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# Incorporation of local novel feed resources in livestock feed for sustainable food security and circular economy in Africa

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In livestock production, feed resources are very crucial, particularly in Africa where food security and sustainable development are major considerations. The incorporation of locally available novel feed resource alternatives can promote circular economy concepts, increase food security, and improve sustainable livestock production. This review attempts to compile the most recent information on the use of locally available novel feed sources found in Africa while assessing their potential benefits for circular economy principles and sustainable livestock production. We conducted a thorough literature search to find appropriate publications that were published between 2010 and 2022. The search was done using keywords relating to local novel feed resources, sustainable development, circular economy, livestock feed, and food security across a number of research databases, including PubMed, Scopus, and Web of Science. After the search and screening, relevant publications were chosen for inclusion based on their applicability to this review design, topicality (Africa), and regional focus. This review discovered a wide range of locally available novel feed resources, such as native plants, agricultural byproducts, food processing byproducts, and weeds, all of which have the potential to serve as alternative supplements or substitute feed sources for livestock. These resources frequently have a good nutritional composition and advantageous phytochemicals and can be obtained locally, decreasing reliance on foreign feed components. By exploiting locally accessible resources, the inclusion of these materials in livestock feed has significant potential to enhance livestock performance, lower production costs, and promote circular economy concepts in Africa. African countries' sustainable food security and circular economies stand to gain significantly from the use of locally available novel feed resources in livestock feed. However, further investigation is required to determine their nutritional worth, safety, and the best inclusion rates in livestock rations. For their implementation to be effective, it will also be essential to comprehend the socioeconomic, cultural, and environmental elements impacting their adoption. This review offers a thorough synthesis of the body of research, emphasizing the value of locally available novel feed sources in improving the production of livestock and advancing Africa's sustainable development targets.

KEYWORDS

**Africa, alternatives, circular economy, food security, livestock, SDGs, sustainability**

## 1. Introduction

To provide food security, economic growth, and sustainable development in Africa, livestock production is essential. There is an urgent need to increase livestock productivity while simultaneously addressing environmental issues and supporting circular economy concepts due to a growing population and rising demand for animal protein. The availability and quality of feed resources, which have a direct impact on livestock health, performance, and overall production efficiency, is a crucial component of the African livestock industry (Rust and Rust, 2013; Jalal et al., 2023). The sector does, however, confront a number of difficulties, such as restricted availability of high-quality feed resources, high import feed costs, and environmental deterioration brought on by subpar waste management. Climate change, which affects the quantity and quality of feed resources, worsens these problems (Asmare, 2014). To overcome these difficulties, it is necessary to investigate and use locally available, novel feed and feed ingredient options that are economical, sustainable, and easily accessible. Using locally readily available feed resources can lower production costs, generate employment possibilities, and advance sustainable agricultural methods (United Nations, 2014; Paul, 2019). The use of unconventional feed resources in animal feed has garnered more attention in recent years. These resources include agriculture remnants, invasive plant species, and waste products from the food processing industry (Chisoro and Nkukwana, 2020a,b). These resources can give animals a substantial amount of nutrients yet they are frequently misused or discarded. There are various benefits to including these locally available feed materials in livestock feed. First, it lessens the reliance on imported feed and convectional feed ingredients, which are frequently expensive and occasionally challenging to find. Second, it gives farmers an alternative way to make money since they can sell the leftovers or byproducts to companies that make premium livestock feed. Finally, it supports the circular economy idea, which calls for recycling refuse from one industry to create resource efficiency and reduce environmental impact (Chisoro et al., 2018; Jalal et al., 2023).

However, when incorporating locally available novel feed sources into animal feed, it is important to pay close attention to a number of characteristics, including nutrient composition, antinutritional elements, digestibility, and palatability (Mwale et al., 2008; El-Deek et al., 2020; Rahaman et al., 2022). These elements may have an impact on animal output, health, and growth. To make the most of these resources, research must be done and proper processing and feeding methods must be developed. The use of non-traditional feed sources in livestock feed, particularly in the production of pigs and poultry, has been the subject of numerous research (Mukumbo et al., 2014; Akinmutimi and Afolayan, 2016; Chen et al., 2019; Nkukwana, 2019; Mbukwane et al., 2022). For instance, it has been demonstrated that the usage of rice bran, palm kernel meal, common vetch, duckweed, Azolla, baobab leaves and seeds, sweet potato vines, cassava leaves, marula seeds, moringa leaves, etc. can boost the growth and productivity of pigs and broiler chickens. Banana stems and oil palm fronds have also been found to be viable sources of fiber for ruminants and non-ruminants (Karangiya et al., 2016; Nduku et al., 2021; Shuang et al., 2022). This review's main goal is to provide a thorough examination of the use of locally available novel feed resources in livestock feed as a strategy for long-term food security and a circular economy in Africa. We will pay special attention to locating and evaluating the variety of local new feed supplies that are available in Africa, such as native plants, agricultural byproducts, food processing byproducts, and weeds. Despite being frequently disregarded, these resources have the potential to be effective ingredients in livestock feed. Additionally, the review will evaluate if using locally available innovative feed resources is feasible in light of sustainability and circular economy concepts. The African livestock industry may lessen its impact on the environment, generate economic possibilities, and improve the resilience of the African food system by lowering its reliance on imported feed ingredients and encouraging the use of locally accessible resources. The incorporation of local novel feed resources for sustainable food security and the circular economy in Africa will be addressed in this review, which will serve as a complete resource for evaluating the present state of knowledge and identifying future research possibilities.

## 2. Outlook on Africa and the African population

The population of sub-Saharan Africa is increasing at a rate of 2.7% per year, more than twice as quickly as that of South Asia (1.2%) and Latin America (0.9%). In other words, in 2 years, Africa gained the population of France (or Thailand). Despite having a population four times that of Asia, nearly two more children are born in Africa each year than in Asia (Statista, 2023). Over the coming decades, the population of Africa is expected to continue growing rapidly, according to the UN. Africa currently has approximately 1.3 billion people, and by 2050, that number is expected to increase to 2.5 billion, with most of the growth taking place in sub-Saharan Africa (United Nations, 2014; IFPRI, 2020b). In recent years, the population growth rate in Africa has slowed significantly, but it is still larger than in any other part of the world. High fertility rates, better healthcare and living conditions, and a young population with a sizable number of women of childbearing age are all factors that contribute to this expansion (GASL, 2014; United Nations, 2019). The COVID-19 pandemic has, nonetheless, had a considerable impact on the African populace, particularly in terms of health and economic results (FAO, 2020a). The pandemic has put a strain on the already flimsy healthcare systems of many African nations, and the economic downturn brought on by the pandemic has made poverty and food insecurity worse across most of the continent. Africa faces serious food security issues, which will only worsen as the continent's population increases (The Guardian, 2021). The agricultural production of many African nations is severely constrained by problems including climate change, land degradation, and a lack of investment in rural regions, all of which contribute to low yields and food insecurity (World Bank, 2020). Even though it is anticipated that Africa's population will continue to expand quickly over the coming decades, the COVID-19 epidemic and food security are significant issues that will need to be resolved to maintain sustainable growth and the wellbeing of the people in the continent (Lukuyu et al., 2020, LGH 2020, Jalal et al.,

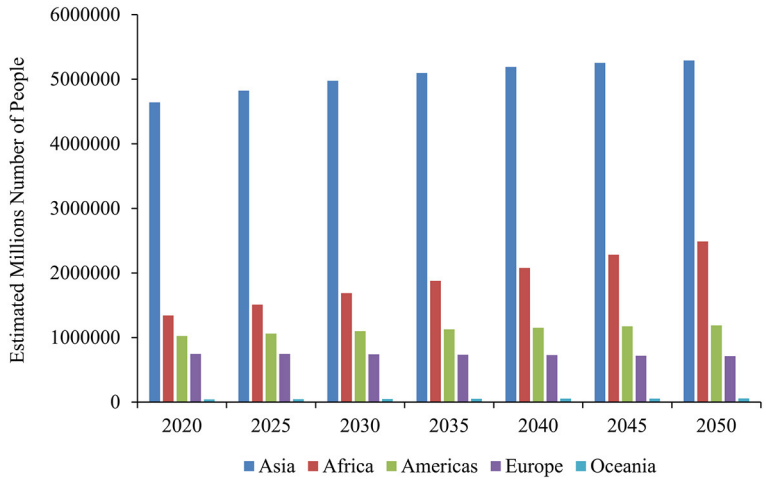


FIGURE 1
Estimated expected population growth by continent from 2020 to the year 2050. According to Statista (2023), Africa's population is forecast to expand annually by an average of 2.37% between 2020 and 2050. Overall, Africa has recorded faster population growth than other world regions, with the continent's population almost doubling in the last 25 years.

2023). Africa as a continent with such population growth and still ridden with hunger and poverty, strategic ways have to be thought of and implemented to try and support Africa's food security. If sufficient food security is achieved, Africa can focus on other opportunities, such as technological advancement, vehicle and equipment manufacture, stable financial institutions and economic establishment, and education advancement, and contribute to the global order (Ramirez et al., 2021). Figure 1 shows the trajectory of Africa's population growth relative to other continents.

## 2.1. Food security status in Africa

Due to the continent's widespread poverty, political unrest, and negative effects of climate change on agricultural output, food security in Africa remains a major concern. Approximately 256 million people in Africa, or more than half of the world's population, were undernourished in 2019, according to the FAO (2019a). In addition, the COVID-19 epidemic has worsened food security in Africa by disrupting supply networks, limiting access to markets and labor, and driving up food costs. Remittances, an important source of income for many households in the area, have decreased due to the pandemic. Food security in Africa is seriously threatened by climate change (Paul, 2019; Lukuyu et al., 2020; Marchant-Forde and Boyle, 2020). Reduced agricultural yields and a rise in food insecurity have been observed in several regions of the continent due to erratic rainfall patterns and rising temperatures. Conflicts and migration have also disrupted food production and market access, worsening the situation with regard to food security (Chen and Yang, 2021; Sattar et al., 2021). In addition, there have been some devastating events in some parts of sub-Saharan Africa, which greatly affected the food security status of this region. Both Cyclones Idai and Kenneth, which struck Southern Africa in March and April of 2019, respectively, left Mozambique, Zimbabwe, and Malawi in utter ruin (UNDP, 2019; UNICEF, 2019). In addition, Cyclone Freddy recently struck in March 2023, particularly in Madagascar, Malawi, and Mozambique. Heavy rains and flooding caused by the cyclones killed people and wrecked crops, homes, and infrastructure (OCHA, 2019). The cyclones had a substantial effect on the region's food security. Many people lost access to food due to the floods destruction of crops and animals and the disruption of the food supply systems. Over 1.85 million people were reportedly affected by the cyclones in Mozambique alone, and over 1 million hectares of crops were damaged. People found it challenging to afford food due to a shortfall in food output and an increase in food prices. The cyclone, in particular, Idai, in Zimbabwe destroyed infrastructure and crops, notably in the eastern regions of the nation. The World Food Program (2019) estimates that 270,000 people were affected by the cyclone, of whom 131,000 required emergency food assistance. The cyclones (Idai and Freddy) in Malawi caused flooding and infrastructure damage, disrupting the flow of food (OCHA, 2023). The WFP also estimates that the cyclones affected over 1.7 million people, of whom 868,900 required emergency food assistance. Overall, Cyclone Idai, Cyclone Kenneth, and Cyclone Freddy had a substantial impact on Southern Africa's food security, and the rebuilding process has been difficult and quite slow (OCHA, 2019, 2023).

Despite these difficulties, recent years have seen some encouraging trends in Africa's food security. For instance, some nations have implemented laws and initiatives meant to increase agricultural productivity and decrease hunger. These initiatives have expanded food output and given small-scale farmers better market access (FAO, 2020b; United Nations, 2021). Additionally, there has been a rising emphasis on establishing climate change-resistant sustainable agricultural techniques. Overall, even though there has been improvement in food security in Africa, much more needs to be done to guarantee that everyone on the continent has access to healthy and cheap food (FAO, 2019b). As shown in Figure 2, there will be continued consumption of meat and

livestock products, since with the growth in population and income people will be more willing to spend more on better food products, which mostly tend to be meat-related. However, with the poor infrastructure around the African livestock sector, it is to some extent challenging to meet this estimated demand (Figure 2), since most contributors to the livestock sector in Africa tend to be rural and smallholder farmers, who either keep animals at a subsistence level or for retail in local communities through their butchery outlets (LDIA, 2014; Chisoro et al., 2019). Nevertheless, research seems to have found opportunities or to some extent options or ways that these farmers can use to enhance their production and contribute more to the African economy, especially the circular economy. The use of local novel feed substitutes or supplements to convectional feed resources has been researched and is still being researched extensively as a way that rural and smallholder farmers can use to feed their animals and produce more. These studies are being conducted globally and with special attention to Africa, since Africa has a lot to benefit from this as a vast alternative resource, such as oilseeds from fruit-bearing trees, leaf meals from local trees, crop residues, food processing plants (candy producers, biscuit makers, potato chips manufacture, etc.), insects, and agro-industry byproducts, which can be used in livestock feed and are readily available and sourced in Africa (Belluco et al., 2013; Negi and Pant, 2017; Chisoro et al., 2018; Nyamukonda and Ndlovu, 2019; Chisoro and Nkukwana, 2020b). The use of these local novel feed resources in Africa will significantly promote the growth of the livestock sector in Africa and allow it to meet its estimated consumption of meat and livestock products and the projected growth of livestock products, as highlighted in Figure 2.

This resultant growth and use of local novel feed resources in livestock feed in Africa have counterintuitive results, such as limitation and reduced dependence on traditional feed resources, promotion of the use of local resources hence promoting UN SDGs on climate action and responsible consumption, and finally the growth and advancement of Africa's circular economy. The circular economy is promoted with this action by the creation of employment through the procurement of these resources and the creation of processing facilities to process these resources for use in feed manufacture and income diversification, thereby promoting Africa's economic growth (Ward et al., 2016; Ramirez et al., 2021; Ominski et al., 2023).

## 2.2. Livestock status in developing countries

Millions of people in developing nations rely on the livestock business for food, income, and work possibilities (FAO, 2020b). However, the state of the industry today might differ significantly depending on the region, country, and even the particular livestock industry sector. In general, the livestock sector in the developing world especially Africa is dealing with a number of difficulties, such as:

1. *Epidemics of disease*: Livestock diseases, including foot-and-mouth disease, avian influenza, and African swine fever, can have a serious financial impact on farmers and the entire industry (FAO, 2020b).
2. *Climate change*: The effects of climate change can impact the quantity and quality of pasture, water, and other resources essential to livestock nutrition (Lukuyu et al., 2020), as seen by the disruptions in the livestock sector and agriculture sector as a whole that occurred due to the cyclones that hit Southern Africa in 2019 and 2023.
3. *Degradation of the environment*: Excessive grazing, deforestation, and other types of land use change cause soil erosion, water pollution, and other environmental issues, which limit the full growth and development of the livestock sector in these regions (Omollo et al., 2020).
4. *Local and international market accessibility*: Many smallholder farmers find it difficult to sell their livestock products, which might reduce their ability to earn an income. However, this is mainly influenced by product inferiority to commercial products and product processing, which tend not to meet market requirements (Imathiu, 2021).
5. *Lack of proper investment*: In some developing nations, the livestock industry suffers from a lack of funding for infrastructure, technology, and other areas that could boost production and profitability, limited by the lack of adoption of innovative techniques from research and to some extent education on alternative production forms and ways, and also lack of the full use of locally available feed resources (United Nations, 2014).

Despite these difficulties, the livestock industry in developing countries has prospects. For instance, the rising export potential for livestock farmers is brought on by the rising demand for meat and other animal products in developing nations such as China and India (Paul, 2019). Technology advancements and breeding initiatives are also assisting farmers in enhancing their livestock productivity and health while minimizing negative environmental effects. It is significant to remember that the livestock industry is extremely diversified, and the opportunities and challenges faced by various sectors and areas might differ significantly. For instance, the obstacles faced by the dairy and poultry industries may differ, and the livestock business may be more developed and successful in one location than in another (Makkar, 2018; Balehegn et al., 2021; Jalal et al., 2023). As represented in Table 1, the most yearly estimated growth in meat and milk markets will be in developing regions of the world such as Africa, Asia, and the Near East. Despite this article mainly focusing on Africa, the same measures and techniques on the use of local novel resources in animal feed can be applied to all regions of the world and have a significant influence on respective circular economies. In addition, considering that the UN SDGs have to significantly be influenced and addressed not in just one area of the world but as a whole, using local novel feed resources in livestock will greatly promote their implementation and achieve the UN's climate goals, delivering quality education, eradicating hunger and poverty, and responsible use and consumption of resources. The influence of the use of local novel feed resources on UN SDGs is highlighted in detail in part 5 of this article.

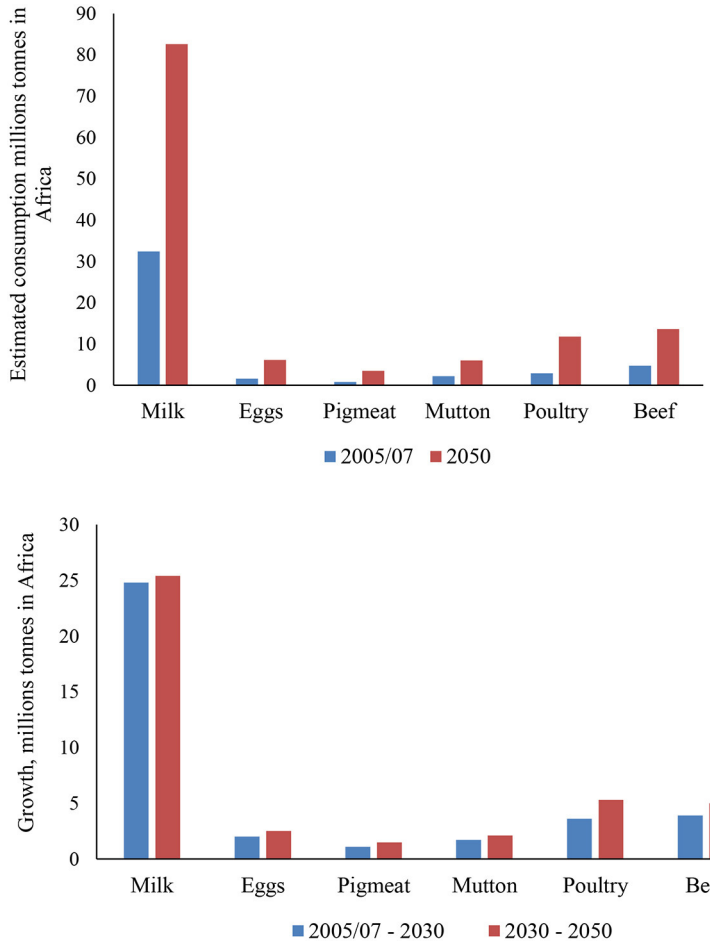


FIGURE 2
Above graphs show the estimated market size of livestock products in Africa for 2005/7 and 2050 **(Top)** and the projected growth in livestock products from 2005/07 to 2030 and from 2030 to 2050 **(Bottom)** as taken from the complied data in the 'Livestock data innovation in Africa report' (LDIA, 2014), data sourced from the FAO Global Perspective Studies Unit (2006). No similar report like this has been done yet. However, with the trajectory of Africa's population growth and the middle-income populace, the figures' trajectory will continue despite the disruptions of COVID-19, Cyclones, and global inflation.

TABLE 1 **Estimated and projected percentage annual growth rates of meat and milk markets in major world regions 2005/7–2050.**

| | Developed | Africa | Near East | Latin America | South Asia | East Southeast Asia |
|---|---|---|---|---|---|---|
| Meat market | 0.4 | 2.8 | 2.4 | 1.3 | 4.1 | 1.4 |
| Milk market | 0.4 | 2.2 | 1.7 | 1.1 | 2.0 | 1.5 |

Information taken and sourced from the "Livestock data innovation in Africa report" (LDIA, 2014).

## 2.3. Influence of smallholder farmers in Africa

To ensure food security in Africa, smallholder livestock farmers are essential. Over 70% of Africa's entire livestock production, according to the FAO (2011, 2019a, 2020a), is produced by smallholder farmers. These small-scale farmers frequently work on marginal ground and employ conventional, low-input farming techniques. However, they feed and support millions across Africa (Paul, 2019). Small-scale livestock producers are crucial for several reasons. First off, they generate a lot of food, such as meat, milk, and eggs, which are crucial sources of protein and other critical elements for many people. Second, they help millions of people, notably those in rural regions who depend on livestock for food and income, to have good livelihoods. Additionally, small-scale livestock farming offers both men and women job opportunities, and it is frequently a significant source of income for women who work in the processing and marketing of livestock products. However, smallholder livestock farming in Africa has numerous difficulties, including low production, inadequate feed and water supplies, poor animal health, and restricted access to veterinary services (Lukuyu et al., 2020). These difficulties may lead to low production levels, subpar product quality, and restricted market access, all of which may impact smallholder farmers' incomes and

standard of living (Balehegn et al., 2021). Governments, funders, and development organizations are attempting to increase the productivity and sustainability of smallholder livestock farming in Africa to solve these issues. This includes programs to enhance animal nutrition and health, widen access to veterinary care, encourage environmentally friendly land use methods, and bolster market ties (IFPRI, 2020b). Making major strides toward achieving food security in Africa is attainable through assisting smallholder livestock farmers and enhancing their productivity and sustainability.

## 3. Local novel feed resources in Africa

In sub-Saharan Africa, the low dietary intake of animal protein has resulted in a high prevalence of protein malnutrition (Chisoro and Nkukwana, 2020b). Soybean, a noteworthy protein source in monogastric and ruminate nutrition, is a human food ingredient. Hence, livestock production competes vigorously with man for soybean for sustenance (García-Moya et al., 2019; Nyamukonda and Ndlovu, 2019). Similarly, cereal grains, the major energy sources in intensive livestock production, are in limited supply for human consumption in the sub-Saharan African region resulting in substandard and to some extent contaminated cereal grains being fed to livestock (Chisoro et al., 2019; African Development Bank, 2020). This was further worsened by the recent COVID-19 pandemic from 2020 to 2021 and the Russo-Ukraine war that began in early 2022. The supply of grain, wheat, and other agricultural products from these countries was affected vigorously due to the war since they are among the top producers and exporters of some of these products worldwide and mostly in Africa. In addition, the sanctioning of Russia by the world heavily affected agriculture production in Africa. Most African countries get some of their fertilizers and other agricultural resources from this country, resulting in low farming productivity and disruption of some African countries' food security (Feed Additive, 2022; Tokozwayo et al., 2022). Competition and drought-induced soybean scarcity, the restrictions to the use of fishmeal, and the lack of cereal grain impose a great necessity to search for non-conventional human and livestock feed sources of protein and energy that are adaptable to harsh climates and edaphic environments of the sub-Saharan African region and elsewhere particularly in livestock feed (African Union, 2014; IFPRI, 2020a). Various studies have noted that a practical approach to cutting down nutrition costs for livestock nutrition is by the supplementation or replacement of conventional feed ingredients with high protein and energy products such as indigenous wild fruit tree products, local novel feed resources, and insects (Chakraborty and Gupta, 2017; Kinyuru et al., 2018; García-Moya et al., 2019). Considering that the prices are on the rise for these convectional ingredients, it implies that for sub-Saharan African farmers, maize and soybean will be less accessible. This makes the prospects of utilizing these local novel feed resources in livestock feed as alternative energy and/or protein supplements feasible, considering their ready availability in most parts of sub-Saharan Africa and ease of propagation and use (Nyamukonda and Ndlovu, 2019).

### 3.1. Categories of local feed resources

The ultimate feed resources or ingredients for livestock are maize (corn) and soybean meal. They are extensively used in feed manufacture and also in human diets. With the world's population growth, their demand is going to increase continually. For Africa with its continued population growth and the need to grow the livestock industry, they are continually going to be needed and procured either through more cultivation or importation for use in animal feed and human diets (Chisoro and Nkukwana, 2020a). Maize is not just used as a feed ingredient in Africa similar to the U.S.A, Europe, and other developed nations but also is a staple food in many African countries such as Zimbabwe, South Africa, and most of West and East Africa, while soybeans are used for oil production globally. A great need to substitute these ingredients in livestock feed or supplement with alternative novel resources is of great importance (Mazizi et al., 2020). As highlighted earlier, vast research studies have been done to look into alternatives to at least partly reduce their inclusion levels in feed or completely substitute these traditional feed ingredients with great success (Chisoro and Nkukwana, 2020b). For sustainable food security and a circular economy particularly in Africa and most developing countries, there are a variety of locally available novel livestock feed resource categories from which alternatives or supplements can be taken to at least limit complete reliance on these vital ingredients (maize and soybean) that can be used into livestock feed (Chisoro et al., 2017; Chioma et al., 2021). These alternatives have also been shown to have nutritional compositions similar or to some extent better than these traditional feed and food ingredients. The groups that novel feed resources fall under consist of those represented in Table 2. Looking at these categories, there is a vast array or novel feed resources that African farmers can use and benefit from and minimize their heavy reliance on traditional/convectional feed ingredients and increase the sustainability of their agricultural systems.

Using these locally available feed resources has excellent economic benefits for African farmers especially smallholder farmers. First, utilizing these alternative novel feed resources in livestock feed can be cost-effective, that is, feed costs, production costs, and increased revenue. The resources are often abundant and can be harvested easily, reducing the need for expensive commercial feed concentrates and convectional feed ingredients (Nyamukonda and Ndlovu, 2019). Similarly, despite some of these resources being byproducts or waste, such as oilcakes, leaf meals, or crop residues, they still contain and can provide valuable nutrients that can complement traditional/convectional feed sources (Sengupta and Banerjee, 2019). Second, utilizing novel local feed resources has positive impacts on local economies by creating income-generating opportunities, especially in rural communities. For instance, farmers can sell excess processed feed ingredients to other farmers or process the feed ingredients and sell them to commercial feed processers when ready for direct use in feed formulations. Most of these feed resources require prior processing before use in feed formulations, to reduce, mycotoxins, antinutritional factors, and pathogens, making them more palatable for livestock nutrition (Adamu et al., 2022; Jalal et al., 2023). In addition, if they harvest wild fruits for use in livestock feed

TABLE 2 Categories of some of the novel feed ingredients or supplements in livestock feed.

| Category | Examples | Explanation |
|---|---|---|
| Oilseeds and leaf meals of indigenous fruit-bearing trees | Neem seeds, Baobab leaves and seeds, Red sour plum seeds, Moringa leaves and seeds, etc. | - Indigenous trees have many properties and most bear fruit that have been eaten and used since ancient times. Some have been used as food and medicine in African rural communities. They have great potential as feed resources in particular their seeds, leaf, and oilcake meals (Chisoro and Nkukwana, 2020b). |
| Grain and pulses crop leftovers | Rice, Sorghum, Millet, Groundnut stover, Wheat hay, etc. | - Crop leftovers are byproducts obtained after crop harvest, especially for grain crops. These can be used as partial replacers for more expensive feeds like maize or wheat because they are excellent sources of fiber and carbs in livestock diets (Sebola et al., 2021). |
| Pasture and forage crops | Alfalfa, lucerne, Rye grass, Black clover, etc. | - These are plants, the likes of legumes, grasses, and browse species, that are planted to be fed to livestock. Mostly they are utilized as significant sources of protein and other nutrients to enhance the nutritional value of livestock diets (Chioma et al., 2021). |
| Agro-industrial byproducts | Dried distillers' grains, Peanut shells, Cottonseed cake, palm kernel cake, etc. | - These are substances produced during the processing of agricultural products like, peanut butter production, cooking oil, beer manufacture, etc. They can be used to enhance livestock performance and in diets as valuable sources of fiber, energy, and protein (Girma, 2019). |
| Insects | Black solider fly, Silkworm, Locust, Crickets, etc. | - These have taken the feed sector by storm, due to their high protein value, ease, and sustainable propagation from organic waste, insects have gained popularity as a source of protein in livestock feed especially for pigs and poultry (Khan, 2018). |
| Aquatic plants and animals | Duckweed, Azola, Water hyacinth, Water lettuce etc. | - These include plants, fish, and other aquatic creatures. In aquatic systems, they are often regarded as "waste or weeds", however, they can be used as sources of nutrients for livestock (Mahgoub and Al-Mutairi, 2015). |
| Leftovers of food processing and manufacturing factories | Biscuit meal, Candy and Potato chips byproducts, etc. | - In the making of candy, biscuits, potato chips, and other foods they produce a lot of byproducts, and all the broken and deformed products that do not meet market and production standards are left behind. They still contain valuable nutrients that are still useful for use in livestock feed (Mbele et al., 2019). |

since wild fruits are also part of the locally available potential feed resources such as baobab fruit, tamarind, neem, and red sour plums, they can sell some of the excess fruit or byproducts as livestock feed ingredients or for other purposes, such as for medicinal uses or as fuel (Hammond et al., 2019). Nevertheless, several challenges are still associated with incorporating these feed resources into livestock diets. Availability, quality, quantity, and seasonal variability of these products can make it difficult for consistent and calculated incorporation of these novel resources in livestock feed. Additionally, some or more or less most of these resources may have limited nutritional value or potential negative effects on livestock health if not properly processed or prepared before incorporation in feed formulations as stated earlier (Rahaman et al., 2022). Despite these challenges, there are also many opportunities for further and continued research and development in this area. Most studies have been mainly focusing on their inclusion levels in animal diets and some on processing techniques on their respective palatability, nutrient digestibility, and antinutritional factor reduction, as represented in some of the case studies in Table 4 with significant success in their potential as substitutes or supplements to convectional feed ingredients. Future studies could now focus on identifying and calculating the seasonal, quality, and quantity variability of these feed resources in the various communities in which they are found. This will help make the proper calculations in feed formulations, be it on farm or at feed processing and manufacturing plants (Chisoro et al., 2018; Mazizi et al., 2020).

Utilizing the knowledge of their inclusion levels and processing techniques to promote their full utilization in livestock feed as shown in Table 4, while taking into account their proximate composition as presented in Table 3. In addition, wild fruits as feed resources will be valuable if the potential for breeding new plant variates can be explored. These wild fruit trees can be planted back in overgrazed or deforested areas. Thereby reforesting these lands and preserving these wild fruit trees as they work both as food and feed for humans and livestock, respectively, promoting sustainable agriculture and a circular economy in Africa, and also promoting some of the UN SDGs as detailed in part 4 of this review.

## 4. Sustainable food security and circular economy in Africa

An economic structure intentionally intended to be regenerative and restorative is known as a circular economy (EMF, 2018; Nhamo, 2020). In such a system, as much value as possible should be extracted from resources while they are still in use, and at the end of each service life, goods and materials should be recovered and renewed. According to Huchzermeyer (2019), a circular economy differs from the conventional linear economy, which uses the "take-make-dispose" model and is based on the idea that resources are always accessible and affordable. Various examples of circular economy approaches are already being used in the context of the African economy. For instance, the use of mobile money has emerged as a key tool for financial inclusion and economic expansion in various African economies (Nhamo, 2020). Mobile money allows users to transfer and receive money electronically, eliminating the need for physical cash and promoting faster, safer transactions (EMF, 2018; Huchzermeyer, 2019). Many people in Africa now have better living standards and increased economic activity due to this innovation. Another example of such an initiative is using renewable energy such as solar energy, to promote economic expansion (EMF, 2018). Generally, Africa has an abundance of sunshine in many of its

TABLE 3 Examples of alternative livestock feed ingredients sources with their relative nutrient composition values on dry matter basis.

| Item | Animal products | | | Leaf and foliage meals | | | Oilseeds and forage legumes | | | Oilseed extraction by products | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BSF[a] | LGM[b] | SWP[c] | SPF[d] | DW[e] | AF[f] | FB[g] | RS[h] | RSPS[i] | BSOC[j] | COC[k] | MOC[l] |
| DM, % as fed | 91.3 | 91.7 | 93.8 | 88.5 | 80.2 | 91.9 | 85.9 | 92.3 | 95.5 | 90.9 | 89.6 | 95.3 |
| GE, MJ/kg DM | 22.1 | 21.8 | 22.0 | 17.5 | 17.1 | 16.4 | 18.7 | 28.8 | - | - | 19.2 | 28.6 |
| Chemical composition, % DM | | | | | | | | | | | | |
| Crude Protein | 42.1 | 57.3 | 75.6 | 13.2 | 27.8 | 21.5 | 31.0 | 20.9 | 18.2 | 22.9 | 35.9 | 39.3 |
| Crude Fat | 26.0 | 8.5 | 4.7 | 2.8 | 4.0 | 3.3 | 1.3 | 46.0 | - | 8.13 | 2.9 | 43.8 |
| Dietary Fiber | 7.0 | 8.5 | 6.6 | 19.9 | 13.1 | 16.1 | 8.5 | 10.1 | - | 19.9 | 33.6 | 5.8 |
| Indispensable amino acid, % protein | | | | | | | | | | | | |
| Lysine | 6.6 | 4.7 | 6.1 | 4.8 | 4.0 | 5.6 | 6.3 | 6.3 | 1.03 | 1.04 | 2.8 | 2.3 |
| Methionine | 2.1 | 2.3 | 3.0 | 1.4 | 1.8 | 1.5 | 0.8 | 2.0 | 0.16 | 0.26 | 1.6 | 1.8 |
| Threonine | 3.7 | 3.5 | 4.8 | 4.4 | 3.6 | 4.3 | 3.5 | 4.8 | - | 0.44 | 3.2 | 2.1 |
| Essential minerals, g/kg DM | | | | | | | | | | | | |
| Calcium | 75.6 | 1.3 | 4.0 | 12.4 | 20.3 | 12.5 | 0.4 | 4.9 | 17.9 | 0.24 | 18.5 | 1.3 |
| Phosphorous | 9.0 | 1.1 | 8.7 | 3.1 | 5.2 | 6.7 | 4.6 | 7.3 | 34.5 | 0.66 | 6.7 | 10.0 |

[a]BSF, Black Soldier Fly, dehydrated.
[b]LGM, Locust or Grasshopper Meal, processed.
[c]SWP, Silkworm Pupae, defatted and dried.
[d]SPF, Sweet Potato Foliage, aerial part and dry.
[e]DW, Duckweed, dried.
[f]AF, Azola Foliage, dried.
[g]FB, Faba Beans, low tannins cultivars and processed.
[h]RS, Rapeseeds, low erucic, low glucosinolates.
[i]RSPS, Red Sour Plum Seeds, dried and processed, source Chisoro and Nkukwana (2020).
[j]BSOC, Baobab Seed Oil Cake, defatted and processed, source Chisoro et al. (2018).
[k]COC, Castor Oil Cake, detoxified and processed with oil < 5%.
[l]MOC, Marula Oil Cake, defatted and processed.
The - denotes that the information is not available.
All other alternative ingredient data were sourced from the Feedipedia (2023) animal and feed resources website.
*From the table, we can see that most of these novel feed ingredients contain protein and energy values similar to/or comparable to sunflower meal that has a protein value of around 24.4–36.7 CP and energy values of 19.1–20.2 kJ/kg; and soybean hulls with 10.5–19.2 CP protein value and 17.5–18.7 kJ/kg energy value, which are major traditional feed ingredients.

nations, which can be used to produce electricity and run homes, schools, production companies, and government institutions. This lessens the reliance of many African countries on fossil fuels, which are expensive and cause much damage to the climate, with the investment in renewable energy (EMF, 2018; UNSDG, 2018; Huchzermeyer, 2019).

This also will contribute to employment opportunities, the eradication of poverty, and long-term economic growth in Africa. Circular economy initiatives are not just limited to the financial and energy sectors. The African agricultural sector is also home to numerous examples of circular economy initiatives. For example, farmers can use organic waste from livestock production or sewage treatment plants as fertilizer to improve soil health while lowering their reliance on synthetic fertilizers. Some communities in Africa have begun to implement with the support of the government and NGOs (Huchzermeyer, 2019; Nhamo, 2020). Additionally, agricultural wastes and other waste materials can be used by farmers to produce energy through biogas digesters, which in turn lowers the need for fossil fuels and reduces greenhouse gas emissions. Overall, the circular economy presents Africa with numerous opportunities to build more robust and sustainable economies that may benefit both its people and the environment in the long run (UNSDG, 2018; Huchzermeyer, 2019).

Given the great potential to increase food productivity and create employment opportunities, sustainable food security and the circular economy are vital components for the growth and development of Africa's agriculture sector (Food and Agriculture Organization 2018). At present, Africa is currently dealing with a number of issues that have affected its agricultural industry, including climate change, insufficient resource management, the recent COVID-19 pandemic after-effects, floods due to cyclones, and restricted access to efficient and healthy food systems (UNICEF, 2019; FAO, 2020b; IFPRI, 2020b). In addition, the population in Africa is growing and is anticipated to reach 2.5 billion people by 2050 (Statista, 2023). Therefore, it is vitally important for Africa to establish sustainable farming practices. One way is the exploitation of the use and incorporation of local innovative feed resources in livestock production and help in securing sustainable food security and a circular economy in Africa (Belluco et al., 2013; Nyamukonda and Ndlovu, 2019; Chisoro and Nkukwana, 2020b). Although they have not traditionally been utilized as livestock feed ingredients or supplements, these resources, which include plant and animal byproducts, might considerably improve livestock production and advance Africa's circular economy as presented in Figure 3 (Nsoso and Chanda, 2020; Chioma et al., 2021). Using insects such as black soldier flies

TABLE 4 Examples of studies on the incorporation of alternative novel feed ingredients or supplements in different livestock diets.

| Ingredient | Animal | Aim | Results | Reference |
|---|---|---|---|---|
| Macadamia nut cake | Broilers | Study I: Determine the apparent metabolizable energy (AMEn) value of Macadamia nut cake (MNC) for broiler chickens at different ages. | - Results indicated that AMEn of MNC-supplemented diets is comparable to traditional feedstuffs (Soy and Maize) and can be incorporated in broiler diets. | (Berrocoso et al., 2017) |
| | | Study II: Aim was to study MNC inclusion in corn-soybean meal-based diets on BW, FI, ADFI, ADG, and FCR in broiler starter and finisher diets. | - MNC can be included up to 150 g/kg in broiler diets without compromising the growth performance parameters of broilers. | (Yadav and Jha, 2021) |
| *Moring oleifera* leaf meal | Finisher Pigs | Investigate the influence of dietary inclusion of *Moringa oleifera* leaf meal (MOLM) on the feed conversion ratio (FCR) of finisher pigs, meat quality, fatty acid (FA) composition, and shelf life of pork. | - No significant differences were observed for carcass, physico-chemical quality traits, and FA ratios.<br>- The inclusion of MOLM improved shelf life and the n-6: n-3 FA ratios of the meat. In addition, the inclusion of 7.5% MOLM improved the FCR of the finisher pigs. | (Mukumbo et al., 2014) |
| Cocoa pod husks | Rabbits | The aim was to determine the influence of processed Cocoa pod husks (PCPH) on the hematological and biochemical indices of rabbits. | - Increased inclusion of PCPH up to 20% improved the tested hemoglobin concentration significantly ($P < 0.05$).<br>- Inclusion of PCPH at 10, 20, and 30% in rabbit diets resulted in higher red blood cell count and mean cell volume than those of the control diet. | (Adeyeye et al., 2019) |
| Cassava peels and palm kernel cake | Grower Pigs | Study objective was to assess the effect of cassava peels and palm kernel cake (CP: PKC) inclusion at a 50:50 ratio on overall performance in grower pigs. | - Significant ($p < 0.05$) differences in performance characteristics of weaner pigs were noted as pigs given 25% CP: PKC in diet.<br>- They gave the best results compared to other diets on final weight gain, feed conversion ratio, and protein efficiency ratio (25.67 kg, 2.06, and 2.52), respectively. | (Oboh et al., 2018) |
| Okara meal | Dairy Cows | Aim was to investigate the effects of replacing soybean (SBM) with okara meal on nutrient utilization, milk components, and plasma amino (AA) concentration in lactating dairy cows. | - Dry matter intake was not affected by the substitution of SBM with okara meal.<br>- No significant differences among the treatments were noted for milk yield and milk components, the concentrations of milk fat, lactose, and total milk solids.<br>- Study concluded that okara meal can completely replace SBM with no negative effects on production and nutrient digestibility in early to mid-lactation Jersey cows. | (Zang et al., 2021) |
| Rice bran | Broilers | Study I: Influence of sterilized rice bran (RB) fermented for 48, 72, and 96 h by *Aspergillus flavus* inclusion in broiler diets on broiler chicks' performance. | - Study concluded that fermented rice bran has beneficial effects on broiler performance parameters (Feed Intake, Body Weight, Feed Conversion Ratio, and Mortality). | (Ahmad et al., 2016) |
| | | Study II: Investigate the nutrient digestibility of broiler diets with different inclusion levels of variously processed RB treated with antioxidant, Bianox Dry (0, 125, 250 g/ton), stored for varying periods on broiler chick digestibility. | - Interaction of RB storage, processing, and inclusion levels were significant ($P > 0.005$) for fat digestibility.<br>- Treatments of RB with different levels of antioxidants had no detrimental effects on the digestibility of fat and fiber when incorporated in broiler feed. | (Mujahid et al., 2003) |
| Neem seed cake | Common Carp Fingerlings | Study was a feeding trial for 42 days and a nutrient digestibility study for 25 days to evaluate the effects of supplementation of water-washed neem seed cake (WWNSC) in diets of common carp fingerlings. | - No significant differences were noted in dry matter and nutrient digestibility.<br>- Supplementation of WWNSC up to 150 g/kg inclusion levels in feed did not affect both the amylase and protease enzyme activity in the intestines of the fingerlings. | (Lenka et al., 2010) |
| Cottonseed hulls | Sheep rams | Aim was to determine the effects of cottonseed hull (CH) inclusion in the diets of rams on ingestive behavior, feed intake, digestibility, and blood metabolites of rams. | - Water intake and crude protein digestibility were linearly increased with the inclusion of CH.<br>- The best inclusion level was 5% CH; higher inclusion levels are not advisable for unprocessed CH as they reduce intake and nutrient digestibility. | (Zanine et al., 2023) |
| Sweet potato peels | Cichlid Fish | The study was conducted to investigate the growth performance of cichlid, *Oreochromis niloticus* (Linnaeus) fed different levels of processed sweet potato peels (PSPP). | - The greatest increase in body weight in fish was noted on the control diet and the diet with a 5% inclusion rate of PSPP ($P < 0.05$).<br>- No significant differences were noted in plasma glucose and plasma protein of fish due to the dietary inclusion of the sweet potato peels.<br>- The study concluded that PSPP can be incorporated into fish feed to reduce feed costs associated with farmed fish production. | (Omoregie et al., 2009) |

*(Continued)*

TABLE 4 (Continued)

| Ingredient | Animal | Aim | Results | Reference |
|---|---|---|---|---|
| Wheat hay | Holstein Bulls | Investigate the replacement of *Leymus chinensis* (LC) with whole-crop wheat hay (WCWH) in rations of Holstein bulls in the fattening stage on blood parameters, serum, and rumen microbiomes. | - No differences in saturated, monounsaturated, and polyunsaturated long-chain fatty acid proportions of rumen liquid among study treatments were noted. In addition, no differences were noted for other blood and serum parameters.<br>- Conclusion was that LC can be partially replaced with WCWH in diets of Holstein bulls in the fattening stage with no adverse effects. | (Niu et al., 2018) |
| Tamarind | Laying Hens | A study was done to evaluate the potential for dietary tamarind inclusion to alter serum and egg yolk cholesterol concentrations and overall performance in varying layer strains. | - No differences ($P > 0.05$) among layer strains or egg production, egg mass, egg weight, yolk weight, feed consumption, or feed efficiency were noted.<br>- The yolk weight directly increased ($P < 0.05$) with increasing levels of dietary tamarind in weeks 1, 2, and 3.<br>- Study conclusion was that 2% supplemental inclusion of dietary tamarind could decrease serum cholesterol concentrations and increase layer performance | (Chowdhury et al., 2005) |
| Sweet potato peels and cashew nut shells | African Dwarf Goats | The experiment assessed the effects of sweet potato peels (SPP) and cashew nut shells (CNS) with *Ocimum gratissium* leaves supplementation in West African Dwarf goats' diets on respective growth performance | - Study results showed the diet I (30:25 inclusion ration of SPP and CNS) had a pronounced effect ($P < 0.05$) on the average total feed intake, feed conversion ratio, and gross energy intake of goats.<br>- Goats on diet II (25:30 inclusion ration of SPP and CNS) had a significantly higher ($P < 0.05$) in final body weight, average total weight gain, and digestibility ratios. | (Okoruwa and Bamigboye, 2015) |

(BSF), silkworm pupae (SWP), grasshopper meal (GM), and cricket meal can increase the nutritional value of livestock feeds while limiting the use and dependence on fishmeal and also lowering the environmental impact of feed production (Kidd et al., 2018; Chioma et al., 2021; Sebola et al., 2021). In addition, vegetable and fruit wastes, leaves, seeds, and foliage from wild trees and cultivated crops can be used in livestock feed as feed ingredients or supplements (Amata and Jideani, 2020). Through the use of local feed resources and the encouragement of regenerative agricultural methods, the circular economy can be encouraged in Africa, especially in livestock production. This strategy also has the additive advantage of lessening Africa's reliance on imported convectional feed resources, particularly soybean, maize, and fishmeal, which would result in large savings in foreign currency used in the import of these feed ingredients (Chibwana et al., 2017; Nyamukonda and Ndlovu, 2019).

Using these unique indigenous novel feed resources in livestock feed production encourages a circular economy and long-term food security in Africa. It not only makes resource use more efficient but also enhances livestock output, lowers the cost of feed production, and opens up job opportunities, which in turn enhance Africa's economic growth (Nhamo, 2020; Chioma et al., 2021; Sebola et al., 2021).

The African livestock industry supports the circular economy in a number of ways, including the following:

1. *Efficient resource use*: By effectively incorporating locally accessible novel feed resources including crop byproducts, food waste, and manure, livestock production can support a circular economy. These materials, which are frequently viewed as waste, can be used to create livestock feed, improving the health and productivity of the livestock in the process (Amata and Jideani, 2020).
2. *Improved soil health*: Using livestock manure as fertilizer increases agricultural yields and soil fertility at the same time improving crop health. Therefore, this lessens the demand for synthetic manufactured fertilizers, which helps promote a circular economy (Sebola et al., 2021).
3. *Diversification of income sources:* Livestock farming promotes a circular economy, by offering farmers and agribusinesses a variety of income streams. The livestock industry is a significant source of revenue and livelihood in many African communities, especially rural communities and smallholder farmers. Farmers' ability to withstand shocks and the effects of climate change can be improved by including livestock in their farming systems (Chioma et al., 2021).
4. *Value addition*: A circular economy is supported through livestock production by encouraging value addition of livestock-derived goods such as meat, milk, and hides. Processing these goods can help economic growth and development by generating new revenue streams and job opportunities (LDIA, 2014).
5. *Climate change mitigation*: Utilizing livestock to produce manure and store carbon can help mitigate climate change while lowering emissions in the livestock production industry (Amata and Jideani, 2020).

Livestock farming makes a considerable contribution to Africa's circular economy through various mechanisms, such as resource efficiency, better soil health, income diversification, value addition, and climate change mitigation. To secure food security, economic growth, and environmental sustainability in Africa, it is important to promote sustainable livestock production, particularly with the incorporation of local novel feed resources as the theme of this article depicts.

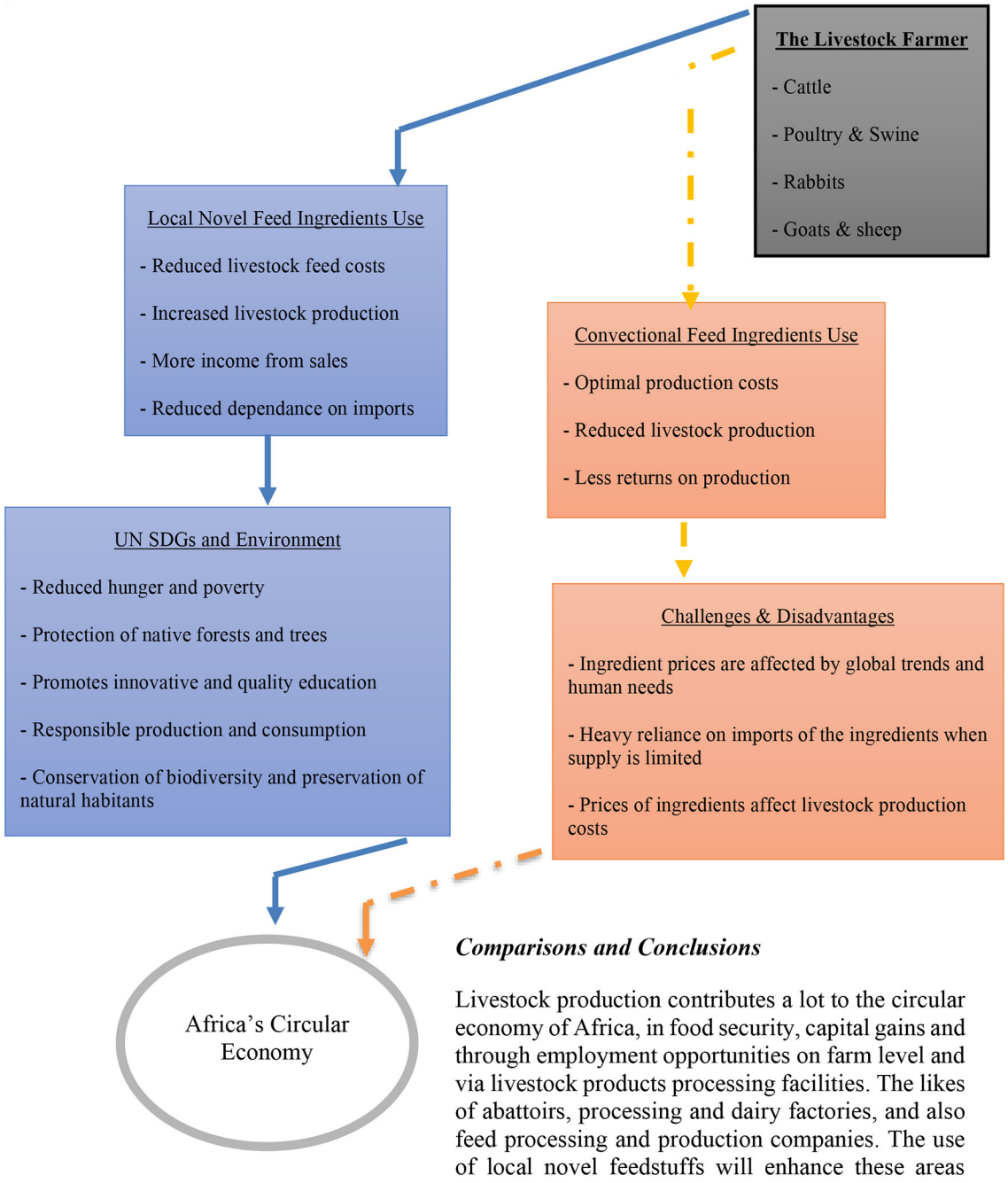


FIGURE 3
Two pathways of livestock production are represented in the figure. Pathway 1 is the one on using local novel feed resources with the solid line, and pathway 2 is represented with the dotted line on the use of traditional feed ingredients in livestock feed. These pathways both have their merits and disadvantages. However, it seems as if the use of local novel feed resources has more contribution to mostly rural African communities, particularly, smallholder farmers, and in turn, the African circular economy and the achievement of UN SDGs in Africa.

## 5. UN sustainable development goals (SDGs)

The use of locally available novel feed resources in livestock feed is very closely linked to several of the United Nations Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 4 (Quality Education), SDG 12 (Responsible consumption and production), SDG 13 (Climate action), and SDG 15 (Life on land) as shown in Figure 4. Below is a detail on how the utilization of locally available feed resources links with these SDGs:

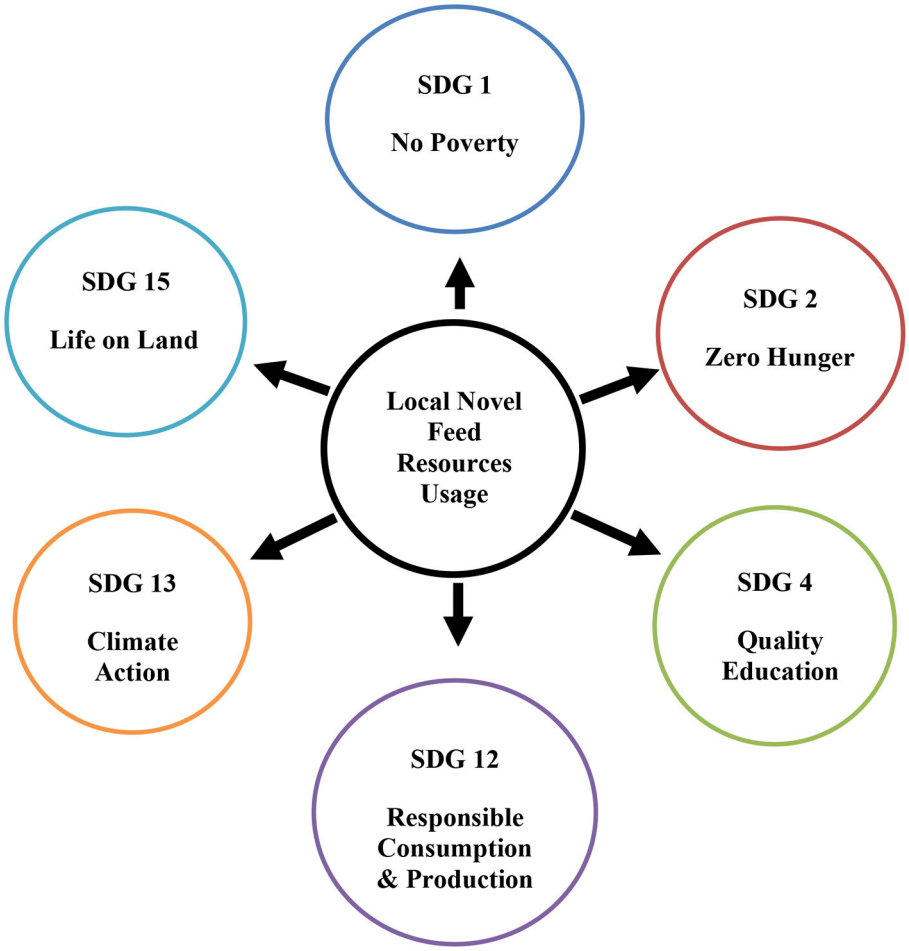


FIGURE 4
The diagram represents the UNSDGs the use of local novel feed resources in livestock diets is connected to.

- SDG 1: *No poverty*: With the boosting of the productivity and profitability of mostly smallholder livestock producers, especially in developing nations, who cannot afford to buy expensive commercial feed, the use of novel local feed resources can help to decrease poverty (UNSDG, 2018). With their use, feed production costs will be reduced, meaning that they will be able to produce their livestock at a lower cost and make them competitive in the commercial market, which will result in more returns for their animals. Farmers will also decrease their reliance on imported feed inputs, increase their income, and enhance their living standards by producing their feed (Chisoro et al., 2019).
- SDG 2: *Zero hunger*: On this SDG, livestock farmers may increase the quality and quantity of available feed for their livestock, improve livestock health and production, and, thereby, eventually, improve food security in their communities, due to the increased utilization of locally available novel feed resources. According to the research, rural communities frequently have greater access to local innovative feed resources (insects, oilseeds, wild fruits and leaf meals from indigenous trees; and crop residues), boosting the availability of high-quality animal feed (Chibwana et al., 2017).
- SDG 4: *Quality education*: Since farmers will have to learn new and creative methods for the use of these novel feed resources, using these local feed resources can help support quality education in livestock production. Incorporating these locally accessible resources into their feeding plans, which eventually results in mixed crop-to-livestock systems, will teach them the importance of these resources, thereby enhancing farmers' knowledge and awareness of agricultural practices through education about sustainable methods of livestock feed processing and manufacture resulting in increased food security, improved livelihoods, and sustainable agroecosystems (Chisoro et al., 2017; Nyamukonda and Ndlovu, 2019).
- SDG 12: *Responsible consumption and production*: This SDG objective emphasizes encouraging more conscientious consumption and production habits from livestock operations, which include waste reduction, resource conservation, and preservation of the diversity of local feed resources. The reduction of the reliance on imported commercial feed ingredients (mainly fishmeal, soybean, and maize grain), which frequently result in significant carbon emissions due to long transit distances and industrial

processing, can assist in assured responsible production and consumption (Huchzermeyer, 2019). This implies that if these local feed resources are incorporated into feed production, be it on a subsistence or commercial level, this can be achieved. Resulting in responsible consumption and production in the livestock sector particularly in developing nations such as Africa, which heavily rely on imported grain and soybeans from nations such as the U.S.A, Europe, Brazil, Argentina, Russia, and Ukraine to meet food and feed demands (Chisoro and Nkukwana, 2020b).

- SDG 13: *Climate action*: Climate action is a crucial component of sustainable food systems. The carbon footprint associated with land preparation, production, processing, and transportation of commercial convectional feed ingredients, mainly soybean and maize globally, can be reduced by utilizing locally accessible feed supplies.

  In addition, using nutrient-rich novel feed sources such as animal products (like insects), leaf and foliage Meals (from indigenous trees), oilseeds and forage legumes (from local trees and pastures), and oilseed extraction byproducts (from food industries and the beauty sector) will greatly improve soil quality, prevent deforestation (for soybean and maize grain production), and lower greenhouse gas emissions from the livestock sector, all of which contribute to the sequestration of carbon in the soil (Chioma et al., 2021).
- SDG 15: *Life on land*: This SDG aims to maintain, restore, and promote the sustainable use of terrestrial ecosystems, including forests, grasslands, and croplands. This connects with utilizing local novel feed resources in livestock feed systems. Vast amounts of land are required for livestock production (feed ingredient production or livestock production which is also related to deforestation and land degradation). However, using locally available novel feed supplies such as legumes, roots, and tubers might encourage more sustainable management techniques and improve the restoration and protection of land resources by reducing the need for clearing land to produce monoculture crops. In addition, this also will support the preservation of ecosystems and biodiversity provided by local flora and wildlife, since forests will be protected through reduced land expansion for monoculture crop growth and also since products from these forest trees will now be in use in livestock feed such as fruits, oilseeds, and leaf meals (Chisoro and Nkukwana, 2020b).

Using local novel feed resources in livestock feed, particularly in Africa, will promote sustainable agricultural practices, a reduction in greenhouse gas emissions, and the preservation of biodiversity while helping it meet the UN SDG goals as highlighted above. This strategy also supports responsible consumption and production behaviors. It helps create a more sustainable and resilient food system by decreasing waste, minimizing the use of natural resources (land and water), encouraging climate change mitigation and adaptation, and protecting or enhancing ecosystems while promoting a circular economy.

## 6. Future prospects and recommendations

The use of locally available novel feed resources in livestock nutrition presents promising opportunities for the future of long-term food security and a circular economy in Africa. Some of the future prospects and areas of focus that could improve the integration of these resources into livestock production systems are covered in this section.

1. *Nutritional analysis and optimization*: Comprehensive nutritional analysis of locally available novel feed resources should remain the main goal of future studies. This entails examining their nutrient composition, digestibility, and antinutritional components and figuring out the best ratios for inclusion in livestock rations. This will make it easier to formulate feed and create balanced, affordable livestock feed if one is aware of the nutritional value of these resources (Chisoro and Nkukwana, 2020b).
2. *Feed processing and value addition*: It is vital to look into appropriate processing techniques, particularly on a commercial level to increase the digestibility, palatability, and usage of local novel feed resources (Nyamukonda and Ndlovu, 2019). The availability of nutrients can be increased, antinutritional factors can be decreased, and feed quality can be improved by using processing techniques such as heat treatment, ensiling, and extrusion (Gürbüz and Özkan, 2018). Further enhancement of the value and marketability by studying the possibilities for value addition, such as creating fortified feed formulations or isolating bioactive chemicals from these resources, still have to continue.
3. *Safety and quality assurance*: Future initiatives should concentrate on guaranteeing the security and caliber of feed resources derived from local sources. As part of this, heavy metals, pesticide residues, possible mycotoxin contamination, and other pollutants that might be present should be addressed (Chisoro et al., 2017). The creation of suitable regulatory frameworks and the development of quality control systems will be essential to guarantee the safe application of these novel feed resources.
4. *Environmental impact assessment*: Although local novel feed resources may have positive environmental effects, it is important to do comprehensive life cycle analyses to determine the resources' total environmental impact. A comprehensive understanding of the sustainability elements related to their production, processing, and utilization will be provided by assessing factors including greenhouse gas emissions, water usage, land utilization, and biodiversity impacts (Mlambo et al., 2020).
5. *Promotion of public–private partnerships*: The encouragement of public–private partnerships is essential to promoting the acceptance and accelerated usage of local novel feed resources for livestock feed. These partnerships should involve government agencies, research institutions, business sector stakeholders, and farmer organizations (FAO, 2020b). Supporting public–private collaborations can promote knowledge transfer, technological transfer, and proper

investment in research and development projects. The incorporation of these resources into mainstream livestock feeding will be strengthened as a result (Mekonnen and Nurfeta, 2021).

6. *Socioeconomic considerations*: Successful adoption of local novel feed resources depends on an understanding of the socioeconomic aspects driving their utilization. It is necessary to take into account elements such as market demand, cultural acceptability, and economic viability (Maphalla and Nsahlai, 2020). An understanding of the potential economic, social, and cultural hurdles and opportunities related to their use will be gained by conducting socioeconomic assessments, including cost–benefit analysis and market studies (Fadare and Olowofeso, 2020).
7. *Knowledge transfer and capacity building*: For the usage of local novel feed resources at grassroots levels, it is essential to disseminate information about their advantages and real-world applications. To inform farmers, feed makers, and other stakeholders about the nutritional value, handling, and use of these resources, training programs, workshops, and extension services should be created (Nhamo, 2020). Supporting programs that increase stakeholders' ability will enable them to take well-informed decisions and successfully integrate locally available novel feed resources into their livestock systems.

Stakeholders may maximize their contributions to sustainable food security, the circular economy, and overall livestock productivity in Africa by addressing these potential outcomes in future. Continued research, collaborations, and knowledge exchange will pave the way for innovative and practical solutions toward a more resilient and sustainable livestock sector.

## 7. Conclusion

Local novel feed ingredients have vast benefits when incorporated into livestock feed particularly in rural communities or by smallholder farmers. Commercial farmers can also benefit from their utilization and if incorporated at the national level, they will have plenty of advantages to the circular economy of Africa. The following points are the conclusion and recommendations for this article:

- The livestock industry in Africa has considerable potential to enhance food security and support a circular economy by utilizing indigenous, local novel feed resources.
- For successful integration of these feed resources in livestock feed systems, several issues still need to be addressed, such as a lack of an in-depth understanding of the nutritive value of these local novel feed ingredients or supplements, challenges in their processing and storage, and restricted access to funding and markets, which limit their full utilization.
- To overcome these obstacles and promote the utilization of local, innovative feed ingredients or supplements in animal feed systems, such strategies include improved collaboration among producers, industry stakeholders, and researchers, investments in technology and infrastructure, and policy interventions that can be used and need to be put in place.
- Implicating these above measures has the potential to enhance sustainable agricultural practices, lessen the environmental effect of livestock production, especially in rural communities, and promote economic growth in rural areas in addition to improving animal nutrition and food security in Africa.

This article emphasizes the value and possibilities of using indigenous, local innovative feed resources in African livestock feeding systems for long-term food security and circular economies. However, cooperation and investment from stakeholders, governments, and researchers will be needed to fully address the implementation issues. For the full use of local novel feed ingredients, they can enhance the African livestock sector and the overall African circular economy.

## Author contributions

The manuscript formulation and design were directly influenced by PC, IJ, and NA. The write-up was done by PC, while all the relevant corrections, suggestions, and reviews were done by NA and IJ. All authors contributed to the article and approved the submitted version.

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This review article aims to recognize the massive alternative novel food and feed resources in Africa but not yet been completely utilized, despite having a great potential to be sustainable food and feed sources and contributors to the African circular economy.

## Conflict of interest

PC was employed by Gwaimana Consolidated (Pvt) Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

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