

Review Article

Phytochemical Benefits of Agroresidues as Alternative Nutritive Dietary Resource for Pig and Poultry Farming

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Received 6 July 2018; Revised 13 October 2018; Accepted 8 November 2018; Published 11 December 2018

Academic Editor: Jose A. Pereira

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The growing world population is challenging the animal products supply system, particularly in developing countries, where demand for meat and milk in 2050 is estimated to increase to 109% and 116%, respectively, amidst deteriorating livestock feed sources. Globally, adequate production and availability of animal feed products to subsistence farmers has been declining due to factors such as global warming, growth in population, and low economic growth. This paper seeks to examine the existing scientific literature on the utilization of some unconventional feed resources, to abate the challenge of feed deficit and thus improve animal nutrition. The use of fruit waste and agricultural farm residues affords alternative, nutritive livestock dietary supplements; it has been proven they contain a spectrum of vital bioactive phytochemicals essential for sustainable growth and development of animals. The biochemical composition of the plant wastes and residues include carbohydrates, proteins, nucleic acids, and fatty acids, while the common bioactive phytochemicals are polyphenols, alkaloids, carotenoids, and flavonoids, along with tannins, terpenes, and saponins, which play vital roles in reducing disease-causing agents, such as bacteria, viruses, and free radical-associated diseases. The phytochemicals exhibit antioxidant, antimicrobial, antifungal, and anti-inflammatory, as well as anti-parasitic and antiprotozoal properties. However, it is important to guard against antinutritive and toxicity levels in animal feed products. The paper concludes that agroresidues/wastes' nutritive and therapeutic potential could serve as alternative livestock feed resource, while also acting as additional job and income generator for communities.

1. Introduction

The world population is expected to increase by an additional two billion people by 2050, which will require approximately 73% more meat and 58% more milk. Developing countries are estimated to require more than 112% of the combined average of livestock products (meat and milk) by the same year [1]. While there is increasing demand for livestock products in most developing countries, many of these countries are experiencing a feed deficit, unable to adequately source sufficient animal feed materials to raise healthy livestock and poultry. There is thus a huge need to increase production of animals and allied products. These needs have driven farmers to use synthetic growth hormones and antibiotics to improve the health and weight gain of their animals.

Although the utilization of xenobiotic drugs in the livestock industry improves the general performance of the animals, their prolonged use has been reported to exhibit detrimental reproductive effects on animals, induce livestock antibiotic resistance, and lead to an accumulation of chemical residues in the bodies of the animals, which are potentially passed on to humans [2]. Consequent to the ban of xenobiotics in some countries in Europe and America, growing concerns of animal product consumers in developing countries explored alternative medicinal and nutritive plants as substitute for the resented synthetic drugs [2, 3]. Nutritious plant-based feed supplements are widely claimed to obviate the problems of artificial medicaments.

To provide and sustain quality food needs of the purported population growth, the feed resources will severely challenge

already overextended, conventional feed production systems. Limited arable land, scarce water sources, competition between human food-biofuel-animal feed, as well as global warming and its associated climate variations have imposed a mammoth threat to the sustainability of the animal feed production structure. To develop a sustainable livestock dietary scheme in the present, unfavourable environmental conditions mean that available unconventional feed resources [4–6] should be efficiently used: minimizing wastage, in addition to increasing the feed resource base by innovatively utilizing new feed supply sources not in competition with the human food system. Agricultural residues, which include domestic and industrial fruit/vegetable wastes, as well as farm residues, are favoured in this context [1, 7]. The utilization of the agroindustrial by-products/wastes in livestock and poultry feeding has been a worldwide study of interest for decades. In 1981, workshop by FAO and International Livestock Centre for Africa on “Crop residues and agroindustrial by-products in animal feeding” established guidelines for research on crop residues and agroindustrial by-products, hence the development of “Guidelines for Research on the Better Utilization of Crop Residues and Agro-Industrial By-Products in Animal Feeding in Developing Countries. Volume 1. State of Knowledge.” This was followed by volume 2 (A Practical Manual for Research Workers), which describes the utilization of agroresidues as livestock feed resource [8]. Huge amounts of fruit and vegetable wastes generated and dumped in landfills or rivers, which cause environmental contamination, could be good sources of nutritive feed components and therapeutic compounds for livestock feeds.

Fruit and vegetable wastes and by-products are generated during industrial activities, such as sorting/cleaning, processing, cooking, and packaging. The common by-products/wastes of the agroprocessing include skins, leaves, pomace, and peels, along with cores, rinds, pulp, and pits, as well as seeds, stems, and poor-quality farm-produce [9]. Farm residues or leftovers are dead plants or poor market-quality produce left during harvesting of the fruits and vegetables. By-products of industrial and agricultural applications, which include fruit waste and farm residues, have gained much attention recently. This popularity is attributed to the fact that plant products produce essential secondary metabolites, known to be highly beneficial in animal health, particularly in the livestock and poultry industry [10]. Furthermore, fruits and vegetables contain important macromolecules (primary metabolites), such as carbohydrates, lipids and fatty acids, nucleic acids, and amino acids, needed to drive metabolic reactions in living organisms.

Fruit and vegetable waste is known to possess a plethora of antioxidative phytochemicals, which include vitamins C and E, carotenoids, and polyphenols amongst other bioactive compounds [11]. Phytochemicals consist of many secondary metabolites; however, the major four classes are alkaloids, glycosides, polyphenols, and terpenoids. The secondary metabolite phytochemicals (SMP) are generally bioactive in the host plant, play a role in plant growth, reproduction, or defence against threats of pathogens, the environment, and predators. Some plant species use SMP for survival strategies, for example, production of toxic

substances or odour to prevent predation. Nonetheless, SMP may not be responsible for the organism’s growth, as SMP’s presence ensures that the organism is supplemented with additional nutrients required for a long healthy life. The absence or lack of secondary metabolites in a living organism significantly reduces its life span [12].

The incorporation of bioactive phytochemicals derived from agricultural residues is not only vital in animal health and development; it is claimed to be a possible alternative to synthetic growth hormones and antibiotics utilized in the livestock and poultry industries [2]. Fruit waste and farm residues exhibit natural-occurring antimicrobial properties (vitamins and hormones), which can assist in the development of livestock and poultry products, without the use of chemically induced disease infection-control parameters [13]. Fruit waste and farm residues are abundant resources worldwide. In organized industrial production sectors, fruit and vegetable waste generated in India, the Philippines, China, and the USA is estimated to be more than 55 million tonnes per year [7].

Haile et al. [14] noted the potentials of the use of farm-residues and agroindustrial by-products (FR-AIBP) in supplementing animal dietary requirements and their invalid qualities of high-fibre content, as well as low-metabolized energy (ME), and crude protein, which consequently lowers degradability in ruminants. Studies have also revealed that adding certain agricultural residues in the livestock feed rations not only improve the animals’ general well-being, but also reduce the cost of feeding, and consequently raise the profit margin of the farmers [2, 7, 15]. In spite of this, the phytochemical composition and benefits of the farm residues and agroindustrial by-products are hidden within other topical issues/articles or are sparsely published in some difficult-to-access journals. This paper thus summarises the available literature on the utilization of the phytochemical composition and benefits of some unconventional agricultural residues, as alternative livestock nutritive dietary resources.

2. Selected Agricultural Residues in Livestock Nutritive Diet or Dietary Needs: Phytochemicals and Benefits

Livestock feedstuff deficiency, growing competitive human-food-animal-feed demand, and economic and environmental issues necessitated the search for alternative economic animal dietary supplements. Increase in the demand for agroproducts (fresh and processed) has given rise to accumulation of large amount of agricultural residues and wastes. The development of a dietary system that is founded on the locally available farm residues and agroindustrial by-products/wastes could serve as a prospective feedstuff source for animal production.

Most of the FR-AIBP, which could be an excellent and unusual dietary source of animal nutrients and energy, are disposed in refuse dumps. Some of the fibrous residues can substantially replace cereals in animal feed for ruminants. The rumen microbes of ruminants can convert the fibres into

useful nutrients. Studies have shown that inclusions of some of the residues/wastes (apple, banana, cabbage, chicory, citrus, grape, mango, peas, pineapple, and pumpkin) in poultry and livestock rations have significantly improved the animals' general well-being and reproductive traits [16–23].

2.1. Apple (*Malus domestica*) Wastes. The consumption of apple (*Malus domestica*) is extensive globally. The fruit belongs to the family Rosaceae and has been reported to contain important macronutrients, such as brix, ash, fats, pectin, proteins, and fibre. In addition, the mineral composition in apples is high and includes sodium 11.01, calcium 20.79, phosphorus 16.4, and magnesium 14.62 (mg/100 g). Apples are also rich in vitamin C (ascorbic acid) 4.2 mg/100 g and vitamin A 0.97 mg/100 g. Vitamin C assists in the biocatalytic conversion of glucose in mammals to ascorbate [24, 25]. The high antioxidant activity of apple is attributed to the rich polyphenolic content of the fruit. The assertion is supported by the chromatographic analysis of apples, which reveals a massive account of polyphenolic compounds such as (-)-epicatechin (flavan-3-ols or flavanols), phloridzin (dihydrochalcone glycosides), (+)-catechin, quercetin (flavanols), cyaniding (anthocyanins), chlorogenic acid (phenolic acids), cyanidin-3-O-galactoside (anthocyanins), and hydroxycinnamates (p-coumaric acid) [26, 27].

2.1.1. Nutritious Dietary Resources Derived from *Malus domestica* Wastes. Apple wastes contain pectin as well as other beneficial nutrients, including dietary fibre, carbohydrates, vitamin C, and a vast array of minerals. The inclusion of apple pulp in the diet of chickens has proven to significantly improve their performance and reproductive rates [17]. Apple pulp is rich in pectin, making it advisable to supplement apple pulp ration with a dose of multienzymes to ensure that the efficacy of the pulp is greatly improved in chickens [28]. Furthermore, it has been reported that provisioning chickens with apple pulp significantly reduces the levels of uric acid and increases blood glucose levels [29].

(1) Avocado (*Persea americana*) Waste. The consumption of avocado is extensive globally [30]. The waste generated during processing of avocado for human consumption contains high concentrations of bioactive compounds such as polyphenols. Rodriguez-Carpena et al. [31] stated that the rich polyphenolic content in avocado is responsible for high antioxidant and antimicrobial bioactivity. In addition, avocado contains flavonoids that have been reported to exert high antibacterial activity capable of combating various resistant bacterial strains [32]. Furthermore, polyphenols can assist in the prevention of several chronic diseases that emanate through the presence of free radicals including hypertension, inflammatory disorders, asthma, cardiovascular disorders, Alzheimer's, and diabetes [33].

(2) Nutritious Dietary Resources Derived from Avocado Skin and Seeds. Avocados have been used as animal feed. The source of avocado waste feed to animals arises through dismissed fruit that are meant for human consumption;

however, due to lack of adherence to certain commercial standards and industrial processes, the seeds and skin are discarded. Avocados are rich in unsaturated fatty acids, tocopherols, and other important phytochemical compounds that are responsible for initiating positive biological responses in animals, including pigs [34]. According to Grageola et al. [34], dietary avocado is responsible for maintaining the equilibrium between nitrogen and energy balance in young pigs. Furthermore, Wood et al. [35] reported that the juiciness and flavour of avocados are considered as sensory traits that can influence the composition of meat, the intramuscular fat (IMF), and fatty acid composition.

In a study by Hernandez-Lopez et al. [36], the experimental muscle of treated pigs was compared to the muscle obtained from a group of pigs fed a control diet without avocado waste. Pigs were analysed for fat composition, oxidative stress, and colour stability. The results showed that dietary avocado had a significant impact on the content and concentration of intramuscular fat (IMF), reduced lipid content in the LTL muscle, and increased the level of unsaturated fats.

2.2. Banana (*Musa acuminata*) Foliage and Peels Phytochemicals. Banana (*Musa acuminata*) is an important crop widely cultivated around the world. It grows best in tropical and subtropical regions and is endowed with abundant macroelements and phytonutrients, such as resistant starch, dietary fibre, slow digestible starch, and rapid digestible starch [37], along with proteins, lipids, and phenolic compounds. A study of the chemical composition of selected fruits presents the approximate biochemical composition of banana peels (in g/100 g dry peel) as follows: proteins 10.44 ± 0.38 , lipids 8.40 ± 1.15 , ash 12.45 ± 0.38 , fibre 11.81 ± 0.06 , and carbohydrates 43.40 ± 0.55 [38, 39].

The literature has noted that oligosaccharides contained in bananas boost some significant health benefits, including the lowering of blood pressure, prevention of cancerous cells (e.g., colon cancer), diabetes, and treatment of intestinal complications. Banana peels contain high concentrations of pectin [40], which are rich in sugars (galactose, rhamnose, and arabinose), as well as galacturonic acid and fatty acids [41]. The turning black of banana skin indicates that the starch content of the banana has been converted into sugary intermediates such as fructose, sucrose, and glucose [42]. Banana peels are rich in phenolic compounds which include hydroxy benzoic acids, benzoquinones, phenyl acetic acids, and acetophenones, in addition to anthraquinones, naphthoquinones, isoflavanoids, and flavonoids, along with lignins, lignans, and tannins [43]. The total polyphenolic concentration in banana peels is estimated to be around 0.90 to 3.0 g/100 g dry weight, according to the study conducted by Nguyen et al. [44]. Additional phytochemical compounds contained in banana peels include galocatechin and dopamine, which are classified as natural antioxidants that can be used in various pharmacological therapies, as well as food preservatives [45, 46].

(1) Nutritious Dietary Resources Derived from Banana Foliage and Peels. Livestock and poultry that are fed rations of

the high starch content banana peels, receive an additional amount of nutrients and energy that assists their growth, general development, as well as sexual reproductive activities [16]. The banana foliage, on the contrary, contains flavonoids, tannins, and terpenoids that are crucial in animals' fight against internal parasites, especially in ruminants [47]. However, when banana foliage and peels are used as the main animal feed, it is advisable to supplement the animal provisions with proteins and minerals, as they are only available in minute quantities in most *Musa acuminata* variants [48]. Table 1 presents the total phenolic and flavonoid content in different varieties of banana [49].

2.3. Cabbage (*Brassica oleracea* Var. *Capitata*) Leaves and Phytoconstituents. Cabbage (*Brassica oleracea*), of the *Cruciferae* family, includes mustard, broccoli, Brussel sprouts, cauliflower, and kale species. Cabbage contains high levels of fibre and is an important source of vitamin C, calcium, and folic acid. The fibre content of cabbage (acid detergent fibre and neutral detergent fibre) is prominent, as depicted in Table 2 [6].

Biochemical analyses of cabbage reveal carbohydrate as the major macronutrient, which represents almost 90% of the dry weight. The composition is structured in a way that 30% is dietary fibre, while 60% is the low-molecular weight carbohydrates [50].

Cabbages are important source of phytonutrients and are utilized worldwide for both food and traditional medicinal purposes. The major phytochemical components are polyphenols, glucosinolates, and vitamins, and these secondary metabolites are vital for treating various ailments such as cancer, oxidative stress, inflammation, and cardiovascular disorders [51]. Phytochemical analyses of cabbage extracts have revealed a plethora of different active ingredients, such as glycosides, alkaloids, flavonoids, and saponin, as well as tannin, terpenes, steroids, and phytosterols. These phytochemical constituents play vital roles in the health of living organisms, including livestock [52].

2.3.1. Nutritious Dietary Resources Derived from *B. oleracea* Leaves. Cabbage leaves are a good source of nutrients in ruminants and are known for significantly improving the growth parameters of the ruminants. The antioxidant activities of cabbage included in livestock rations aid in protecting the livestock against a variety of diseases, ensuring well sustained growth, reproduction, and development for ruminants [22]. Despite the growing popularity of cabbage as a nutritive livestock feed in temperate agricultural regions, high water content (8.6% dry matter) and anti-nutritive components discourage their use [53].

2.4. Chicory (*Cichorium intybus*) and Phytochemical Composition. Chicory (*Cichorium intybus*) is a herbaceous plant that belongs to the family *Asteraceae*. The plant is rich in macronutrients, such as proteins, carbohydrates, vitamins, and minerals, along with soluble fibre and trace elements [15]. The free amino acids and proteins are shown in Table 3 [54].

TABLE 1: Total phenolic and flavonoid content in different varieties of banana [49].

Variety	Total phenolic content ($\mu\text{g GAE/mg}$)	Total flavonoid content ($\mu\text{g QE/mg}$)
Green	180 \pm 8.220	3.58 \pm 0.162
Yellow	154 \pm 2.217	3.06 \pm 0.025
Rasthali	125 \pm 4.203	4.78 \pm 0.334
Karpuravalli	113 \pm 1.707	3.32 \pm 0.136

TABLE 2: Nutrient composition of waste cabbage and corn silage [6].

Nutrient (% DM)	Waste cabbage (%)	Corn silage (%)
Dry matter	7.0	35.0
Crude protein	16.6	8.5
ADF (acid detergent fibre)	15.8	24.0
NDF (neutral detergent fibre)	20.0	43.0
Sulfur	0.70	0.13
TDN	74.0	72.0
Net energy lactation (Mcal/lb)	0.77	0.74

Chicory contains a wide array of phytochemical compounds, which includes saponins, tannins, flavonoids, and cardiac glycosides, in addition to terpenoids and anthocyanins. Chicoric acid is one of the most abundant phytochemical constituents of chicory, whereas terpenoids are available in minute quantities in the plant. Moreover, it has been reported that a significant number of the chemical constituents are in chicory flowers and they include methoxy-coumarin, cichorine, saccharides, essential oils, and flavonoids [55].

2.5. Nutritious Dietary Resources Derived from Chicory. Chicory forage is identified as a quality feed for broiler chickens because it is rich in fibre and regarded as one of the best palatable rations. Provision of appropriate fibre content to chickens' dietary requirements is critical because it helps promote the development of the upper gastrointestinal tract system [11]. It is also noted that nonstarch polysaccharides contained in chicory forage, greatly improve the utilization of feed by chickens [56]. In addition to being palatable for chickens, chicory is considered as one of the most palatable forage crops for both sheep and cattle. The incorporation of chicory forage on cereal-based diets designated for weaned pigs produced results that showed a significantly high feed intake and growth performance [15, 18].

2.6. Citrus (*Citrus limetta*) Pulp. The genus *Citrus* is part of large family of *Rutaceae*, which consists of 130 genera, classified in seven different subfamilies. These subfamilies consist of some of the important fruit species and essential oil producers. *Citrus* harbour some of the important molecules such as vitamin C, folic acid, potassium, pectin, and dietary fibres [57]. In addition, citrus fruits contain a variety of macronutrients: sugars, folate, thiamine, and vitamin B6, along with niacin, riboflavin, and pantothenic acid, as well as a good source of essential elements: calcium, magnesium, copper, and

TABLE 3: Biochemical composition (g/100 g dry weight) of different parts of *C. intybus* [54].

Plant parts	Sugars			Proteins		
	Total	Reducing	Nonreducing	Water soluble	Salt soluble	Free amino acids
Root	2.03 ± 0.02*	0.13 ± 0.02	1.89 ± 0.04	5.57 ± 0.58	7.94 ± 0.30	1.23 ± 0.07
Stem	2.12 ± 0.10	0.24 ± 0.10	2.06 ± 0.11	9.43 ± 1.77	6.85 ± 0.38	5.98 ± 0.31
Leaf	4.50 ± 0.37	0.23 ± 0.01	4.27 ± 0.37	14.13 ± 1.50	6.91 ± 0.53	8.46 ± 0.24
Seed	3.05 ± 0.06	0.44 ± 0.10	2.61 ± 0.06	8.35 ± 1.82	6.81 ± 0.51	2.03 ± 0.05

Means ± SD.

phosphorus [58]. However, the carbohydrate, fibre, fat, and protein contents are significantly low in citrus, as evidenced from a study conducted by Sidana et al. [59], which reviewed different families of citrus fruits, as shown in Table 4 [59].

The phytochemical composition of citrus includes a rich source of bioactive compounds, such as phenols and carotenoids. It has been reported that consumption of citrus products assists with the reduction of cardiovascular diseases and the formation of cancerous cells [60, 61]. A wide variety of citrus extracts have been assayed over the years for phytochemical composition, and the resultant bioactive compounds, thus far, include terpenoids, flavonoids, alkaloids, and steroids, as well as saponins, tannins, and cardiac glycosides [61]. Moreover, bioactive compounds contained in *Citrus* fruits are vital for human health, because of their pharmacological therapeutic potential in the treatment of various diseases, such as oxidative stress, inflammation, cancer, heart diseases, and neurological disorders [58].

2.6.1. Nutritious Dietary Resources Derived from Citrus Pulp.

The fact that *Citrus* fruit pulp contains dietary fibre presents as an advantage for livestock, because the vast microbiological population contained in ruminants requires high levels of fibre content to meet their daily nutrient intake. The daily provisions of fibre content ensure that livestock are well maintained, and that growth, reproduction, and production are efficient. In addition to the beneficial fibre content, fermentable carbohydrates contained in the pulp of the *Citrus* fruit provide a source of energy to ruminal microbes. However, soluble carbohydrates and acid detergent fibres equally play a vital role in providing ruminal microorganisms with energy required for the digestive system [23].

2.7. Grapes (*Vitis vinifera* L) Seeds and Pomace.

Extensively cultivated and consumed in varied forms around the world, grape seeds are abundantly available as agro-residues or industrial by-products. The grape seeds contain a significant amount of unsaturated fatty acids, which accounts for 38–52% of the dry matter. The fatty acid composition mainly comprised linoleic acid [62]. Grape contains high concentrations of dietary fibre, ileal (free) proteins, and abundant vitamin E. Some of the ileal amino acids include lysine, threonine, methionine, and arginine, along with leucine and valine [63]. In addition to beneficial oils and proteins contained in grapes, macro- and microelements are also well represented, comprising phosphorus, potassium,

calcium, and magnesium, as well as sulfur, iron, zinc, and manganese, together with boron and copper [64].

Further to this, grapes are rich in proanthocyanidin, a chemical constituent that belongs to the group of flavonoids and known for its high antioxidant potential [65]. Proanthocyanidins are available in high densities in grape skin and seeds, which occur in the form of oligomers and polymers, comprised of polyhydroxy flavan-3-ols of catechin and epicatechin. Usually, the polyphenolic compounds are available as glycosides or gallate, performing their biological reactions by scavenging free radicals responsible for causing oxidative stress in animals.

2.8. Nutritious Dietary Resources Derived from *Vitis vinifera* Seeds and Pomace.

Industrial processing of grapes to create products such as ethanol, fruit juice, and wine production results in the production of extensive by-products comprising stems, skins, peels, and seeds. Provision of these waste products to livestock benefits them greatly, because the grape seeds and pomace contain a wide array of antioxidative compounds, such as monomeric phenolic compounds, flavonoids, epicatechins, and catechins [66, 67]. In the poultry industry, provision of animal feed containing grape by-products has been reported to be beneficial, as they contain polyphenols, which are biologically active against microorganisms and free radicals in chickens [20].

2.9. Mango (*Mangifera indica* L) Peels and Seed Kernels.

The biochemical profile of mango shows that its kernel (seed) is rich in carbohydrates, about 58–80%, while the protein and fat concentrations are about 6–13% and 6–16%, respectively. The report of Diarra [68] state that the oil concentration of mango seed kernel is highly rich in linoleic and stearic acids. Mango peels are rich in calories, with a calculated amount of 60 Kcal/100 g fresh weight. Chemical analysis of the fruit revealed high concentrations of fibre, potassium, and vitamins.

The nutritious value of *Mangifera indica* fruit consists of the following parameters (calculated on a 100 g dry weigh sample): carbohydrates 14.98 g, proteins 0.82 g, fat content 0.38 g, and fibre 1.6 g [69]. The seed of *Mangifera indica* carries a lot value, considering the fact that it is rich in important bioactive compounds including trans fatty acids and high concentrations of proteins [70].

Scholarly research findings indicate that mango peels contain a rich supply of flavonol O- and xanthone C-glycosides, and these phytochemical components can be

TABLE 4: Chemical composition of *Citrus* fruits (per 100 g of edible portion) [59].

Chemicals	<i>Citrus aurantifolia</i>	<i>Citrus aurantium</i>	<i>Citrus limon</i>	<i>Citrus paradise</i>	<i>Citrus reticulata</i>	<i>Citrus sinensis</i>
Moisture (g)	84.6	87.6	85.0	88.5	87.8	88.4
Protein (g)	1.5	0.7	1.0	1.0	0.9	0.8
Fat (g)	1.0	0.2	0.9	0.1	0.3	0.3
Fibre (g)	1.3	0.3	1.7	—	—	0.5
Carbohydrates (g)	10.9	10.9	11.1	10.0	10.6	9.3
Minerals (g)	0.7	0.3	0.3	0.4	0.4	0.7
Calcium (mg)	90	26	70	30	50	40
Phosphorus (mg)	20	20	10	30	20	30
Iron (mg)	0.3	0.3	2.3	0.2	0.1	0.7
Thiamine (mg)	0.02	—	0.02, juice	0.12	40	—
Riboflavin (mg)	0.03	—	0.01, juice	0.02	—	—
Niacin (mg)	0.1	—	0.01, juice	0.3	—	0
Vitamin C	63	30	39, juice	—	68	50
Carotene (μ g)	15	1104	0	—	350	0
Energy (K cal)	59	48	57	45	—	43

utilized extensively in pharmacological studies [71]. The vast majority of phytochemical constituents are contained on mango seed kernels, and studies have shown these to also include polyphenols and phytosterols, which are available as sitosterol, tocopherols, and campesterol. Moreover, mango seed kernels are rich in essential oils, such as stearic acids, oleic acid, and palmitic acid [72].

Mango seed kernels are rich in gallotannins, which are used in pharmacological studies as antimicrobials, antioxidants, hepatoprotectives, antsnake venom, and anti-tyrosinase [73–75]. When a total amount of 486 g/kg of mango peels was assayed for its total phenolic content, vast concentration of phenolic compounds on a mango was shown to be in the peels, with the flesh having negligible amounts of phenols [76].

2.9.1. Nutritious Dietary Resources Derived from Mango Peels and Seed Kernels. The added advantage of utilizing mango seed kernel as poultry feeding supplement is that it has good supply of carbohydrates, required for sustainability and energy provision. Besides the quality, carbohydrate contents of the mango seed kernels are also rich in proteins and fats (Table 5) and are good for keeping poultry products satiated for long periods of time [68]. Generally, ruminants such as cattle find mangoes palatable and when consumed consistently by livestock, their health status is positively affected, due to their known antimicrobial, antioxidants, and anti-parasitic properties [21]. In the poultry industry, it has been reported that provisions of mango fruit waste promote radical growth and development in chickens [77].

2.10. Papaya (*Carica papaya*) Waste. *Papaya* is abundant with bioactive compounds such as ascorbic acid, carotene, riboflavin, iron, calcium, thiamine, niacin, pantothenic acid, vitamin K, and vitamin B-6. The whole plant part of papaya from the root to shoot can be utilized for medicinal purposes, i.e., the seeds of *papaya* are rich in amino acids and can be used in the treatment of sickle cell disease and mitigation of poisoning-related disorders, whilst young leaves alleviate stomach problems [78]. The chemical mixture obtained from

papaya known as *papaya* latex is used to treat various ailments including boils, warts, freckles, asthma, genitourinary ailments, tumour disorders, digestive tract infections, and chronic indigestion [78]. Furthermore, *papaya* latex can help cure chronic noncommunicable diseases such as arteriosclerosis, high blood pressure, and cardiovascular disorders.

Barroso et al. [79] reported that over the years *papaya* has gained a lot of interest, due to the vast bioactive constituents contained in the plant, such as vitamins A, B, and C, proteolytic enzymes (papain and quimiopapain), alkaloids (carpaine and pseudocarpaine), and benzyl isothiocyanate (BITC), which has been reported to have anthelmintic bioactivity. Raji et al. [80] reported on the administration of *Carica papaya* for the alleviation of boils, warts, and freckles. The administration protocol includes taking it as an emmenagogue or vermifuge. Furthermore, vitamins and proteolytic enzymes contained in *papaya* exhibits strong antiviral, antifungal, and antibacterial properties.

2.11. Nutritious Dietary Resources Derived from Papaya Waste. Al-Fifi [81] investigated alternative coccidiosis treatment, in response to reduce the extensive use of conventional anticoccidial drugs due to their well-documented side effects. A cohort of 600 *E. tenella* experimentally infected day-old Harco chicks formed in a factorial design was utilized. The effects of dry leaf powder of *C. papaya* incorporated at a concentration of 15% in conventional feedstuff showed that *C. papaya* reduced the infected control group by a proportion of 53%. The reduction in the infected chicks was attributed to chemical compounds such as papain and vernoside present in *C. papaya*.

Haruna and Odunsi [82] studied the effects of *Carica* latex coupled with crude enzyme complex as a feed additive for broiler chicken. Variables such as growth performance, cell-mediated immunity, and carcass and organ measurements were assessed. After 49 days, the broiler chickens were slaughtered to measure the daily feed intake (DFI), daily weight gain (DWG), feed to gain ratio (FGR), and protein efficiency ratio (PER) in cut-up parts including thighs, breast, neck, back, drumstick, and abdominal fat. The results

TABLE 5: Proximate composition of dry mango seed kernel (MSK) (g/100 g dry matter) [68].

Constituents	Mango seed kernel
Dry matter	89–91.5
Crude protein	6–10
Crude fibre	1.11–2.9
Ether extract	7.87–14.80
Nitrogen-free extract	67–82
Metabolizable energy (kcal/kg)	3.275–3.454*

* Value for boiled mango kernel.

obtained showed that the papaya latex contained 54.9% crude protein concentration, 6.28% ether extract, 18.79% nitrogen-free extracts, 5.5% ash, and 4.65% crude fibre. Initially, the introduction of increasing concentrations of papaya latex caused a reduction in DFI, DWG, and FGR [82]. However, during the period of 28 to 49 days, broiler chickens induced with a concentration of 0.1% papaya latex feed additives were found to be comparable to the broiler chickens fed a papaya latex-free diet. Furthermore, the hypertrophy of gizzard, intestines, and liver produced high levels of papaya latex [82]. The experiment showed that variables such as carcass yield, immune response, and survivability of broiler chickens were greatly improved. It is therefore clear that papaya waste can significantly improve profitability in the poultry industry.

2.12. Pea (*Pisum sativum*) Pods, Vines, and Straw. Pea is one of the important agronomical crops. It is rich in dietary proteins and is known widely as an excellent nitrogen fixer. Some of the macronutrients available in pea include boron, cobalt, and molybdenum, and these macronutrients play a critical role in promoting *Rhizobium* growth as well as nitrogen fixation. Besides boron assisting in the biosynthesis of amino acids and proteins [83], the compound also regulates the catabolism of carbohydrates. This step is important as it ensures carbohydrates are transformed efficiently into simpler sugars [84].

2.12.1. Nutritious Dietary Resources Derived from Pea Pods, Vines, and Straw. Pea residues are fed to livestock as silage and are said to provide essential proteins and starch required for prolonged periods of fulfilment and storage of energy reserves in livestock [85]. Pea waste products have demonstrated inducement of significant growth performance, as revealed in a study conducted to assess the effects of pea residues on nonruminant rabbits [86].

2.13. Pineapple (*Ananas comosus*) Waste. Pineapple (*Ananas comosus*) is an important agricultural crop for many countries. The biochemical profiling of pineapple is reported to be rich in macronutrients such as sugars, fibre, and proteins. In addition to the macronutrient constituents, aqueous pineapple extracts produce an elevated level of ferulic acid and chlorogenic acid, which are vital reducing agents or antioxidants [87]. Pineapple fruit contains bromelain, a mixture of protein digestible enzymes known as proteases. Bromelain extracts have been assayed and have tested positive for the presence of antimicrobial properties,

especially to Gram-positive bacteria such as *E. coli* and *Proteus* spp [88]. The sugar composition of pineapple waste is diverse and includes glucose, sucrose, and fructose.

Pineapple peel wastes are made up of important bioactive compounds, such as ferulic acid, phenols, and vitamin A and C, used in pharmacology and food science as antioxidants and food preservatives [87]. The proteolytic enzyme, bromelain, is useful in medicine due to its healing properties that are reported to perform their action, especially in cancer reduction, by interfering with formation of cancerous cells. Further to this, platelet aggregation is inhibited by these properties, which are also anti-inflammatory, enhance drug absorption, and remove dead skin cells [89].

2.13.1. Nutritious Dietary Resources Derived from Pineapple Residues. According to a study by Suksathit et al. [19], which investigated silage from pineapple fruit residue as an alternative livestock feed, the results indicated that the energy and mineral contents of pineapple residues are far more superior to that of maize green fodder. These results suggest that supplementing livestock feed with pineapple wastes will provide additional energy required for optimum growth and development. Furthermore, pineapple wastes have been proven to be highly palatable to sheep and cattle. Supplementing animal feed with pineapple waste increases the digestibility of ruminants; it accordingly allows nutrients to be distributed in the animals' bodies efficiently, without digestive complications, maintaining the ruminal microbial population with adequate supplies of essential nutrients required for performing digestive processes [19].

2.14. Pumpkin (*Cucurbitaceae*) Peels and Seeds. Pumpkin, belongs to the *Cucurbitaceae* family and is rich in nutritional and therapeutic phytochemicals, such as proteins, amino acids, polyphenols, and polysaccharides, as well as essential elements such as potassium, phosphorus, magnesium, and zinc. Pumpkin seeds contain high levels of essential oils and nutrients. The fats and oils are used as building blocks in biosynthesis of long-chain fatty acids and glycerol. Table 6 depicts the biochemical composition of selected pumpkin parts [2], while Table 7 indicates some important fatty acids derived from *Cucurbita maxima* seed oil [90]. In animal body cells, fats and oils play vital role of supplying large quantities of energy reserves required to maintain a stable body temperature [90]. The percentage composition of some important nutrients found in *C. maxima* are carbohydrates 28.68%, proteins 33.48%, lipids 30.66%, ash 3.98%, and fibre 3.07% [91].

Pumpkin contains some of the important phytochemical constituents. Carotenoids, triterpenoids, ent-kaurane-type diterpene, and *cucurbita* glycosides are groups of phytochemical compounds found in pumpkins, which are classified as being important in carrying out ethnomedicinal properties in living organisms, including livestock and poultry. Besides carotenoid and γ -tocopherol compounds in pumpkin positioning the fruit as one of the most nutritious foodstuffs, it is endowed with antifatigue properties based on activities observed during mice studies, reported by Achilonu et al. [2].

TABLE 6: Biochemical composition of selected pumpkin parts (g/kg raw weight) [2].

Nutrients	Part	Species		
		<i>C. pepo</i>	<i>C. moschata</i>	<i>C. maxima</i>
Carbohydrates	Flesh	26.23 ± 0.20	43.39 ± 0.84	133.53 ± 1.44
	Peel	43.76 ± 0.74	96.29 ± 1.11	206.78 ± 3.25
	Seed	122.20 ± 7.47	140.19 ± 7.60	129.08 ± 8.25
Protein	Flesh	2.08 ± 0.11	3.05 ± 0.65	11.31 ± 0.95
	Peel	9.25 ± 0.12	11.30 ± 0.99	16.54 ± 2.69
	Seed	308.83 ± 12.06	298.11 ± 14.75	274.85 ± 10.04
Fat	Flesh	0.55 ± 0.14	0.89 ± 0.11	4.20 ± 0.23
	Peel	4.71 ± 0.69	6.59 ± 0.41	8.69 ± 0.99
	Seed	439.88 ± 2.88	456.76 ± 11.66	524.34 ± 1.32
Fibre	Flesh	3.72 ± 0.02	7.41 ± 0.07	10.88 ± 0.35
	Peel	12.28 ± 0.15	34.28 ± 1.37	22.35 ± 0.01
	Seed	148.42 ± 0.55	108.51 ± 8.36	161.54 ± 6.79
Ash	Flesh	3.44 ± 0.04	10.36 ± 0.01	10.53 ± 0.11
	Peel	6.30 ± 0.06	13.96 ± 0.16	11.20 ± 0.64
	Seed	55.02 ± 1.00	53.15 ± 0.20	44.22 ± 0.36
Moisture	Flesh	967.70 ± 0.15	942.31 ± 0.08	840.43 ± 0.17
	Peel	935.98 ± 0.27	871.86 ± 0.09	756.79 ± 0.44
	Seed	74.06 ± 0.91	51.79 ± 6.04	27.51 ± 0.21

TABLE 7: Fatty acid composition of *Cucurbita maxima* seed oil [80].

Retention time	Fatty acids	Relative percentage (%)
14.82	Palmitic acid (C15H31COOH)	17.39
17.38	Linoleic acid (C17H31COOH)	14.97
17.9	Oleic acid (C17H33COOH)	40.58
18.1	Stearic acid (C1735COOH)	27.06

Under favourable conditions, pumpkin seeds can produce a secondary metabolite, known as squalene. In living organisms, squalene is used as a building block during the biosynthesis of vitamin D, cholesterol, and steroid hormones. What is more, pumpkin seeds are rich in acetylated phenolic glycosides, cucurbitosides F-M (e.g., 4-(2-hydroxyethyl)phenyl 5-O-(2-S-2-methylbutyryl)- β -d-apiofuranosyl(1 \rightarrow 2)- β -d-glucopyranoside) [2].

2.14.1. Nutritious Dietary Resources Derived from Pumpkin Waste and Farm Residue. The added benefits of fruit waste and farm residue derived from pumpkin are that it contains large amounts of phenolic antioxidants. The presence of these antioxidants can assist livestock and poultry to live longer due to their defensive mechanisms against oxidative stress and other degenerative diseases [92]. It has been reported that animal feed containing pumpkin waste assists in the treatment of diabetes in animals, as observed in a study on the action of pumpkin feeds, with respect to cytoprotectivity on streptozotocin-induced diabetic animals [93].

2.15. Tomato (*Solanum lycopersicum* L.) Peel and Seed By-Products. Industrial processing of tomato produces two different types of by-products, the material emanating from tomato peeling and the removal of seeds. It has been

reported that tomato peel contains 100.8 g protein, 256.4 g ash, and 299.4 g acid detergent fibre kg^{-1} [94]. Seed by-products contain 202.3 g protein, 51.8 g ash, and 537.9 g acid detergent fibre kg^{-1} . The dry matter of peel by-products contains lycopene measured to be around $734 \mu\text{g} \cdot \text{g}^{-1}$, and the seed by-products accounts for $130 \mu\text{g}$ of lycopene kg^{-1} [94]. Furthermore, both peels and seeds of tomato contain high fractions of β -carotene, lutein, and cis- β -carotene [94].

The impact of secondary metabolites such as lycopene as an antioxidative agent is profound. Their capability to interact with reactive oxidative species (ROS) and mitigate their destructive effects can help prevent the development of chronic diseases. Furthermore, lycopene is reported to impact other biological processes such as metabolic reactions, immunomodulatory effects, and hormonal induction [95]. In addition, high lycopene-containing products have been proven to reduce the incidence of developing prostate cancer in humans [96, 97]. Therefore, it is highly likely that high concentrations of lycopene intake are directly proportional to the reduction of prostate cancer in most mammals.

2.16. Nutritious Dietary Resources Derived from Tomato Peels and Seeds. An investigation conducted by Knoblich et al. [94] to determine the transfer of carotenoids to yolk, on hen fed with $75 \text{ g} \cdot \text{kg}^{-1}$ of tomato peels and seeds by-products, observed that when hen was fed diets consisting of $75 \text{ g} \cdot \text{kg}^{-1}$ tomato waste products, lycopene of dry yolk was estimated to be around $0.9 \mu\text{g} \cdot \text{g}^{-1}$. Essentially, an approximate amount of 0.1% of lycopene from peel by-products and 0.7% lycopene from seed by-products was transferred from the feed to the yolk [94]. It was concluded that lycopene appeared like carotene than to oxycarotenoids (xanthophylls) with respect to its transformation in the yolk, low moisture content and high protein content.

Furthermore, oxycarotenoids contained in tomato peels and seeds function by providing the pigment to the eggs and skin of commercial chickens. The yolk colour is heavily dependent on the concentration of oxycarotenoids in the diet. Hence, better oxycarotenoids combination in the diet produces yellow to red shades. In milk production, wet tomato by-products can be mixed with corn plants resulting in silage capable of producing good milk in ruminants [94].

2.17. Phytochemical Impact on Feed Palatability, Feed Intake, and Animal Products Quality. Animal feed composition (i.e., nutrient content and nutrient balance) is an important factor that determines feed intake. The palatability of animal feed can be improved by incorporation of some feed additives. Palatability (i.e., degree of acceptance of feed to be eaten by animal) is mostly determined by the feed's physical properties such as appearance, texture, and temperature and sensory qualities like odour and taste. Another major influence on feed intake is the digestibility efficiency of the diet. Rate of feed digestion is directly related to amount of energy released. Accordingly, a ration that has a high content of feedstuffs of low digestibility needs to be eaten in great quantities by the animals to obtain the required energy level. Unpalatable diets characteristically are feedstuff that are dusty, severely deficient in amino acids, and low in digestibility, thus causing bloating in animals; hence, feed intake by the animals is limited, and the impact on the health and product qualities are usually deleterious.

Chicory is established to be rich in fibre and palatable for broilers and helps to develop animal's upper gastrointestinal tract system [11]. Rations enriched with chicory (high insulin nonstarch polysaccharide) improve palatability of feed and therefore increase feed intake, feed conversion rate, and growth performance of animals [15, 18, 56].

Blandon et al.'s [98] review paper reported significantly high feed intake, live-weight gain, and feed conversion efficiency of chickens fed banana peels meal diets up to 10 % inclusion level. However, decrease in feed ingestion and performance parameters started thereafter. The decrease in feeding with percentage increase in banana peels meal could be attributed to tannins content in the meal and is in agreement with earlier assertion of Emaga et al. [99] noting that banana peels' antinutritive tannins negatively affect the utilization of the fruit waste in monogastric dietary. A study has established that tannins content in dry banana peels of 1.2 g/100 g did not cause significant changes in broilers' performance (liver, gizzard, heart, breast, and drumstick weights and in abdominal fat), even when incorporation in the animal's ration up to 15%. However, increasing the peels meal to 30 and 45% inclusion showed a significant decrease in the broilers' dressed weights, indicating huge drop in feed ingestion and consequential harmful impact on the animal and product value. The studies have demonstrated that inclusion of banana peels meals in the diets up to 10% would improve the animal's feed intake and feed conversion ratio resulting in better growth performance, carcass characteristics, egg qualities, and haematological parameters as well as reduced feed costs.

Recent review paper by Achilonu et al. [2] highlighted several opinions of the beneficial effects of pumpkin residues inclusion in poultry rations as follows: inclusion of 10% pumpkin seed meal in broiler chicken diets improved reduction in excessive abdominal fat, which resulted in increased production performance and improved organoleptic meat quality; broilers fed pumpkin leaf meal demonstrated reduction in total serum cholesterol and fat content of heart, gizzard, and muscles, as well as high-feed conversion and body weight gain; poultry ration enriched with pumpkin seed oil lowered bird mortality, reduced total cholesterol, phospholipids, and triglyceride concentrations in blood plasma. Pumpkin seed was reported to improve the fertility and egg hatchability traits of Turkey hens, lower embryonic dead-in-shell. Pumpkin seed oil fortified diets afford more production: about 9.7% more eggs per hen per week and higher average chicken weight of 2.8% than the control. This result is attributed to the pumpkins (phytogens), which promote the secretion of gastric juices in chickens' digestive tracts and thus improve the integrity of the intestinal mucosa, stimulating the olfactory receptors and taste buds, accordingly increase feed intake, endogenous enzymes production and digestive juices, and better nutrient digestibility of feed, consequently enhancing the reproductive parameters [2].

Guil-Guerrero et al. [32] summarised several literature studies on plant residues as sources of health-promoting agents for livestock industry. Most of the fruits and vegetables by-products/wastes that supplement animal diets are rich in bioactive compounds (phenolics, sterols, carotenoids, saponins, and peptides). The by-products of avocado, mango, pineapple, papaya, potato, and tomato contain good amount of phenolic compounds such as phenolic acids (exhibit antibacterial activities: reduce the potential transmission of bacteria from cattle to the environment) and flavonoids (exhibit antibacterial activities: works in synergy with other antibacterial agents against some bacteria resistant strains). The carotenoids exhibit antioxidant properties: enhance immunity in farm animals, while saponins possess the qualities to improve growth, feed efficiency, and ruminants' health [32]. Condensed tannins (proanthocyanidins), besides improving liveweight gain, milk yield, ovulation rate, protein concentration (by binding to plant proteins in the rumen, thus preventing their microbial degradation and prevention of bloat in cattle), also decrease the viability of the larval stages of several nematodes in sheep and goats by interfering with parasite egg hatching and development to infective stage larvae [32].

In Wadhwa et al.'s [100] summary of different opinions on the utilization of fruit wastes and by-products as animal feed, it was noted that dried apple pomace is low in protein, essential amino acids, and vitamin C but rich in insoluble carbohydrates (cellulose and hemicellulose) and reducing sugars (glucose, fructose, and sucrose). Hence, the recommendation for the fruit residues' utilization as feed in different farm animal species. In ruminants, the investigators recorded best food conversion rate when 15% of ensiled apple pomace (composed of 10% each of wheat barn, chopped alfalfa, and milled rice bran) was incorporation

in the diet fed dairy cow. The result showed increased milk production, decreased milk fat, and reduced feeding cost. In poultry, a replacement of 10% of maize in broiler ration with apple pomace did not adversely affect the poultry production; however, inclusion level more than 10% resulted in wet litter and reduced feed efficiency. They also noted that replacement of 20% of maize in the broiler diet with dried ground apple leftovers decreased feed cost and showed no harmful effect. The review paper also noted that incorporation of 2% of dried orange pulp in the dietary of broiler chicken improved the chickens' feed intake and resulted in body weight gain, decreased liver and abdominal fat, as well as serum triglyceride in the chickens [100].

3. Biochemical Modulatory Effects: Improved Physiological Parameters

The phytochemical composition of fruit wastes and farm residues plays a significant role in the health and general performance of animals. The bioactive and therapeutic compounds exhibit properties that considerably enhance the health status of livestock and poultry. Antioxidants, such as polyphenols and vitamins C and E, which are contained in most fruit by-products and wastes, prevent the damaging effects caused by harmful free radicals in animals' body systems. The antimicrobial and/or antioxidative properties of the phytochemicals are crucial in the fight against pathogenic microorganisms, fungal growth, preventing inflammation, and health-threatening oxidative free radicals that, accordingly, assist in the rapid growth and development of the livestock and poultry industry [101–103].

3.1. Performance Traits. To combat the shortage of nutritional feed resources for livestock and poultry feeding, more farmers have started incorporating nonconventional feed resources (NCFRs), because of their nutritious benefits, in addition to the pharmacological and physiological qualities imparted to animals. One of the physiological traits that normally prevail in livestock fed agroresidues is the reduction of hypercholesterol levels in their body systems. NCFR products are low in cholesterol; therefore, they reduce the levels of serum cholesterol and LDL (low-density lipoprotein cholesterol, also known as "bad" cholesterol) in the body of animals. This normally coincides with the defence mechanism strategies adopted by antioxidants that aim to protect animals against degenerative disorders. Generally, the health-promoting activities attributed to NCFR are anti-inflammatory, anticarcinogenic, antiviral, and antibacterial, as well as antimutagenic, antifungal, anthelmintic, immune-stimulating, and antioxidative qualities.

The literature [2] reveals that when pumpkin seed meals (PSM) are appropriately used in animal diet, they demonstrate comparatively better potential in animal growth promotion than the resented conventional synthetic growth-promoting antibiotics and hormones. The mode of action of

the bioactive compounds is purported to be modification of the gut microflora within the gastrointestinal tract, which consequently maximises feed digestibility, blood parameters, carcass quality, and growth rate [2, 15].

The complex and bioactive compounds are also proposed to proffer unique mode of control of pathogenic and parasitic organisms by stimulating the animal's nutrition, accordingly improving resistance to infectious diseases and the general well-being of the animals. Different research opinions, summarized by Achilonu et al. [2], show that inclusion of approximately 10% of PSM in poultry rations could significantly reduce abdominal fat, reduce serum levels of harmful lipids, increase serum levels of beneficial lipids, as well as improve live performance and yield of the poultry. Reports have further established that some plants, such as *Ananas comosus* (pineapple), *Momordica charantia* (bitter melon), *Azadirachta indica* (neem), *Eucalyptus staigeriana*, and *Cichorium intybus* (chicory), when added to pig rations, reduce the boar taint [2, 15].

3.2. Reproductive Qualities. Recently, Nwafor et al. [15] summarised previous opinions on the benefits of plant material chemical compounds on reproductive parameters of animals. One of the studies observed that the extracts of okra and pumpkin seeds improve fertility and egg hatchability properties of Turkey hens. Another study on the performance parameters of laying hens that were fed rations fortified with pumpkin seed oil (PSO) established that egg production per hen per week increased by 9.7%, and the hen's body weight improved by 2.3%.

The authors' assertion was that the PSO phytochemicals stimulate the hen's sensory organs (olfactory receptors and taste buds), which increased feed consumption, enzyme and digestive juice production, effective digestibility of the feed, and resultantly enhanced reproductive qualities [2]. Farmers have also demonstrated that secondary metabolites (including condensed tannins) in chicory residues effectively removed internal parasites in lambs, lower methane production, and consequently, increased the reproductive rate in sheep [15].

3.3. Antinutritive Compounds. Antinutrients are natural compounds in food that act to reduce food intake and/or prevent effective digestion and the subsequent absorption of nutrients. Some plant phytochemical constituents are composed of both nutritional bioactive and antinutritive compounds, which at certain amount of intake may pose a threat to bioavailability and digestibility of nutrients, affecting the health and performance of the livestock [2]. Some examples of phytoantinutritive compounds are phytates, oxalates, tannins, and saponins.

Phytic acid, when strongly bonded to essential elements (Ca, Mg, Fe, Cu, and Zn), renders the minerals unavailable for absorption in the intestine. Phytate is a phytic acid bound to minerals in the plant material. Phytic acid is more concentrated in whole grains (the bran) and beans, in the cotyledon layer.

3.4. Oxalic Acid and Oxalates. Oxalate (hydrogenoxalate anion), a conjugate base of oxalic acid, is a chelating agent for metal cations naturally found in many food and plants as a dehydrate oxalic acid, which when ingested in excess binds with Ca to form Ca oxalate (the main component of kidney stone), causing kidney failure and joint pains. Oxalates occur in plants in high concentrations. This is exemplified by a forage plant (*Setaria sphacelata*) for ruminants, contains 5.6% oxalate, which binds with Ca in the intestine of the animal to form insoluble oxalate, consequently causing low serum Ca levels and renal failure of the animal.

Glucosinolates (alkyl aldoxime-*O*-sulphate esters with a β -D-thioglucopyranoside group) are plant secondary metabolites found especially in the *Brassicaceae* family (species example is cabbage). When the plant structure is being broken down (including grinding and chewing) in the presence of water, the glucosinolates are converted into isothiocyanates, exazolidinethiones, thiocyanates, and nitriles and derivatives. The breakdown products interfere with iodine uptake, consequently hampering the production of thyroid hormones, triiodothyronine, and plasma thyroxine, which subsequently result in hypothyroidism and goitre. The changes in thyroid function accordingly cause growth retardation, as well as reduced milk and egg production, reproductive activity, and liver and kidney functions [104].

Tannins are *polyphenolic compounds*, ubiquitous in many plant species, especially legumes and some sorghum species. The astringent, bitter polyphenolic compound binds and precipitates amino acids, proteins, and alkaloids. Besides the antioxidant and therapeutic qualities of tannins, high tannin content in animal dietary is argued to decrease the animals' feed ingestion, feed efficiency, protein digestibility, and growth rate, while faecal nitrogen is increased [105].

Saponins are complex structure phytochemicals that foams in aqueous solutions, contains aglycone that is linked to sugar or polysaccharide molecules. When in high concentrations, the saponins are very bitter and astringent, hence are argued to be responsible for reduced feed intake when high saponin diet is fed to monogastric animals (pigs and poultry) and consequent poor growth rate [105].

3.5. Toxicology. The use of fruit waste and farm residues as alternative animal feed for livestock and poultry has potential for creating long-term health risks factors. This assertion is supported by current extensive use of agricultural pesticides, herbicides, and fungicides. Reports have exposed common use of nonbenign pesticides, such as organophosphorus, organochlorine, carbamate, and pyrethroid insecticides in citrus and vegetable production. Poor control or management of the use of certain pesticides/herbicides in agricultural production can endanger the lives of livestock and poultry [106], as well as the food quality of the animals' products.

The toxicological nature of pesticides is to neutralize the target organisms without harming nontarget organisms, including livestock. Pesticides perform this action by interfering with normal biological reaction on target organisms, for instance, inhibition of certain metabolic reactions in target organisms vital for the normal living organisms, which

subsequently cause the target pest to perish [107]. However, there are currently bioassays that can assess the toxicity levels of fruit waste and farm residues before they are fed to livestock and poultry, and they include, amongst others, brine shrimp lethality bioassay and MTT bioassay [108, 109].

4. Conclusion

The implementation of fruit waste and farm residues as a supplement for livestock and poultry feed is becoming urgent. The necessity of this is informed by the rapid depleting, more competitive and costly, conventional animal feed sources. Besides the cheapness of the agroresidues, the plant materials are endowed with an overabundance of health-nourishing compounds that positively impact the animals' general well-being and reproductive traits. The complexity and diversity of chemical components of the agricultural residues and agroindustrial by-products have proven to be biologically active against different sources of disease-causing agents. The nutritive compounds play a critical role in metabolic reactions and physiological transformations on the animal bodies, while the secondary metabolites available in plant waste products inhibit certain degenerative disease-causing agents that can potentially cause harm in livestock and poultry, thereby stagnating the growth and development of the animals.

However, antinutritive substances in complex plant waste feeding products, if not properly managed with controlled dietary care, can interfere with essential nutrients by blocking their synthesis or utilization by the animals' digestive systems. This problem, if not picked up early, results in the livestock and poultry becoming undernourished because of competitive nutrient factors in the body. The toxicity levels in some of the fruit waste and farm residues have been studied, and inclusion levels recommended for adequate dietary requirements to ensure livestock and poultry and their products are not exposed to contaminated agroresidues.

Despite the challenges, studies have established that agroresidues' effectiveness as alternative livestock nutritive dietary resource does alleviate the problem of feed shortage, cost, and nutritional deficiency, as well as abating some of the socioeconomic factors, such as joblessness and poverty in under-resourced communities.

Abbreviations

SMP:	Secondary metabolite phytochemicals
USA:	United States of America
FR-AIBP:	Farm residue and agroindustrial by-products
ME:	Metabolized energy
NCFR:	Nonconventional feed resources
LDL:	Low-density lipoprotein
PSM:	Pumpkin seed meals
PSO:	Pumpkin seed oil
Ca:	Calcium
Mg:	Magnesium
Fe:	Iron
Cu:	Copper
Zn:	Zinc

MTT: 3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide.

Data Availability

Literature studies gathered from popular search engines visited during the compilation of this review paper are presented in the manuscript and widely available to all readers.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

MCA conceptualized, outlined the review paper topic, and critically reviewed the draft manuscript. MM summarized different opinions expressed in the literature to populate the outline of the review topic. GA, KN, and KS reviewed the manuscript and made contributions in their areas of expertise. All authors read and approved the final manuscript.

Acknowledgments

The authors acknowledge the financial support of the Mangosuthu University of Technology, Durban, South Africa.

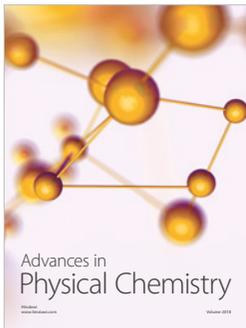
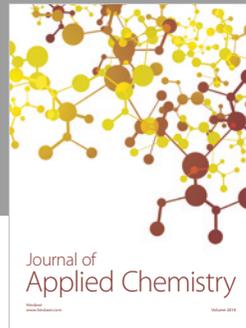
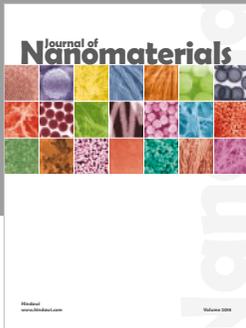
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