Chapter 7

Current and Future Improvements in Livestock Nutrition and Feed Resources

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Additional information is available at the end of the chapter

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Abstract

This study reviews the current and future trends in the improvements being made in livestock nutrition and feed resources. There had been continuous improvements in global livestock production for past decades. Most of the improvements have been in response to increasing human populations, urbanization, income growth, production system efficiency, and environmental sustainability. To meet up with the increasing global demand for livestock products was the role earmarked to be played by animal nutritionists in a manner that there would be optimization of feed efficiency to achieve more livestock products from less feed. There has been the development and adoption of biotechnological applications such as the feeding of genetically modified plants and the use of in-feed additives such as antibiotics. In the past decades, the livestock feed industry had been centered on the use of antibiotics as livestock growth promoters. However, there has also been the negative development of microbial antibiotic resistance with various countries promulgating laws and regulations to ban and discourage in-feed antibiotic applications in the livestock feed industry. Thus, present and future improvements in livestock nutrition and feed resources are now being directed at the use of approved probiotics and the application of nanotechnology in livestock nutrition and feeding.

Keywords: improvements, livestock, nutrition, feeding, biotechnology

1. Introduction

Nutrition could be a serious limitation to livestock production especially when feed resources are inadequate in both quality and quantity. Global livestock production over the years has increased consistently and brought about increases in animal numbers [1, 2]. However, these increases in the number of animals have not always been accompanied by an improved availability of livestock feed resources. These may result in overgrazing, erosion, reduced health, and performance [2]. Feed quality and quantity combined with low producer prices have often forced farmers and feed producers to remain at low levels of animal feed production, compensated by large numbers of animals. It is evident that high global population growth, accompanied by high future projections of demand for livestock products, stresses the need for higher productivity per animal as well as increases in the number of animals. Inadequate feed quality and quantity impedes increased animal production. As the world population is expected to increase from 6 to about 8.3 billion in 2030 at an average growth rate of 1.1% per year, it is essential to be prepared to produce sufficient food for the increased population based on locally available feed resources especially in the developing countries [3]. These authors [3] also stated that there are opportunities and challenges for researchers to increase animal productivity in terms of quantity and quality, through the application of appropriate technologies in production systems, nutrition, and feeding of livestock. Feed is the most important input in all livestock production systems in terms of cost, and the availability of low priced, high-quality feeds is critical if livestock production is to remain competitive and continue to grow to meet demand for animal protein. A researcher [4] mentioned that conventional methods of livestock improvements (genetics and breeding, livestock nutrition and livestock disease management) have been used in the past and served the purpose of increasing livestock productivity. However, these options can no longer sustain higher production; consequently, new intensive techniques including biotechnology are now required to augment productivity. Modern biotechnology has the potential to provide new opportunities for achieving enhanced livestock productivity in a way that alleviates poverty, improve food security and nutrition, and promote sustainable use of natural resources.

Considerable improvement has occurred in livestock nutrition and feeding over the past two decades. Globally, livestock production is growing faster than any other sector, and by 2020, livestock is predicted to become the most important agricultural sector in terms of added value [5]. In a research conducted [6], it was also reported that the feeding of genetically engineered (GE) crops to livestock for the past 15 years has shown compositional equivalence and comparable levels of safety between GE crops and their conventional counterparts. Previous researchers [7] stated that recently production demands on the livestock industry have been centralized against the use of antibiotics as growth promoters due to growing concern over microbial antibiotic resistance. Thus, with many countries reporting increased incidences of antibiotic-resistant bacteria, laws and regulations are being updated to end in-feed antibiotic use in the animal production industry. This calls for suitable alternatives to be established for inclusion in livestock feed. Many reports have shown evidence that approved probiotics and nanoparticles may be better alternatives for animal growth promotion and antimicrobials. Researchers [7], however, explained that despite the expansion of antibiotic resistance in bacteria, antibiotics have not yet been rendered totally ineffective against them. And that the delivery and efficacy of antibiotics could, however, be enhanced by nanoparticle carriers, thereby potentially decreasing the dosage of antibiotics required for treatment.

Recent advances in livestock nutrition, especially in monogastrics, have focused on three main aspects: (i) developing the understanding of nutrient requirements of livestock, (ii) determining the supply and availability of nutrients in feed ingredients, and (iii) formulating least-cost diets that bring nutrient requirements and nutrient supply together efficiently.

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2. Nutrient requirements for livestock

Nutrient requirement tables provide a summary of recommended minimum levels of nutrients for different livestock species. Livestock should be fed differently to meet body requirement based on their species, age, and purpose of production. The recommendations only serve as guidelines used for choosing dietary nutrient (energy, protein, essential amino acids, essential fatty acids, minerals, vitamins) concentrations in practical diets. Most nutrients are obtained from digestion of feedstuffs but few such as minerals, vitamins, and some essential amino acids are often supplied as synthetic supplements particularly in monogastrics.

2.1. Formulation of diets for poultry

Poultry raised under intensive system should be fed balanced diet based on species, age, and purpose of production. The major classes of chickens are meat chickens (broilers) and laying hens (layers). **Table 1** provides a summary of recommended minimum levels of selected

- Laying chickens

Nutrient requirements for laying chickens consuming between 80 and 120 g/hen/day are as follows: 12.50–18.80% crude protein, 2.71–4.06% calcium, 0.21–0.31% nonphytate phosphorus, 0.13–0.19% mg/kg potassium, 29.00–44.00 mg/kg zinc, and 0.13–0.19% sodium.

- Broiler chickens

Broilers of ages between 0 and 8 weeks old require the ranges of nutrients as follows: 18–23% crude protein; 0.80–1.00% calcium; 0.30–0.45% nonphytate phosphorus; 0.30% potassium; 8.00 mg/kg copper; 40.00 mg/kg zinc; 0.123–0.20% sodium.

- Broiler breeders

Broiler breeders require the following nutrients ranges: 19.5 g/day crude protein, 4.0 g/day calcium, 350.0 mg/day nonphytate phosphorus, and 150 mg/day sodium.

- Turkey poults

Turkey poults at 0–12 weeks old require the following ranges of nutrients: 22.0–28.0% crude protein, 0.85–1.20% calcium, 0.42–0.60% nonphytate phosphorus, 6.00–8.00 mg/kg copper, 50.00–70.00 mg/kg zinc, and 0.12–0.17% sodium.

- Turkeys 12–24 weeks old

Turkeys 12–24 weeks old require the following ranges of nutrients: 14.00–19.00% crude protein, 0.55–0.75% calcium, 0.28–0.38% nonphytate phosphorus, 6.00 mg/kg copper, 40.00 mg/kg zinc, and 0.12% sodium.

- Turkey tom breeders

Turkey tom breeders require the following ranges of nutrients: 12.00% crude protein, 0.50% calcium, 0.25% nonphytate phosphorus, 6.00 mg/kg copper, 40.00 mg/kg zinc, and 0.12% sodium.

- Turkey hen breeders

Turkey hen breeders require the following ranges of nutrients: 14.00% crude protein, 0.25% calcium, 0.35% nonphytate phosphorus, 8.00 mg/kg copper, 65.00 mg/kg zinc, and 0.12% sodium.

Table 1. Summary of recommended minimum levels of some nutrients for different classes of poultry.

nutrients for layers, broilers, broiler breeders, turkey poults, turkey growers, turkey tom breeders, and turkey hen breeders. In poultry, particularly in chickens, since each specific genotype has its own requirements, most commercial feed formulations are carried out based on minimum requirements recommended by the breeding companies from which they were obtained.

2.2. Formulation of diets for pigs

There are numerous feed ingredients that provide nutrients that pigs require for normal performance. Pigs do not require specific ingredients in their diets, but instead they require energy and nutrients such as amino acids, minerals, and vitamins. They should be fed diets that are balanced with respect to amino acids, containing adequate levels and ratios of the 10 essential amino acids required by pigs for maintenance, growth, reproduction, and lactation. The 10 essential amino acids are arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. In a review article [8], it was explained that in pigs, amino acids are reported to be the chemical components of protein and are generally supplied to the pig from the crude protein in the diet. Failure to supplement low protein diet or feedstuff with sufficient amounts of good quality protein source was observed [8], which results in poor growth, insufficient feed utilization, increased carcass fatness, general unthriftiness, and or reduced reproductive performance. This researcher [8] also mentioned that in pigs, diet crude fiber should not exceed 10–15% of the diet as feed intake may be depressed. Growing and lactating pigs should be fed *ad libitum* while others could be limitedly fed. Presented in **Table 2** are some amino acid requirements in pigs.

Amino acid	Growers	Pregnancy	Lactation
Arginine	nd	0.15	0.41
Histidine	nd	nd	0.37
Isoleucine	nd	0.42	0.46
Lysine	1.10	0.43	0.55
Methionine	0.26	0.12	0.30–0.36
Methionine/cystine	0.57	0.06	nd
Phenylalanine	nd	nd	nd
Threonine	0.60–0.70	0.41	0.42
Tryptophan	0.18–0.20	nd	0.12
Valine	nd	0.32	0.53–0.68

nd, not determined; source: [9].

Table 2. Amino acid (%) requirements for pigs.

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2.3. Formulation of diets for fish

Fish farmers need to make use of well-balanced, less expensive feeds as well as good fish farming management practices in order to achieve profitable production [10]. Species-specific feed formulations, which address the nutritional requirements of the different life stages of fish, are required in fish farming. Also, each specific genotype has its own nutrient requirements that meet the requirement for the different life stages. The fish larvae production and nutrition are usually undertaken by specialist breeding companies. Most commercial fish diets or feeds are formulated based on minimum requirements recommended by the breeding

Life stage/size class	Range of values of crude protein (CP%)
Fry	45–50
Fingerling	45
Juvenile	43
Grower	42
Broodstock	35–40
Amino acids	Requirement for all life stages (% aa)
Arginine	2.0
Histidine	0.7
Isoleucine	0.8
Leucine	1.4
Lysine	1.8
Methionine	1.0
Phenyalanine	1.2
Threonine	0.8
Tryptophan	0.2
Valine	1.3
Lipids	Requirement for all life stages is 8–10% lipids
Essential fatty acids	(minimum %)
Arachidonic acid (20:4n-6)	0.5
Eicosapentaenoic acid (EPA) (20:5n-3)	1.0
Docosahexaenoic acid (22:6n-3)	0.5
Carbohydrates (CHO)	Requirement for all life stages is 12% CHO
Crude fiber, % max.	3.0
Gross energy, min. kJ/g	15.5

Life stage/size class	Range of values of crude protein (CP%)
Digestible energy, min. kJ/g	15.5
Protein:energy ratio, mg/kJ	25.0
Minerals	Requirement for all life stages
Macroelements (%)	
Calcium, max.	1.0
Phosphorus, min.	0.8
Magnesium, min.	0.05
Sodium, min.	0.06
Microelements, min. (mg/kg)	
Potassium	0.7
Iron	60.0
Copper	3.0
Manganese	13.0
Zinc	30.0
Selenium	0.3
Iodine	1.1
Vitamins min. (IU/kg)	Requirement for all life stages
Vitamin A	2500
Vitamin D	2000–2400
Vitamins, min. (mg/kg)	Requirement for all life stages
Vitamin E	25–100
Vitamin K	1.0
Thiamine	10.0
Riboflavin	5.0
Pyridoxine	6.0
Pantothenic acid	20.0
Niacin	10.0
Folic acid	2.0
Vitamin B 12	0.02
Choline	800.0
Inositol	300.0
Biotin	0.15
Ascorbic acid	40.0

Requirements were measured in fingerling and juvenile fish. Values for other life-history stages are estimates. Data source: [12].

Table 3. Dietary nutrient requirements of rainbow trout (***Oncorhynchus mykiss***) (requirements are expressed for dry feed).

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companies that supply the fry or fingerlings. Fish require nutrients such as crude protein, essential amino acids, essential fatty acids, lipids, carbohydrates, crude fiber, minerals, and vitamins [11]. **Table 3** presents the summary of dietary nutrient requirements and utilization of rainbow trout (*Oncorhynchus mykiss*) (fish) at different life stages or size classes.

2.3.1. Ingredient composition for different life stages of fish

Some of the ingredients required in early fry to brooder stages are as follows: fish meal of between 30 and 68%, corn meal of 0–4%, poultry by-product meal of 2–8%, ground wheat of 17–22%, fish oil of 9–12%, vitamin premix of 1.5%, and mineral premix of 0.5%. Sources: [10, 11].

2.3.2. Feed parameters and proximate composition for different life stages of fish

Some of the feed parameters and proximate composition requirements between early fry and brooder stages are as follows: 3–8% of body weight, 6 months maximum shelf life of feed, addition of probiotics to improve the feed conversion efficiency, 2–5 mm pellet size (mash for early fry), 35–48% crude protein, 8–21% crude lipid, 9–12% ash, less than 3–6% crude fiber, 12–13% nitrogen-free extract, and 17–21 kJ/g gross energy. Sources: [10, 11].

2.4. The feeding of ruminants: cattle, sheep, and goats

Ruminants have distinct advantage over monogastrics in being able to convert organic materials that are not suitable for human consumption into products that are of high nutritional value such as meat, milk, and by-products [13–15]. They also provide fertilizer from the faecal and undigested residues. The aim in the feeding of ruminants thus should be to feed as much forage as possible that could satisfy most of the nutrient requirements of the animal. The quantity and quality of roughage made available to the ruminant will then determine the amount and type of supplement or concentrate to be fed.

2.4.1. Feeding of young ruminants

In young stock, the rumen will not be developed and it will take a few months until the rumen is fully developed and starts functioning. Until then, the young ruminant is similar to a simple-stomached animal nutritionally. In young stock, essential amino acids should be provided in required quantity in the ration. The B-complex vitamins, vitamins A and D, and minerals should be provided usually from the milk. Colostrum should be given at days 1–3 after birth as antibodies (gamma globulins) are transferred from the dam to its young.

2.4.2. Feeding of adult ruminants

Ruminants have a forestomach composed of fermentation compartments, which contain large amounts of microorganisms (bacteria, protozoa, fungi). These break down the cellulose in fibrous plant material into a form that can be digested in the animal's stomach and intestines. There is a symbiosis between ruminants and microorganisms, as the microorganisms need the energy and nutrients in forage for their own nutrition, and the microorganisms are finally broken down as protein source for the host ruminant. Thus, ruminants need lesser grains and concentrate diets than monogastrics such as pigs and poultry, which do not have a forestomach full of microorganisms, which act as protein source.

2.4.3. Ruminant nutrition

In ruminant nutrition, one must know the amount of energy required by an animal for a specific production function, if it is desired to obtain the most efficient utilization of a feedstuff. During food metabolism, energy in the diet is broken down from gross energy into net energy for maintenance and for production. To meet the energy requirements in ruminants, the energy value of feeds is most important but one also needs to have a balance of other nutrients such as proteins, amino acids, fats, minerals, and vitamins as shown in **Table 4**. The deficiency in any one of the nutrients may impair metabolism. To minimize the possibilities of nutritional deficiencies, various feeding systems have been formulated to assist nutritionists in selecting ration components. These systems involve (i) practical application of the basic concepts of energy systems, (ii) metabolic processes whereby energy is released from specific nutrients, and (iii) the roles played by volatile fatty acids in ruminant nutrition. It is important to know that in general, as the fiber level of ruminant rations decreases, the concentration of acetic acid in the rumen contents also decreases. The fiber fraction of feeds are usually broken down into acetic, propionic, and butyric acids, and about 60% of

• Dry matter	• Fat
• Feed category/class (e.g., forages, concentrates, etc.)	• Major minerals: Ca, P, K, Mg, Cl, Na
• Processing factor (e.g., drying, ensiling, pellets production, urea treatment, multi-nutrients-blocks production, etc.)	• Minor minerals: S, Co, Cu, I, Fe, Mn, Se, Zn
• Neutral detergent fiber (NDF): 15–19% of DM of minimum forage NDF, 25–33% of DM of minimum NDF in diets	• Amino acids: methionine, lysine, arginine, histidine, isoleucine, leucine, cystine, phenylalanine, threonine, tryptophan, valine
• Acid detergent fiber	
• Lignin	• Vitamins: A, D, E
• Nonfibrous carbohydrates (NFC): 36–44% of DM of maximum NFC* in diets	• Digestibility coefficients of: CP, NDF, fat, NFC
• Crude protein—rumen degradable protein (RDP), rumen undegradable protein (RUP)	• Feed additives

*Starch as source of NFC.
Source: [17].

Table 4. Some nutrient supply input requirements and the limits of neutral detergent fiber (NDF) and nonfibrous carbohydrate (NFC) requirements in ruminant diets (%).

the digestible energy from fibrous carbohydrates is converted to volatile fatty acids (VFA) within the rumen. The conversion of carbohydrates to VFA is dependent on the microbes present in the ruminant digestive tract. The level of 8% crude protein of diets is required to provide the minimum ammonia levels required by microorganisms for optimum rumen activity [16].

2.4.3.1. Formulation of diet in ruminants

Tables of values of nutrients (CP, fat, minerals, vitamins, etc.) required by ruminants are never given because these values are calculated based on how rapidly the nutrients degrade in the rumen (rate of digestion) and how rapidly the feed passes through the rumen i.e., rate of passage [17]. The rate of digestion is related to the properties of the feed, while rate of passage increases with increasing dry matter intake (DMI), body weight of animal, etc. These values are usually not constant; however, effort is being made to calculate more approximate values. The protein requirement of ruminants can be divided into two groups: rumen degradable protein (RDP) or by pass proteins, which is degraded in the rumen by the rumen microbes e.g., groundnut cake, fish meal, soybean meal, rape seed cake, etc. [18]. These degraded proteins are then broken down into amino acids and urea. However, rapid fermentation of proteins in the rumen results largely to feed wastage (except in high milk production), since most of the ammonia by-products liberated are excreted as urea through urine. Rumen undegradable proteins (RUP) are not easily degraded by rumen microbes e.g., nonprotein nitrogen (NPN) compounds such as urea, uric acid, biuret (usually present in fermented forages) and other treated nitrogen sources, which normally escape the rumen fermentation. Shown in **Table 4** are some nutrient supply input requirements and the limits of neutral detergent fiber (NDF) and nonfibrous carbohydrates (NFC) requirements in ruminant diets.

3. Livestock feed availability and nutrition

Livestock nutrition can be categorized into diets for nonruminants (monogastrics) and ruminants. Most nonruminants are omnivorous, having simple digestive system commonly with nonfunctional caecum. However, the digestive system in ruminants has the four roughage diet digestion chambers, rumen, reticulum, omasum, and abomasum.

3.1. Commonly used conventional and alternative feedstuffs and/or agroindustrial by-products

Energy sources normally constitute the highest proportion (about 50–60%) of livestock diets, followed by plant protein sources (about (10–20%), next is the fiber and animal protein sources (10–15%), and the lowest rates of inclusions usually occur in the minerals and additives as feed ingredients. Globally, maize (corn) is the most commonly used energy source, and soybean meal or cake is a common plant protein source, while fishmeal is the major animal protein ingredient used in livestock rations. These three feed ingredients are known to be the conventional livestock feed ingredients, and they usually constitute a part of livestock concentrate feeds. They have been facing market competition with human food demands, especially in the developing countries, and this trend has been tagged as "feed-food competition" [19]. To cope

Conventional feedstuffs	Alternative feedstuffs	Range of inclusion rates (% of DM)
Energy source		
Maize, vegetable oils	Sorghum, cassava root meal or peel meal, yam peels, potato root meal or peel meal, palm oil slurry, sesame seed meal, forage plants	50–60
Fiber sources		
Wheat bran, maize bran	Rice bran/husk, maize husk	10–15
Plant protein sources		
Soybean meal, groundnut cake, Palm kernel cake	*Palm kernel cake, cotton seed cake, pigeon pea meal, cowpea vines, groundnut haulms, soybean haulms, potato vines	10–20
Animal protein sources		
Fish meal, blood meal	*Blood meal, poultry offal meal, hydrolyzed feather meal, dried poultry manure meal, snail meat meal, insect fly, pupal and larval meals, earthworms, crystalline amino acid sources	5–10
Mineral sources		
Oyster shells	Periwinkle shells	2–5
Bone meal	Limestone	2–3
Dicalcium phosphate	Malt dust	1–2
Feed additives		
Vitamin premix		1
Common salt		0.25–0.50
Others (probiotics, prebiotics		0.25–0.50

*Serves as both conventional and alternative feedstuff.

Table 5. Conventional and the alternative feedstuffs commonly used in nonruminant and ruminant concentrate diet formulations.

Ingredients (%)	DM	CP	EE	CF	NFE	Ash	Source
Wheat bran	88.0	14–19	6.5	10.6–16.0	59.5	4.0	[10, 20]
Maize bran	93.0	10–15	4.4	11.6	70.8	3.2	[10]
Rice bran	91.0	12–13	2.4–3.4	12.3	63.0	0.9	[20]
Maize	87.0	9.9	4.4	2–3	70.0	4.5	[21]
Cassava root meal	88.3	1.5–3.5	3.4	3.7	91.0	1.1	[20]
Cassava peel meal	33.5	6.5	1.3	16.6	68.5	5.9	[22]

Ingredients (%)	DM	CP	EE	CF	NFE	Ash	Source
Groundnut cake	90.0	45.3	11.0	5.0	27.5	1.2	[20]
Palm kernel cake	94.0	14–21	5–17	13–23	48.0	3–12	[23, 24]
Cotton seed cake	86–93	26–36	6.7	7.1	44.5	5.8	[10, 20]
Fish meal	95.0	35.0	8.6	17.6	45.0	9.1	[20]
Blood meal	89.5	76–80	1.2	1.5	47.1	1.3	[20]
Poultry manure	92.6	16.8	2.5	10.0	50.2	13.1	[25, 26]
Snail	86–91	65–67	7.9	3.06	17.2	7.8	[27]
House fly larva	nd	60.0	20.0	nd	nd	nd	[26, 28]
Leaf-meal (duck weed)	92.3	24.8	5.7	12.1	54.5	2.0	[20]

nd, not determined.

Table 6. Proximate analysis of some commonly used livestock feed ingredients.

with the feed-food competition, it has been necessary to explore the use of locally available, cheaper alternative feedstuffs for use in livestock feed formulations. A wide range of alternative feedstuffs are being used in livestock feeding globally, and these could be categorized into alternative energy, fiber, plant protein, animal protein sources, and feed additives as shown in **Table 5**. **Table 6** presents the proximate analysis of some commonly used livestock feed ingredients.

4. Formulation of least cost rations

The aim in formulating least cost rations, particularly on large commercial farms, is to undertake a precision feeding in order to lower cost and to maximize economic efficiency. In the past, there was a great tendency to over formulate diets when the exact requirements, especially for critical nutrients such as amino acids and phosphorus for monogastrics, were uncertain. This practice is currently known to be wasteful and also lead to the excretion of excess nutrients in manure, ultimately serving as source of environmental pollution [29].

After defining the nutritional needs of a group of livestock, next step would be to match these needs with the use of combination of ingredients and supplements to arrive in a balanced diet that provides appropriate quantities of biologically available nutrients, particularly for nonruminants. Thus, given the range of possible feedstuffs' proximate composition (as shown in **Table 6**), and the targeted dietary nutrient levels expected, a lot of calculations are then carried out to arrive at least-cost diets. However, over the years, feed formulation has evolved from a simple balancing of a few feedstuffs for a limited number of nutrients to a linear programming system that operates with the use of computers [29].

	Application	Examples	Functions
1.	Microbial proteins	Single-cell protein, multicellular (yeast protein)	To serve as new feed sources in the form of microbial proteins for livestock feeding
2.	Genetically engineered forage crops	Low phytate maize, high-oil maize	Reduce the levels of antinutrients in forages and other feedstuffs. Enhance nutrition
3.	Feed additives		
(a)	Crystalline amino acids	Methionine, lysine, threonine, tryptophan	Play vital role in improving protein utilization
(b)	Antioxidants	Butylated hydroxy toluene (BHT), butylated hydroxyl anisole (BHA), ethoxyquin	To prevent auto-oxidation of fats and oils in the diet
(c)	Antifungals	Aflatoxin	To control mold (e.g., *Aspergillus flavus*, *A. parasiticus*) growth in feed, to bind and reduce the negative effects of mycotoxins
(d)	Antibiotics	Avilamycin, virginiamycin, zinc bacitracin, avoparcin, tylosin, spiramycin	To control gram-positive, harmful bacterial species in the gut, improve production efficiency, used as a prophylactic measure against necrotic enteritis
(e)	Antibiotic replacers		
(i)	Probiotics	In-feed microbials	Source of beneficial microbial species such as *Lactobacilli* species and *Streptococci* species
(ii)	Prebiotics	Oligosaccharides	Renders harmful bacteria inactive

NB: The use of avoparcin, zinc bacitracin, spiramycin, virginiamycin, and tylosin phosphate as animal feed additives was banned in the European Union in 1998 and in 2006. The US, starting January, 2017, enforced a ban on the use of antimicrobials (antibiotics and antifungals) to promote food animal growth. Sources: [29, 32].

Table 7. Biotechnological and allied applications that are employed in livestock nutrition.

5. Some biotechnological and allied applications employed in livestock nutrition

Modern biotechnology has the potential to provide new methods for achieving enhanced livestock productivity in ways that could alleviate poverty, promote food security and nutrition, and also promote sustainable use of natural resources [4]. The applications of biotechnology in animal nutrition were reported [29] and are as summarized in **Table 7**. The author mentioned that there could be the formation of new ingredients such as single-cell protein and yeast protein, and the aim is to manufacture microbial proteins as new feed sources for animal feeding. These could also be included in the ration of livestock in order to upgrade the crude protein content of the ration.

Secondly, as outlined in **Table 7**, there could be the application of designer ingredients that could be applied in designing genetically engineered plants and forage crops, which are genetically modified using recombinant DNA technology with the objective of introducing or enhancing a desirable characteristic in the plant or seed used. This author [4] explained that transgenic forage crops are aimed at bringing about some benefits to consumers. Thus,

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when transgenic forage crops are first fed to ruminants, then the animal products to be consumed by humans from these ruminants are not themselves transgenic. This implies that food products derived from animals fed with transgenic forage crops are safer than when directly modified crops are consumed by humans. Also, in another research [30], it was demonstrated that the inclusion of genetically modified corn silage in dairy cows diets did not affect feed intake or milk production. The corn silage diet fed to the dairy cows was engineered with substantial improvements in their nutrient (proteins, amino acids, oils, fatty acids, starches, sugars, fiber, vitamins, minerals, enzymes) contents. The feed intake or milk production was not negatively affected, and there was absence of transgenic DNA in the milk harvested from these experimental cows. Thus, designer ingredients or plants (e.g., high oil maize) with genetic modification are made to enhance nutrition. There could also be designer ingredients (e.g., low-phytate maize) or forage crops engineered to reduce the level of antinutritive compounds, which occur in livestock feed ingredients. A researcher [5] reported that feeds derived from genetically modified (GM) plants (a quarter of which are now grown in developing countries), such as grain, silage, and hay, have contributed to an increase in livestock growth rates and milk yield. Also, genetically modified crops with improved amino acid profiles can be used to decrease nitrogen excretion in pigs and poultry. The author [5] explained that increasing the levels of amino acids in grains means that the essential amino acid requirements of pigs and poultry can be met by diets that are lower in protein content.

Other biotechnological applications of different classes of feed additives outlined in **Table 7** are the use of crystalline amino acids, antioxidants, antifungals, antibiotics, and different classes of antibiotic replacers. Feed additives may be added to the diet to enhance the effectiveness of nutrients, and they also exert their effects in the gut or on the gut cell walls of the animal [31]. They are used for the purpose of promoting animal growth through their effect in increasing feed quality and palatability. Besides, they are mixed with the feed in nontherapeutic quantities and thus protecting the animal against all sorts of harmful environmental stresses. Low levels of additives in animal feed may contribute to increased production of animal protein for human consumption and thereby decrease the cost of animal product. The use of avoparcin, zinc bacitracin, spiramycin, virginiamycin, and tylosin phosphate as animal feed additives was banned in the European Union in 1998 and in 2006 [29]. The US, starting January, 2017, also enforced a ban on the use of antimicrobials (antibiotics and antifungals) to promote food animal growth [32]. Envisaging a total ban on in-feed antibiotic use, a multitude of compounds (individually and in combinations) are being tested to serve as alternatives [29].

Probiotics are defined as feed supplements that are added to the diet of farm animals to improve intestinal microbial balance [33]. Thus, in contrast to the use of antibiotics as nutritional modifiers, which destroy bacteria, the inclusion of probiotics in feeds is designed to encourage certain strains of bacteria in the gut at the expense of less desirable gut microorganisms [4]. This researcher [4] also mentioned that probiotics could produce vitamins of the B complex and digestive enzymes, and the stimulation of intestinal mucosa immunity, by increasing protection against toxins produced by pathogenic microorganisms. Thus in ruminants, probiotics are effective in controlling the diseases of the gastrointestinal tract of young animals. It was found that in adult ruminants, yeasts could be used as probiotics to improve rumen fermentation [33]. The use of these feed additives may help to make animal products to be more homogenous and of better quality.

6. Practical application of biotechnology in monogastrics (poultry, pigs, and fish) and ruminants (cattle, sheep, and goats)

Biotechnology is offering a lot of opportunities for increasing agricultural productivity and for protecting the environment through the reduced use of agrochemicals [34]. Techniques of modern biology such as genetic manipulation of rumen microbes, and chemical and biological treatment of low-quality animal feeds for improved nutritive value among others have become a reality in the past few decades and are finding their ways into present research and development programs. These go along side with fleeting coverage of issues concerning the potential environmental hazards of genetic engineering and other biotechnologies, and the need for their ethical evaluation and for an international regulatory mechanism [34]. Practical application of biotechnology in monogastrics (poultry, pigs, and fish) and in ruminants (cattle, sheep, and goats) is hereby discussed below.

6.1. Practical application of biotechnology in poultry feeding

Nonnutritive feed additives such as the enzymes xylanases, β-glucanases, and phytates are used to overcome antinutritional effects in some grains and to improve overall nutrient availability and feed value. Antioxidants such as butylated hydroxyl toluene (BHT), butylated hydroxyl anisole (BHA), and ethoxyquin are used in poultry feeds to prevent auto-oxidation of fats and oils in poultry diets. Antifungals such as aflatoxins are added to poultry feed ingredients such as grains, groundnut cake, and cottonseed cake to control fungi growth in feed and to bind and reduce the negative effects of mycotoxins. Probiotics are used in poultry to encourage the growth of certain strains of bacteria in the gut at the expense of other less desirable microorganisms. Prebiotics (oligosaccharides) may function to bind harmful bacteria in the digestive system of poultry. In laying hens and broilers, research findings [35] showed that feeding recombinant DNA-produced crops and newly expressed proteins in genetically modified plants did not show chemical and physical properties different from those fed with native plants.

6.2. Practical application of biotechnology in pig feeding

In a research review article [36], it was reported that the quest to widen the narrow range of feed ingredients available to pig producers has prompted research on the use of low cost, unconventional feedstuffs, which are typically fibrous and abundant. Maize cob, a by-product of a major cereal grown worldwide, has potential to be used as a pig feed ingredient. Maize cob is usually either dumped or burnt for fuel. However, the major hindrance in the use of maize cobs in pig diets is their lignocellulosic nature (45–55% cellulose, 25–35% hemicellulose, and 20–30% lignin), which is not easily digestible by pigs' digestive enzymes. These researchers [36] explained that the high fiber in maize cobs (930 g neutral detergent fiber/kg DM; 573 g acid detergent fiber/kg DM) increases the rate of passage and sequestration of nutrients in the fiber, thereby reducing their digestion. The application of simple techniques such as grinding, heat treatment such as sun-drying, and fermentation can modify the structure of the fibrous components in the maize cobs and improve their utilization. Pigs could

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extract up to 25% of energy maintenance requirements from fermentation products. Also, dietary fiber improves pig intestinal health by promoting the growth of lactic acid bacteria, which suppress proliferation of pathogenic bacteria in the intestines.

In another journal article [37], it was reported that in growing pigs, the effects of four dietary levels of microbial phytase (Natuphos) enzyme on the apparent and true digestibility of Ca, P, CP, and AA in dehulled soybean meal were assessed. In the study, the researchers observed that supplemental microbial phytase did not improve the utilization of amino acid provided by soybean meal but was an effective means of improving calcium and phosphorus utilization by the growing swine fed soybean meal-based diets.

It was observed that in pigs, feeding recombinant DNA produced crops and newly expressed proteins in genetically modified (GM) plants showed no biologically relevant effects on feed intake, digestibility, or animal health [35]. Also, there were no unintended effects on the performance and fertility of animals. The food products obtained from the pigs fed with GM plants were of good chemical composition and quality.

6.3. Practical application of biotechnology in fish feeding

In a journal review article [38], it was reported that the use of probiotics in feed for fish and its inclusion in intensive aquaculture to promote healthy gut is growing. These researchers stated the need for alternative measures that will perform closely and effectively to the use of antibiotics after it was banned in the European Union (EU) in 2006. They stated that several definitions of probiotics mainly for aquaculture were considered. Among them is the definition that probiotics is described as "any microbial cell provided via the diet or rearing water that benefits the host fish, fish farmer, and fish consumer, which is achieved, in part at least, by improving the microbial balance of the fish." The authors regarded the direct benefits to the host fish as immunostimulants, improved disease resistance, reduced stress response, and improved gastrointestinal morphology. The benefits to the fish farmers and consumers include improved fish appetite, growth performance, feed utilization, improvement of carcass quality, flesh quality, and reduced malformations. It was explained that combining probiotics with prebiotics could improve the survival of the bacteria and enhance their effects in the large intestine [38]. Thus, probiotic and prebiotic effects might be additive or even synergistic (prebiotic is a nondigestible carbohydrate that helps to render harmful bacteria inactive).

6.4. Practical application of biotechnology in ruminant feeding

Globally, food-producing animals consume 70–90% of genetically engineered (GE) crop biomass. Furthermore, many experimental studies have revealed that the performance and health of GE-fed animals are comparable with those fed isogenic non-GE crop lines [39].

In a mini review article [40], it was reported that probiotic live cells with different beneficial characteristics have been extensively studied and explored commercially in many different products in the world. Their benefits to young ruminants have been supported in several scientific articles. These benefits include enhanced development of the rumen microflora, improved digestion, and nitrogen flow toward lower digestive tract and improved meat and milk production during the adult stage of the ruminant. The author reported that in order to attain higher profit margin in intensive small ruminant production, farmers are now shifting from traditional to high input feeding systems. He explained that in order to harvest real benefits from small ruminants, which are raised on nutrient-rich diets, feed additives like probiotics are needed to be used to enhance the efficiencies of nutrient utilization in growing ruminants. Thus, the more feed an animal consumes each day, the greater would be the opportunity for increasing its daily production. Probiotic supplementation was found to increase feed intake and to influence performance of ruminants [40]. Also, the use of probiotics in a healthy animal stimulated nonspecific immune response and enhanced the system of immune protection. The probiotic that enhanced immunoglobulin level may have more positive effect on growth performance, production, and ability to resist diseases. Examples of probiotics suggested were those containing *Lactobacillus plantarum* (which breakdown carbohydrates into glucose) and *Aspergillus oryzae* (which produce enzymes that are involved in the digestion of carbohydrates and fiber) [40]. Some other researchers [41] observed that the addition of probiotic containing yeast in supplemental diet enhanced growth performance and immune response of Zandi lambs. Another study was conducted that involved a 765-day trial [42]. This trial included two lactations, using nine primiparous, and nine multiparous dairy cows. The experimental cows were fed diets containing whole crop silage, kernels, and whole crop cobs from GE corn and its isogenic non-GE counterpart. There were no significant differences in the gene expression profiles of the cows fed either the transgenic or the near-isogenic rations [42]. Similarly, dairy cows, beef cattle, and other ruminants were fed recombinant DNA-produced crops and newly expressed proteins in genetically modified plants (GMP) [35]. There were no unintended effects in composition and contamination of genetically modified plants compared with isogenic counterparts. Rather, there were lower mycotoxin concentrations in GMP with *Bacillus thuringiensis* (Bt) [35].

6.5. The European Union requirements for the assessment of probiotics or microbial feed additive usage

The following guidelines of usage should be followed: the identity of the product (proposed proprietary name) should be stated. There should be characterization of the active agents (nomenclature, biological origin, genetic modification, compliance with released directive for genetically modified organisms (GMOs), toxin production, virulence factors, antibiotic production and antibiotic resistance, and other relevant properties). Then, the conditions for the usage of the microbial feed additive should be given [43].

Safety guidelines under the conditions for use: there should be performed a detailed safety assessment.

Studies on target species: studies should be carried out on target species or animals of different categories to determine the safety margin for each species. The aim of this trial is to evaluate for the target animal the risk of an accidental overdosing that could originate during feed production (mixing heterogeneity). This trial shall be conducted at a dosage being at least

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10-fold the maximum recommended dosage. Studies on the effect of the microbial additive on the microflora of the digestive tract are also required when claim is made concerning an effect on the intestinal microflora.

Consumer safety assessment: certain toxicological tests are required to be performed to exclude the possibility that when the probiotic product or microbial additive is accumulated in the target animal, it will not form a consumer risk. The test includes both genotoxicity studies (a metaphase cytogenetic assay and other *in vivo* and *in vitro* studies) and oral toxicity test (a 90-day in-feed or drinking water).

7. The application of nanotechnology in livestock nutrition and feeding

Nanotechnology is described as the study of materials at the nanoscale, with at least one dimension generally ranging between 1 and 100 nm (10^{-9} to 10^{-7} m) [7]. Nanomaterials are best referred to as particles. There are three basic systems of nanoparticles in their applications; that is, nanoparticles can serve as a whole functional unit, or as a delivery vehicle for materials conjugated to their surface, or as encapsulated within. The application of nanotechnology in animal production is new as production in livestock industry has been centered on the use of antibiotics as growth promoters [7]. However, there has been much anxiety globally over microbial antibiotic resistance, and laws and regulations are being updated to ban in-feed antibiotic use in the livestock production industry. This has thus set in motion the search for alternatives for animal growth promoters and antimicrobials for inclusion in animal diets. Nanoparticles may present a feasible alternative to antibiotics and may help bar pathogens from entering animal production sites. Metal nanoparticles with net positive charges are drawn to negatively charged bacterial membranes, resulting in leakage and bacterial lysis [44]. There has been the discovery of the use of nanoparticles for nutrient delivery into livestock feeds. Copper is regularly added to feeds for its ability to promote animal growth and performance in addition to its antimicrobial properties [45]. In another research [46], it was demonstrated that nanoform copper could better improve piglet energy and crude fat digestion through the augmentation of lipase and phospholipase A activity in the small intestine compared to a basal diet supplemented with copper sulfate ($CuSo_4$). However, further investigations need to be done to ascertain whether antibiotics in feed can be completely replaced by nano-antimicrobials. Also, despite the expansion of antibiotic resistance in bacteria, antibiotics have not yet been rendered totally ineffective. However, their delivery and efficacy may be enhanced by nanoparticle carriers, and thus substantially decreasing the dosage of antibiotics required for treatment. Thus, it was stated that the inclusion of nutrient supplements in livestock feed, regardless of particle size, may benefit the producer if there is still consumer demand for the final product [7]. These authors [7] further explained that if for example, meat and eggs obtained from an animal fed nanoparticle supplements are enhanced and are indiscernible from the original product, then they are likely to still be favorable to consumers. These researchers mentioned that it is, however, important to understand the role of the nanoparticle as an additive in a given biological system and the by-products from that system and to ensure that it is safe for consumption before its application in livestock production.

7.1. Future prospects

As nanotechnology continues to develop and gain more attention, its application would grow wider in the livestock industry [7]. Thus, nanoparticles may have to be used alongside the use of antibiotics until it gains more understanding and global acceptance.

8. Conclusion

In conclusion, continuous provision of adequate quantity and quality of nutritious feeds for livestock is necessary to sustain the livestock industry. This is not negotiable now that human population is growing exponentially in the twenty-first century. The adoption of new biotechnological applications and biosafety in livestock nutrition and feeding systems is necessary in order to promote improvements in current and future global livestock production. The main cost of livestock production is on the production of concentrate feeds. Alternative feed resources should be properly utilized, and low nutrient quality feeds should be improved upon by the use of various technologies, for better utilization by livestock. There could be the optimizing of production of high-quality forages such as genetically engineered forages with high nutrient contents and genetically manipulated for more digestible cell wall components. Generally, focus could be directed at meeting the nutritional requirements of livestock through biotechnological applications. In the developing countries, particularly during the dry season when forage is scarce, there could be the substitution of forage with nutrient detergent fiber (NDF-)rich feeds and feedstuffs. These may include crop residues, agroindustrial by-products and other feedstuffs that are of little or no value in human feeding. There could be the development of carefully balanced partial or total mixed rations.

Meeting the nutritional need and varied dietary preferences of the growing global population is also needed. This could be addressed through continuous development of better quality feeds for quality livestock products and by-products. The adoption of new biotechnological applications and bio-safety in livestock nutrition and feeding systems is necessary in order to promote improvements in current and future global livestock production. There should be the development and use of biologically safe animal feeds for the production of economically viable and safe animal products. Therefore, the production of feed ingredients that would be affordable for livestock producers with minimum use of chemical additives and use of locally available feed resources is paramount.

Future improvements in livestock feed resources could be based on the application of biotechnology such as use of safe antibiotic replacers. Probiotics and prebiotics could be employed to improve animal performance. The risks that may be involved in the use of antibiotics and the development of antibiotic resistance in livestock and in humans should be kept at minimum levels. These could be checked through continuous enforcement of guidelines in the use of feed additives and microbials. Further expectations about the future improvement in livestock feeding could involve the application of nanoparticles in livestock feeds and feeding to enhance animal nutrition, growth, and performance. The biosafety of the use of nanotechnology, however, needs to be ascertained. Possible risk control in the application of microbials and nanotechnology could include continuous monitoring and control of biological and environmental safety, in terms of guarding against the re-emergence of livestock and human diseases and antibiotic resistance through the livestock feed industry.

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