2017b
* <i>Senegalia senegal</i> (L.) Britton (Gum Arabic tree)	Egg hatch inhibition, larval migration inhibition and adult worm motility	<i>H. contortus</i>	Acetone	Egg hatch inhibition and larval migration inhibition: 0.075, 0.3 and 1.2 adult worm motility: 100	Concentration-dependent ovicidal effects (38% at 0.3 mg/mL) -Extracts induced 60% larval migration inhibition rates at 0.3 mg/mL and 77% mortality in 4h at 0.1 mg/mL	Sisay et al., 2021
** <i>Vachellia etbaica</i> (Schweinf.) Kyal. & Boatwr.	Larval exsheathment inhibition	<i>H. contortus</i>	Acetone-water (70/30)	0, 0.15, 0.3, 0.6 and 1.2	-Larvae exsheathment increased with concentration - $^{2}EC_{50}$ achieved at 0.286 mg/mL	Mengistu et al., 2017b
<i>Vachellia karroo</i> (Hayne) Banfi & Galasso (Sweet thorn)	Schistosomula mortality	<i>Schistosoma mansoni</i>	Water	200	Extract active at 0.25 to 0.30 mg/mL LC = 3.1 mg/ mL after 1h and 0.8 mg/mL after 24 h	Mølgaard et al., 2001
<i>Vachellia nilotica</i> (L.) P.J.H. Hurter & Mabb. (Scented Thorn)	Egg hatch inhibition and larvae exsheathment inhibition	<i>H. contortus</i>	Water or acetone	0.3, 0.6, 1.25, 2.5 or 5.0		Zabré et al., 2017
<i>Vachellia seyal</i> Delile (Shittimwood)	Egg hatch inhibition, larval migration inhibition and adult worm motility	<i>H. contortus</i>	Acetone	Egg hatch inhibition and larval migration inhibition: 0.075, 0.3 and 1.2 adult worm motility: 100	Concentration-dependent ovicidal effects (34% at 0.3 mg/mL) -Extracts induced 57% larval migration inhibition rate at 0.3 mg/mL and 17% mortality in 4h at 0.1 mg/mL	Sisay et al., 2021
*** <i>Vachellia tortilis</i> subsp. <i>raddiana</i> (Savi) Kyal. &	Egg hatch inhibition and larvae exsheathment inhibition	<i>H. contortus</i>	Water or aqueous acetone	0.3, 0.6, 1.25, 2.5 or 5.0	-Inhibition of egg hatch increased with increased dosage and was more effective for acetonic (IC_{50} = 0.68 mg/mL)	Zabré et al., 2017

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Table 3 (continued)

Plant	In vitro assay	Test organism	Extractant	Concentration (mg/mL)	Efficacy	References
Boatwr. (Umbrella thorn)					than water extracts (IC ₅₀ = 1.36 mg/mL) -Extracts inhibited larvae exsheathment with acetone (IC ₅₀ = 0.207 mg/mL) being more effective than water (IC ₅₀ = 0.331 mg/mL) extracts Concentration-dependent ovicidal effects (39% at 0.3 mg/mL) -Extracts induced 62% larval migration inhibition rate at 0.3 mg/mL and 75% mortality in 4h at 0.1 mg/mL	Sisay et al., 2021
Vachellia seyal Delile (Shittimwood)	Egg hatch inhibition, larval migration inhibition and adult worm motility	<i>H. contortus</i>	Acetone	Egg hatch inhibition and larval migration inhibition: 0.075, 0.3 and 1.2 adult worm motility: 100		
	Egg hatch inhibition	<i>H. contortus</i>	Hot water	11.2	Did not inhibit egg hatch at concentrations up to 11.2 mg/mL	Alawa et al., 2003
	Egg hatch, larval development inhibition and viability	<i>H. contortus</i>	Acetone and fractions of butanol, hexane, chloroform and 35% water in methanol	10	-Egg hatch and larval development inhibition, and larval mortality increased with concentration -Butanol fraction was the most efficient for egg hatch (LC ₅₀ = 0.076 mg/mL) -35% water in methanol fraction was most active against larvae inhibition (LC ₅₀ = 0.197 mg/mL)	Ademola & Eloff, 2011
	Larvae mortality	Goat and sheep nematodes	Ethanol	100, 200 and 400	-Larvae mortality increased with concentration -Goats nematodes were more susceptible than sheep nematodes	Fomum et al., 2017
	Egg hatch inhibition, larval migration inhibition and adult worm motility	<i>H. contortus</i>	Acetone	Egg hatch inhibition and larval migration inhibition: 0.075, 0.3 and 1.2 adult worm motility: 100	Concentration-dependent ovicidal effects (40% at 0.3 mg/mL) -Extracts induced 70% larval migration inhibition rate at 0.3 mg/mL and 90% mortality in 4h at 0.1 mg/mL	Sisay et al., 2021
Viscum verrucosum Harv. (Mistletoe)	Egg hatch inhibition and larval development inhibition	<i>H. contortus</i> <i>Teladorsagia circumcincta</i> <i>T. colubriformis</i>	Acetone:water (7:3)	0.1 and 0.5	-No inhibition on egg hatching -Complete inhibition of larval development for all parasites	Tibe et al., 2013
Ziziphus mucronata Willd. (Buffalo-thorn)	Larvae mortality	Goat and sheep nematodes	Ethanol	100, 200 and 400	-Larvae mortality increased with concentration -Sheep nematodes were more susceptible than goat nematodes	Fomum et al., 2017

1LC₅₀ = Concentration of extract that gave a response halfway between the minimum and maximum responses in a concentration-response sigmoid curve.

2EC50 (effective concentration 50) = concentration required to inhibit 50 % of the eggs or larvae (i.e., 50 % effective extract concentration to inhibit exsheathment).

4IC50 = half-maximal inhibitory concentration.

*Senegalia and **Vachellia were formerly Acacia. ***Vachellia tortilis subsp. raddiana was formerly known as Vachellia raddiana (Savi) or Acacia raddiana (Savi).

and composition of phytochemicals present in the different plant species (Table 2). Concentration-dependent ovicidal and larvicidal effects are evident within species (Table 3). Plant intraspecies variation anthelmintic efficacy is attributable to the differences in the chemical structure and composition of phytochemicals (Hoste et al., 2015), which are further influenced by grazing stress, temperature, radiation, light, day length, humidity, precipitation and soil nutrient supply among other environmental factors (Besharati et al., 2022; Uushona et al., 2021).

Egg hatch inhibition reported for *D. cinerea*, *V. etbaica*, and *R. natalensis* suggests that polyphenols had a role (Mengistu et al., 2017b). Similarly, *V. tortilis* rich in hydrolysable tannins had greater efficacy for egg hatch inhibition, whereas *V. nilotica* rich in condensed tannins (CT) had larva development inhibition activity (Zabré et al., 2017). Addition of a tannin inhibitor (polyvinyl polypyrrolidone, PVPP) to the *Vachellia* extracts demonstrated that polyphenols were the main cause of the anthelmintic activities (Zabré et al., 2017). Indeed, extracts from polyphenolic plants have anthelmintic properties

attributed to their interference with energy generation through uncoupling of oxidative phosphorylation and strong affinity for proteins, including those found in the cuticular surface of the eggs, larvae and worms (Martínez-Ortiz-De-Montellano et al., 2019; Adak and Kumar, 2022). This consequently changes their chemical properties and physical structure as lesions and wrinkles may accumulate on the protein-bound structures resulting in rapture, lowered nutrition, motility, and death.

It seems polyphenols were not the sole phytochemicals accountable for larval exsheathment and adult worm mortality in studies by Zabré et al. (2017), Mengistu et al. (2017b) and Sisay et al. (2021). These findings indicate potential synergistic effects of polyphenols and other non-polyphenolic phytochemicals from iENP on larvicidal and adulticidal activities. For example, saponins inhibit acetylcholinesterase, causing worm paralysis leading to death (Adak & Kumar, 2022). In addition, they generate ions and cause lipid oxidation of egg membranes and damage the larval cuticle, thereby inhibiting parasite development

(Nandi et al., 2004). Alkaloids impair regulation of acetylcholine, disrupt the cell membrane and suppress nutrient uptake, leading to helminth death due to starvation (Adak and Kumar, 2022; Ahmed et al., 2023). Essential oils including terpenoids and terpenes, generally induce oxidative stress in parasites, which can lead to cell membrane damage and death of parasites (Panda et al., 2022; Ahmed et al., 2023). The diverse composition and differences in the chemical nature and functions of the iENP phytochemicals suggest multiple mechanisms of action. These include antagonistic, antinutritional, additive, synergistic, pleiotropic and/or entourage effects (Hoste et al., 2015; Besharati et al., 2022). This gives greater scope for selecting of iENP species that positively influence animal health and production. Thus, it is critical to determine molecular mechanisms underlying the effects of iENPs' phytochemicals on egg, larvae and worm structure.

Fomum et al. (2017) evaluated the effects of ethanolic extracts from seven plant species including *V. amygdalina* and *Z. mucronata* at three concentrations on sheep and goat nematodes. At the low concentrations, *V. amygdalina* extracts were more efficient for goat nematodes while *Z. mucronata* extracts were more efficient for sheep nematodes. Apart from the differences in types and contents of the phytochemicals in these plant species, efficacy disparities could be attributed to differences in animal feeding behaviour, pre-exposure and adaptation to phytochemicals (Fomum et al., 2017). At greater concentrations, the thresholds for animal and plant species differences were surpassed and offset, enabling the extracts to fully inhibit the helminths, producing comparable effectiveness for both plant and animal species (Fomum et al., 2017).

Regarding extractants, hot water was not efficient at inhibiting *H. contortus* egg hatch at concentrations up to 11.2 mg/mL of *V. amygdalina* extract (Alawa et al., 2003) but acetone and its fractions of the same plant inhibited egg hatch, larval development and killed larvae (Ademola and Eloff, 2011). However, the butanol fraction was the most efficient for egg hatch inhibition, whereas the 35 % water in methanol fraction was the most active on larvae. Similarly, Zabré et al. (2017) found that acetonitrile extracts had greater ovicidal activity, while aqueous extracts had greater larvicidal activity against *H. contortus*. Lack of anthelmintic activity for hot water reported by Alawa et al. (2003) could be largely attributed to use of high temperatures, which may degrade active compounds. The dissimilarities in anthelmintic activity between extractants can be explained by variations in solubility of phytochemicals in different solvents (Ademola and Eloff, 2011). Water was the most evaluated extractant, and water fractions were observed to be effective against eggs, larvae, and adult worms (Table 3). The popularity of water as an extractant could be ascribed to its affordability and potential to extract both fat- and aqueous-soluble phytochemicals (Oliveira Santos et al., 2019; Ademola and Eloff, 2010; Kahiya et al., 2003).

A study by Ibekwe and Bikom (2019) demonstrated that mortality of trematodes treated with aqueous CT extracts of *O. gratissimum* was concentration, time, and parasite species dependant. In fact, the efficacy and lethality of the extract increased with concentration and time of exposure with *F. hepatica* being more susceptible than *P. cervi*. Tibe et al. (2013) reported similar differential inhibitory effects of ethyl acetate CT extracts from *V. verrucosum*, with *H. contortus* being more susceptible than *T. circumcincta* and *T. colubriformis*. The same authors noted that CT extracts from *V. verrucosum* were more efficient in inhibiting larval development than egg hatching and postulated that the structure of its CT may be ineffective in penetrating the cuticle of the eggs. In the same study, the effect of CT on helminths varied with time of sampling, which was attributed to CT variation in content and chemical structure over time.

Most of the iENPs reported in Table 3 had a larvicidal EC₅₀ below 6 mg/mL, a threshold suggested as a marker for high anthelmintic potential (Adamu et al., 2013). Low EC₅₀ values mean low concentrations of extract would be required to achieve acceptable inhibition. Achieving concentrations above 6 mg/mL *in vivo* could be challenging. The extract from *O. gratissimum* had an exceptionally high LC₅₀ value (56 mg/mL)

while the rest of iENPs extracts had low values ranging from 0.06 to 2.02 mg/mL. The smaller the LC₅₀ value the higher the lethality of the extract and the more susceptible the helminth is to the extract. Overall, the optimum efficacy and safety concentrations may be difficult to attain due to iENPs' variation in phytochemical content and composition among other factors. Since *in vitro* systems do not completely simulate conditions in the gastrointestinal tract or consider variable factors such as feed intake fluctuations and the physiological state of the host ruminant, it is important to conduct *in vivo* trials to determine optimum application conditions and mechanisms of action for the iENPs with high nutritional and anthelmintic potential.

5.3.3. *In vivo* efficacy of leaves from iENPs to SSA

Of the identified iENPs (Table 2), nine have been tested *in vivo* as nutraceutical feedstuffs for ruminants (Table 4). The literature generally indicates that adding iENPs leaves to ruminant diets is effective at reducing helminth loads with either neutral or improved effects on animal production (Table 4). The iENPs were predominantly fed to small ruminants, particularly goats. There are no studies that have simultaneously fed iENPs to cattle, sheep and goats and evaluated the effect of ruminant species on worm burdens and animal production. However, small ruminants, goats in particular, have a greater preference for browse forages and seem to have a better ability to utilise fibrous and polyphenolic feed resources compared to cattle (Domingue et al., 1991; Estell, 2010).

Vachellia (14 citations) and *Vernonia* spp (7 citations) were the most tested *in vivo* (Table 4), maybe because of their high nutrient and phytochemical content (Table 2) and *in vitro* anthelmintic efficacy (Table 3) coupled with abundance, wide distribution, and use by ruminants in the region. The limited use of the other iENPs could be partly attributed to a lack of complete data regarding nutrient and phytochemical content, composition and *in vitro* bioactivity. Again, *Vachellia* and *Vernonia* leaves were the most effective in lowering worm loads and enhancing ruminant production (Table 4), which is reflective of their high protein and moderate contents of fibre and phytochemicals (Table 2). The ability of iENPs to control helminths was, however, largely dependent on the inclusion level of iENPs in the diet (Table 4). On the one hand, very low inclusion levels (100 g/d) of iENPs reduced prevalence of large helminths such as *H. contortus* (10–30 mm long) and *O. columbianum* (12–18 mm long; Max et al., 2007; Sisay et al., 2022). On the other hand, feeding diets containing phytochemicals levels above 60 g/kg DM of the basal diet negatively compromised feed intake, nutrient utilisation efficiency and animal growth performance (Kahiya et al., 2003; Marume et al., 2012; Chingala et al., 2019). Because of this, iENPs with high phytochemical content are rarely incorporated in ruminant diets as sources of nutrients but are commonly fed or drenched as extracts to control ruminant helminths (Yanza et al., 2021; Alem, 2024). While the extraction process concentrates phytochemical compounds, it reduces nutrient content of the original plant material. Thus, it is critical to establish dietary inclusion levels that strike a balance between the nutrition and antihelminth properties of iENPs for optimal animal health and production.

Apart from source and inclusion level of phytochemicals, worm burden and animal performance may have been influenced by basal diet, delivery mode, feeding practices time on feed, helminth species, animal age, sex, physiological status, and assay used (Table 4). Fecal worm egg count was the most common assay used to accurately estimate *in vivo* antihelminth efficacy as it is cost-effective and non-invasive. However, this assay does not directly correlate with adult worm reduction as it may also indicate reduced fecundity of the female worms (Kahiya et al., 2003; Oliveira Santos et al., 2019). It is important to note that interactions between diet, helminths, and the ruminant host are complex (Cortés et al., 2020). Under natural pasture conditions for example, ruminants consume diverse diets and get infected with more than one species of parasites with varying lifecycles and immune responses (Jato et al., 2022). It is difficult to find a single remedy that can fully treat

Table 4*In vivo* anthelmintic efficacy, and animal performance effects of indigenous ethno-nutraceutical plants in Sub-Saharan Africa.

Plant	Host	Inclusion level	Target helminth/s	Time on feed (days)	Findings	References
<i>Ocimum gratissimum</i> L. (Clove basil/Scent leaf)	Goats (Bucks)	5, 10, 15 g/kg DM (dry matter) of leaf meal in concentrate and <i>Panicum maximum</i>	Mixed nematodes	84	– 10 and 15 kg/kg DM decreased faecal egg counts 30 % -Reduced dry matter intake -No effects on average daily gain and feed conversion ratio	Adebayo et al. (2019)
<i>Peltophorum africanum</i> Sond. (African/Weeping wattle)	Goats (wethers)	Leaf meal at 60 % of Buffel grass hay diet	Not assessed (NA)	90	-Reduced dry matter intake and average daily gain	Aganga et al. (2001)
<i>*Senegalia senegal</i> (L.) Britton (Gum Arabic tree)	Goats (Bucks)	<i>Chloris gayana</i> hay supplemented with 100 g/d leaf meal	Mixed nematodes	70	-Reduced faecal egg counts -Increased dry matter intake and average daily gain	Sisay et al., 2022
		Hay supplemented with leaf meal at 1.2 % of live body weight	NA	90	-Increased dry matter intake and digestibility, average daily gain, final weight and carcass yield	Hailemariam et al. (2016)
	Sheep (Rams)	Barley straw supplemented with 80, 160 or 240 g of leaf meal	NA	90	-Increased dry matter intake and digestibility, average daily gain and final weight	Mengistu et al. (2016)
<i>Vachellia karroo</i> (Hayne) Banfi & Galasso (Sweet thorn)	Cattle (Steers)	1.5 kg dry leaf meal/d with nature pastures	<i>H. contortus</i> <i>Strongyloides</i> spp <i>Oesophagostomum</i> spp	60	-Reduced faecal egg counts by 15 % and worm counts -Increased average daily gain, final weight and carcass yield	Mapiye et al. (2009b); Xhomfulana et al. (2009)
	Goats (Wethers)	Fresh leaves 50 % and 50 % alfalfa hay	<i>H. contortus</i>	60	-Reduced fecal, larval and worm counts -Increased body condition and weight	Marume et al. (2012)
	Goats (Does & bucks)	Dry leaves 40 %, 60 % concentrate and <i>Chloris</i> hay <i>ad-libitum</i>	<i>H. contortus</i>	56	-Reduced worm burden by 34 % -No effect on growth performance	Kahiya et al. (2003)
	Goats	Dry leaves 200, 250, 300, 400, 500 g/kg mixed with <i>Setaria</i> hay.	NA	23	-Improved palatability -Increased dry matter intake -Increased digestibility and average daily gain	Brown et al. (2016), 2018
		Dry leaves 20, 60, and 100 % replacing maize in a total mixed ration	NA	42	-Increased average daily gain and final weight	Kugedera et al. (2021)
	Goats (Does & bucks)	Dry leaves 40 % or 60 % of concentrate supplementing <i>Chloris</i> hay <i>ad-libitum</i>	<i>H. contortus</i>	56	-Reduced worm burden by 10 % -No effect on growth performance	Kahiya et al. (2003)
	Sheep (Rams)	Natural pastures supplement with 108, 216, or 325 g/d dried leaves	NA	100	-Linearly increased dry matter intake, nutrient digestibility and utilisation -Increased average daily gain, final and carcass weights	Bekele et al. (2022)
		125.9 g/d of leaf meal supplementing pasture hay	NA	84	-Neutral effect on dry matter intake -Increased average daily gain and final weight	Rubanza et al. (2007b)
<i>Vachellia polyacantha</i> (Wight & Arn.) P.J.H. Hurter. (White thorn)	Goats (Bucks)	100–130 g dry leaves/animal/day and <i>Chloris</i> and <i>Brachiaria</i> hay	<i>H. contortus</i> , <i>Trichostrongylus colubriformis</i> <i>O. columbianum</i>	20	-Reduced faecal egg counts by 27 % and worm counts by 13 %	Max et al. (2007)
	Sheep (Rams)	150 g dry leaves/animal/day and <i>Chloris</i> and <i>Brachiaria</i> hay	<i>H. contortus</i> , <i>O. columbianum</i>	30	-Reduced faecal egg counts by 19 % -No effects on worm counts	Max et al. (2007)
	Steers	50 % of leaf meal replacing soybean in grass basal diet.	NA	120	-Reduced dry matter intake, average daily gain, and final weight	Chingala et al. (2019)
	Goats (Bucks)	125.9 g/d of leaf meal supplementing pasture hay	NA	84	-Neutral effect on dry matter intake -Increased average daily gain and final weight	Rubanza et al. (2007b)
<i>Vachellia seyal</i> Delile (Shittimwood)	Goats (Bucks)	<i>Chloris gayana</i> hay supplemented with 100 g/d leaf meal	Mixed nematodes	70	-Reduced faecal egg counts -Increased dry matter intake and average daily gain	Sisay et al., 2022
		Barley straw supplemented with 200 g/d leaf meal	NA	90	-Increased dry matter intake, digestibility and average daily gain	Gebreselassie et al. (2014)
		<i>Chloris gayana</i> hay supplemented with 100 g/d leaf meal	Mixed nematodes	70	-Reduced faecal egg counts -Increased dry matter intake and average daily gain	Sisay et al., 2022
<i>Vernonia amygdalina</i> Delile (Bitter leaf)	Goats (Bucks)	5, 10, 15 g/kg DM of leaf meal in concentrate and <i>Panicum maximum</i>	Mixed nematodes	84	-Linearly reduced faecal egg counts up to 65 % -Increased dry matter intake and average daily gain	Adebayo et al. (2022)

(continued on next page)

Table 4 (continued)

Plant	Host	Inclusion level	Target helminth/s	Time on feed (days)	Findings	References
<i>Viscum verrucosum</i> Harv. (Mistletoe)	Goats	200, 300 and 400 g DM/day of dry leaves with <i>Catha edulis</i>	NA	90	-Linearly increased dry matter intake and digestibility, final weight, average daily gain and feed conversion ratio	Adem and Misbah (2021)
		150, 300, 450 g/kg DM of leaf meal in concentrate and <i>Panicum maximum</i>	NA	140	-No effect on feed intake and final weight -Decreased average daily gain and feed conversion ratio -increased goat mortality at 300 and 450 g/kg DM	Olosunde and Odeyinka (2020)
		<i>Chloris gayana</i> hay supplemented with 100 g/d leaf meal	Mixed nematodes	70	-Reduced faecal egg counts -Increased dry matter intake and average daily gain	Sisay et al., 2022
		Fresh raw whole leaves and young stalks of <i>V. Amygdalina</i>	<i>Haemonchus contortus</i> , <i>Trichostrongylus</i> spp and <i>Oesophagostomum</i> spp	2	-100 % effective against helminths	Adediran et al. (2014)
		Natural pasture supplemented with 100, 200 or 300 g/d dried leaf meal	NA	90	-Quadratically increased dry matter intake and digestibility, average daily gain and final weight with a peak at 100 g/d	Adugna et al. (2023)
		100, 150 or 200 g/animal/d dried leaf meal plus 900 g/d <i>Eragrostis tef</i> straw	NA	21	-Marginally increased feed intake and digestibility	Bonsi et al. (1995)
<i>Viscum verrucosum</i> Harv. (Mistletoe)	Goats (Does)	20 % leaf meal in total mixed ration	Mixed nematodes	29	-Tended to decrease faecal egg counts in week 4	Madibela and Jansen (2003)
	Sheep (wethers)	200 or 400 g of leaf meal replacing lucerne hay in grass hay basal diet	NA	21	-Increased dry matter intake, digestibility and average daily gain	Letso and Thela (2013)
<i>Viscum verrucosum</i> Harv. (Mistletoe)	Sheep (Rams)	0, 50, 100 and 150 g/kg in total mixed ration	NA	90	-Increased dry matter intake, nutrient digestibility, average daily gain and feed conversion ratio with inclusion level	Njidda et al. (2014)

Senegalia and **Vachellia were formerly Acacia. ***Vachellia tortilis subsp. raddiana was formerly known as Vachellia raddiana (Savi) or Acacia raddiana (Savi).

undernutrition and a blanket of helminths in ruminants. Further research into the use of iENPs may provide promising avenues for improving health and production of ruminants in the region.

6. The future of iENP research, innovation and development

Fig. 3 presents a conceptual framework for future research and development of iENP based anthelmintic and undernutrition remedies

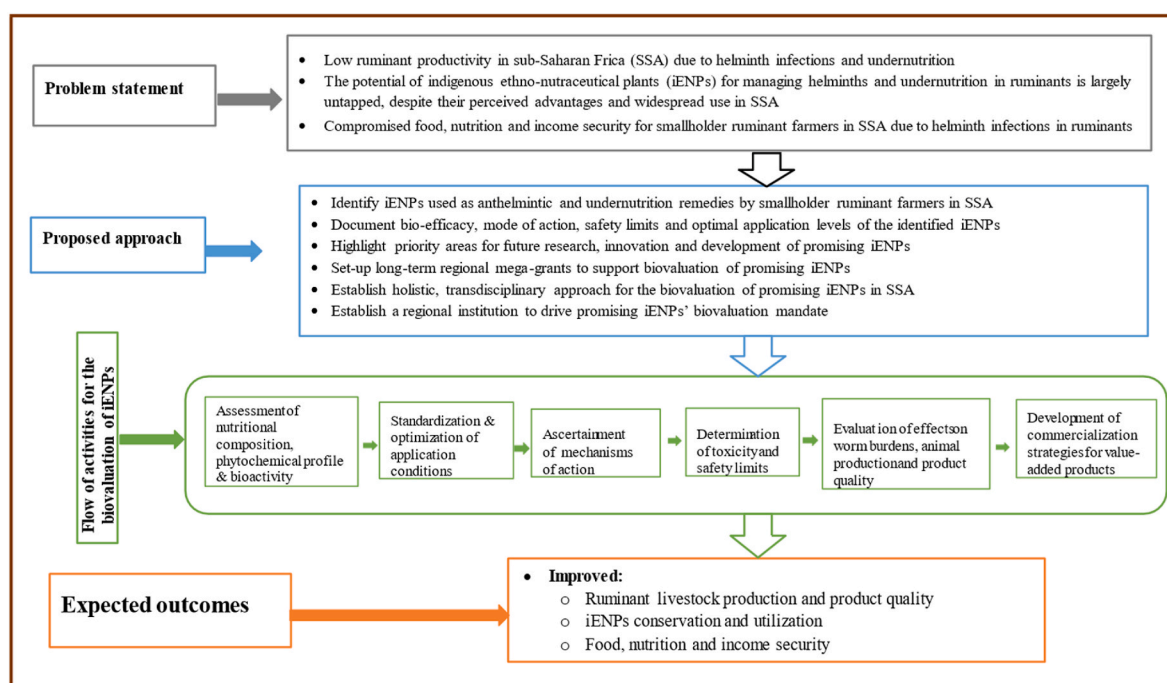


Fig. 3. A conceptual framework for future research and development of iENP based anthelmintic and undernutrition remedies and value added animal products in Sub-Saharan Africa.

and value-added animal products in SSA. The *in vitro* and *in vivo* data in the preceding sections validate the claims that iENPs in SSA have significant potential for the discovery and development of nutraceutical remedies for the sustainable management of helminths and undernutrition in ruminants. However, the efficiency of most of the identified iENPs was inconsistent due to variations in several application conditions of the phytochemicals. Apart from variation in conditions of application, nutritional and phytochemical content and composition have not been fully profiled, mode of action remains unclear, and safety limits are unknown, *in vitro* and *in vivo* bio-efficacy activity studies are limited. In most cases, the few available studies evaluating nutritional and anthelmintic efficacy of iENPs were conducted separately. Moreover, the use of iENPs in managing helminths and undernutrition in SSA has not been holistically integrated with non-chemical methods such as grazing management and selective breeding, which also seem to have great potential under extensive production systems (Hoste and Torres-Acosta, 2011; Gray et al., 2012; Maqbool et al., 2017). In this context, future iENPs research in SSA should prioritize standardisation and optimisation of application conditions, simultaneous evaluation of worm burdens and animal performance, and holistic integration of iENPs with other high-potential non-chemical methods. This could further promote the discovery and development of suitable iENPs-based undernutrition and helminth remedies for ruminants.

The future development of SSA's ethno-nutraceuticals for ruminants will be largely driven by the emerging trends in technological innovation. Given the peculiarities of the SSA ruminant production systems and analytical resources, a plethora of emerging technologies should be tailored to improve analyses, bio-efficiency and economic viability of iENPs phytochemicals under rural farm settings. Proper selection and standardisation of modern green-solvent extraction, chromatographic isolation and spectroscopic identification techniques for phytochemical analyses (Abubakar and Haque, 2020; Sruthi et al., 2023) should form the foundation for the testing of the nutraceutical properties of the target phytochemicals. In this context, a regional iENP pharmacopoeia can be developed to provide appropriate information regarding identification and analytical procedures of these plants. Nanotechnology can be adapted to enhance stability, delivery, absorption, efficacy and target specificity of phytochemicals and nutrients from iENPs (Hamid et al., 2023) under resource-limited rural settings in SSA. The omics, genome editing, and bioinformatics technologies should be customised for SSA to improve understanding of the underlying mechanisms through which dietary and environmental factors interact with genes to influence performance of helminths and ruminants (Pandita and Pandita, 2022).

Sustainability shall be integral to the future utilisation of iENPs in ruminant animal health and production in SSA. This presents a lucrative opportunity for niche marketing of ruminant products free of chemicals. In addition, the biopreservative (i.e., antioxidant and antimicrobial) properties of iENPs could stimulate novel investments along ruminant production and products supply chains which could enhance food and nutrition security, human health and wellbeing, and contribute to economic growth. In this regard, SSA's governments should enact regulations to control collection, identification and authentication of iENPs, as well as testing, marketing and quality control of ethno-nutraceutical remedies and value-added edible products from ruminants fed diets fortified with iENP-based phytochemicals. Intellectual property rights, patents and policies regarding utilisation of iENPs must be established to promote conservation, domestication and cultivation of iENPs and equitable sharing of benefits from the commercialised nutraceutical products among the stakeholders. This should be accompanied by inclusion of iENPs' folkloric knowledge, conservation, and utilisation curricula at primary, secondary and tertiary education levels, and stakeholder education and awareness programs at different administrative levels from local to regional level.

A regional research, innovation and development network should be established to set up long-term public-private-producer partnership funding programs to support the collaborative transdisciplinary

research, extension, prototyping, and commercialisation of iENPs and their value added-products for improved ruminant health and production in SSA. Such transdisciplinary network can include traditional knowledge holders, botanists, phytochemists, agronomists, veterinarians, animal, and food scientists, agricultural economists, among other scientists and specialists and extensionists. In this context, SSA governments should consider launching a regional institution to drive the iENP transdisciplinary research, innovation and development mandate. All these research, innovation and development strategies offer a game-changing opportunity for the dual management of helminths and undernutrition using iENP in SSA.

7. Conclusions

Current scientific evidence in SSA demonstrates nutraceutical potential amongst many indigenous plants, particularly in the family of *Vachellia* and *Vernonia* to overcome undernutrition and helminths in ruminants. The dominant phytochemicals in these plants are polyphenols, alkaloids, saponins, and essential oils. To optimise benefits of iENPs as a dual remedy for ruminant helminths and undernutrition in SSA, further research should be taken to validate their anthelmintic and nutritional potencies, ascertain mechanisms of action, determine safety limits, and optimise conditions of application using controlled *in vivo* experiments. In addition, strategies for conservation of iENPs, quality control and niche marketing of nutraceutical products, stakeholder education and awareness should be developed to allow their commercialisation as sustainable substitutes for chemical undernutrition and helminth therapies. Holistic integration of iENPs with other non-chemical methods supported by collaborative transdisciplinary research, innovation and development of regional networks, customised technologies, science-based policy and regulatory frameworks, and sustainable funding programs could provide a real future progress outlook. To end, a regional institution should be established to drive the holistic valuation of iENPs mandate in SSA.

CRedit authorship contribution statement

Cletos Mapiye: Writing – review & editing, Writing – original draft, Conceptualization. **Farouk Semwogerere:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Leo Nyikadzino Mahachi:** Writing – review & editing, Writing – original draft. **Marizvikuru Mwale:** Writing – review & editing, Writing – original draft. **Munyaradzi Christopher Marufu:** Writing – review & editing, Writing – original draft.

Ethical considerations

This review synthesised data from published articles without including confidential or personal data. Thus, ethical approval was considered unnecessary.

Consent for publication

All authors have reviewed and confirmed the completed manuscript.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: All authors declare that there are no actual or potential conflicts of interest including financial, personal or other relationships with other people or organizations that could inappropriately influence, or be perceived to influence, this work.

Acknowledgements

This review was presented as a keynote paper at the joint meeting of the 23rd International Congress of the International Society for Ethnopharmacology and the 2nd International Congress of the African Phytomedicine Scientific Society (ISE-APSS 2024) hosted by the University of Pretoria from 23 to 26 October 2024 at the Cape Town International Convention Centre, South Africa.

List of abbreviations

ADF	Acid detergent fibre
AR	Anthelmintic resistance
CP	Crude protein
CT	Condensed tannins
DM	Dry matter
DMD	Dry matter digestibility
DMI	Dry matter intake
EC ₅₀	Effective concentration 50
EE	Ether extract
GIN	Gastrointestinal nematode
GIT	Gastrointestinal tract
IC ₅₀	Inhibitory concentration
iENPs	Indigenous ethno-nutraceutical plants
IVDMD	<i>in vitro</i> dry matter digestibility
LC50	Lethal Concentration 50
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PVPP	Polyvinyl polypyrrolidone
SSA	sub-Saharan Africa
TP	Total polyphenols
TT	Total tannins
NDF	Neutral detergent fibre

Data availability

No data was used for the research described in the article.

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