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Advances in Poultry Nutrition Research-A Review

Herbert Kwabla Dei

Abstract

Poultry production involving farmed avian species (chickens, turkeys and ducks) is globally recognised as a vital aspect of animal agriculture. It contributes greatly to supply of high-quality protein (meat and egg) for humans. The intensification and commercialization of the poultry sector is accelerated and continues to be so as a result of research discoveries in the field of breeding, nutrition, housing management and disease control. However, the explosion in poultry nutrition research, in particular, has significant impact on the success of the poultry sector. The progress in nutritional research is made possible by several advanced techniques reported by researchers in both academia and industry. Nutritional research is mainly geared towards improving knowledge on ingredients good for the growth and health of the bird and of nutritional requirements for various types and classes of birds, as well as the ability to match nutritional requirements of any type or class of bird for variable conditions including that of the environment. This chapter discusses the importance and growth of the poultry sector. Also, nutritional research efforts over the years, achievements, some notable advance research techniques employed, and challenges confronting nutritional research in the 21st Century have been highlighted.

Keywords: poultry, nutrition, research, advanced techniques, review

1. Introduction

Globally, poultry (avian species such as chickens, turkeys, ducks and guinea fowls) production is an important aspect of the animal agriculture. It is undeniable fact that the intensification and commercialization of the poultry sector is accelerated by research discoveries in the field of breeding, nutrition, housing management and disease control. That is to say, the success of the poultry sector is underpinned by considerable research efforts over the years through application of scientific innovations. These research efforts were largely geared towards the following: improving genetic strains specialised for food use (meat and eggs) and regional conditions; improving knowledge of nutritional requirements and ability to match these for variable conditions; and ensuring stable environment for growth and production. These research efforts are still ongoing in the light of new challenges facing the animal industry in terms of birds' welfare and issues of environmental pollution as well as consumers' concerns of food quality and safety.

So far, the objectives of nutritional research include selecting ingredients good for the growth of the bird, enabling conditions for the bird to express its full genetic potential, eliminating certain disease conditions, reducing the cost of production,

maintaining product quality and allowing for partial alleviation of the adverse effects of environmental factors. Thus, advances in nutrition research are crucial if the poultry sector is to continue to play a major role in animal protein food production in meeting the needs of ever-increasing world population.

This paper discusses the importance and growth of the poultry sector as well as highlights the nutritional research efforts over the years, achievements, some notable advance research techniques employed, and challenges confronting nutritional research in the 21st Century.

2. Importance and growth of the poultry sector

Poultry meat and eggs are cherished worldwide and consumed in various forms. They are proteins and a source of essential micro-nutrients such as vitamin A, vitamin B₁₂, riboflavin, calcium, iron and zinc [1]. Therefore, they are important in human nutrition and health.

Both the meat and eggs are produced in large quantities all over the world for food and income. As such, the poultry sector is one of the leading suppliers of meat worldwide [2]. So much income can be derived from poultry products. For example, America which is the world's leading producer of poultry in 2017, had its combined value of poultry meat and eggs up to the amount of \$42.7 billion [3]. Besides, poultry products are generally cheap, making them affordable for low-income earners in both developing and advanced countries.

In fact, the poultry sector has the potential to grow faster as a result of enabling factors such as population growth, breeding of highly-productive strains of meat- and egg-type birds, improvements in consumers' incomes, and modern technologies for processing feed/poultry products. However, the cost of feeding poultry is a major factor controlling the push for more incomes by farmers [4].

3. Overview of poultry nutrition research and development

Research involving avian species such as chickens, turkeys and ducks in the early 1900's appeared to be limited in scope (e.g. native birds) and unstructured. However, by the middle of 1900's, there began a surge in research with a structured approach in all aspects of production with greater focus on nutrition [5]. Nutritional science is one that looks at the biological sum of processes that occur before and after food intake as they relate to growth, development and health maintenance [6]. Thus, nutritional science relies very much on the other sciences (chemistry, physics, immunology, biochemistry, behavioural sciences, physiology, microbiology, molecular biology, statistics, genetics and food science) and often studied in an integrated way; since it is not a pure science but draws extensively on these root disciplines. Also, nutrition is complex; therefore, nutrition research requires sophisticated designs and analytic capabilities that can be addressed in an interdisciplinary and multidisciplinary manner.

In terms of progress made in poultry production, it has been reported that research in genetics contributed more than nutrition. For instance, genetics accounted for 85–90% of the change in growth rate of broilers and turkeys over the past 50 years, whereas 10–15% was attributed to advances in nutrition and management [5]. **Table 1** [7] shows some dramatic successes chalked over the years through poultry genetic research. However, the realisation of the genetic potential of birds,

Avian specie	Trait	Performance level		
		1960	2005	Δ (%)
Broiler chicken	Number of days until 2 kg	100	40	60
	Kg feed per kg live weight	3.0	1.7	43
Layer chicken	Number of eggs per year	230	300	30
	Number of eggs per tonne of feed	5,000	9,000	80

Table 1.
Increase of genetic potential with consequent superior efficiency of poultry production.

increased productivity, and decreased susceptibility to disease depend on appropriate nutrition. Hence the relevance of nutritional research.

The phenomenal progress in the poultry sector brought about by scientific researches is achieved through the concerted efforts of researchers in both academia and industry. The academic community comprises centres of higher learning such as universities and national research institutions, while the industrial community consists of the private sector including commercial breeding and development companies. The academic community is primarily involved in basic research by exploring new grounds, which enable building of a storehouse of pertinent knowledge; and applied research for direct application to the industry; whereas the industrial community takes their experimental procedures into the realm of industrial application to build a business.

The nutritional research focus in both academia and industrial sector over the years has been changing in response to challenges that faced poultry production in terms of output, economic, environmental and consumer demands. The nutritional research focus in the 1950’s to 1980’s was on production efficiency with the whole animal in mind; and then, there was a shift in research focus between 1990’s and today to maximisation of biological and economical performance with regards to the whole animal or selected organs and tissues [5]. Also, there has been more integration of nutrition with other disciplines such as microbiology and nano technology. In fact, prevailing challenges in the poultry sector suggest that future research focus will be more about efficiency of meat/egg production, meat/egg quality and safety for human consumption, feed efficiency to reduce environmental pollution and health and welfare of birds [5].

Some spectacular research successes in nutrition have been documented [4, 5] as shown in **Table 2**.

Research Period	Achievements
1900–1910	• Emergence of the notion of a ‘vitamin’ to define secondary dietary factors
	• Discovery of Vitamin and its relationship with carotene
1910–1920	• Discovery of calcium and phosphorus requirements for the young chick and laying hen
	• Distinction between water and fat soluble Vitamin A
	• Lysine recognised as being essential to the growth of young chicks
1920–1930	• Vitamin D recognised as the active factor in cod liver oil
	• Existence of many vitamins within the B group postulated

Research Period	Achievements
1930–1940	<ul style="list-style-type: none">• Discovery of riboflavin a the active factor in milk products necessary to prevent the condition of ‘curled toe’ in young growing chicks• Concept of calcium: phosphorus balance• Discovery of vitamin K• Perosis caused by manganese deficiency• Isolation of vitamin B1 (thiamine)• Initiation of work on improvements to soya bean meal and its use in animal feeding• Discovery of threonine as the latest essential amino acid• Development of the use of fishmeal• Isolation of pantothenic acid• Synthesis of pyridoxine (vitamin B6)• Sale of synthetic riboflavin, niacin, vitamin E, vitamin K, choline and biotin
1940–1950	<ul style="list-style-type: none">• Evidence of biotin deficiency• First definitions of biotin requirements of poultry• Development of pelleting of feeds• First tables from National Research Council (NRC)• Estimations of vitamins and amino acids through microbiological techniques• Sale of synthetic methionine• Discovery of folic acid• Sale of synthetic vitamin A• Appearance of first effective coccidiostats• Formulation of energy rich diets for broilers• Discovery of cyanocobalamin (vitamin B12) previously referred to as ‘animal protein factor’
1950–1960	<ul style="list-style-type: none">• Development of Near Infrared Reflectance Spectroscopy (NIRS) for feed analysis• Vitamin and mineral requirements• Nutrient content of feedstuffs• First use of antibiotics in poultry production• General use of synthetic methionine• First use of analogue computers in diet formulation on the basis of ‘least cost’ (optimisation routines)• Discovery of zinc as a trace element for poultry• First commercial sale of lysine of industrial origin• General use of the concept of metaboilsable energy in poultry production
1960–1970	<ul style="list-style-type: none">• Amino acid content of feedstuffs• Dietary amino acid requirements• First use of linear programmes for diet formulation on personal computers• First commercial sale dwarf breeders

Research Period	Achievements
1970–1980	<ul style="list-style-type: none">• Refinement of nutrient requirements in terms of their digestibility in feedstuffs• Identification of mycotoxins and their dietary tolerance limits• Development of feed additive: antibiotics, growth promoters and coccidiostats• Prediction equations for requirements• Modelling of requirements of poultry• Development of true digestibility in poultry• Nutrition of secondary species (turkey, guinea-fowl, duck)• Routine use of NIRS for the rapid analysis of raw materials
1980–1990	<ul style="list-style-type: none">• Computerised least-cost feed formulation• Understanding anti-nutritional factors in feedstuffs• Use of supplemental enzymes• Development of the ideal protein concept and formulation for digestible nutrients, and the absorption and utilisation of nutrients• Commercial sale of synthetic tryptophan and threonine
1990s until today	<ul style="list-style-type: none">• Use of statistical packages (SAS, GENSTAT, etc) to ease computational burden of large data and accurate estimation of production performance, growth, and feed consumption• Complex modelling for biological and economic performance• State-of-the-art technologies for weighing feed and birds, feed evaluation, meat processing, etc.• Non-intrusive ultrasound technology to assess breast meat yield of live bird• Lixiscope that uses x-ray to safely detect and identify Tibia Dyschondroplasia (TD)• New and advanced microscopy techniques

Table 2.
Nutritional research achievements through the years.

4. Advances in nutritional research

Over the years, researchers have improved or introduced new research techniques in their quest to obtain valid data or keep pace with new challenges confronting the poultry sector. In this section, I will attempt to discuss some of the advances made in poultry nutritional research with the aim of improving productivity and quality of meat/eggs, welfare of birds as well as environmental sustainability. These include modern techniques for feed analysis and nutritional experimentation involving novel feed ingredients and/or feed additives, nano-minerals, mineral toxicity as well as dietary management strategies to curtail problems and constraints of avian health and environment.

4.1 Feed analysis

The surest way of meeting the nutrient requirements of birds is having adequate knowledge of nutrient contents of various feedstuffs available. This requires feed analysis with regards to nutrient composition and anti-nutrient contents. There

have been advanced techniques employed over the years which give true reflections of chemical composition of feedstuffs that enables nutritionists to be able to accurately formulate diets for all types and classes of poultry. These include improved methods for determination of dry matter, proteins, carbohydrates including fibre, fats/oils and macro-and micro-minerals as contained in the official Methods of Analysis (2019) and published by the Association of Analytical Chemists (AOAC) International [8]. These techniques not only determine the true content of feedstuffs but also saves time and amounts of samples to be analysed as well as minimum operator training. Examples are vacuum-oven drying/toluene distillation of high fat feeds for moisture determination; Automatic Kjeldahl Analyser/Dumas technique (LECO)/Amino Acid Analyser for protein determination; Megazyme enzyme kit for starch determination in cereals; Rose-Gottlieb/Soxhlo method for fat determination; Fibre Analyzers for determination of acid detergent and neutral detergent fibres, and the use of Inductively coupled plasma optical emission spectrometry (ICP-OES) analyser for determination of several minerals at the same time; Near-infrared spectroscopy (NIRS) technique for determination of moisture, crude protein, metabolisable energy and digestible amino acids of whole feed sample [8].

The presence of anti-nutritional factors (ANFs) in feedstuffs compromise the potential nutritional value of feedstuffs for poultry. Some have detrimental effects on the health of birds. Thus, identification and quantification of anti-nutrients in feedstuffs through advances made in feed analysis has improved nutritional value of hitherto inedible plant products into useful feedstuffs. For instance, the identification and subsequent elimination of trypsin inhibitors in soybean improved its feed value for poultry substantially. Examples of analytical methods for detecting ANFs are as follows: Yb-precipitation/Vanillin-HCl/4-dimethylamino-cinnamaldehyde (DMACA-HCl)/BSA/PEG/mass spectrometry methods for determination of tannins; High-performance liquid chromatography (HPLC)/Acid-base titration/acid dye colorimetry for determination of alkaloids; and ELISA methods for determination of mycotoxins [8].

4.2 Feed formulation

Feed formulation is crucial in meeting nutrient requirements of poultry. This aims at avoiding excess nutrient supply as much as nutrient deficiency. Advances in this regard are made possible by computer software developers. Prominent among poultry feed formulation software is the Least-Cost formulation software. It is helpful in formulating high-quality diets for different types and classes of birds at a low cost. Generally, feed cost constitutes more than 60% of poultry production cost [9]. Therefore, use of this advance technique in diet formulation greatly reduce the cost of feeding birds; which may account for affordability of poultry products.

The most valuable advance technique in poultry nutrition is the use of the NIRS technology [10–12]. Apart from accurately predicting the chemical composition of raw feed ingredients and feeds, this technology enables the farmer to rapidly measure metabolizable energy (ME) and digestible amino acid (DAA) in real time (or near real time) for major feed ingredients [13–15]. ME and DAA are the main dietary components considered in poultry feed formulation. The actual ME and DAA contents of feed ingredients (e.g. different geographical locations or batches) could vary substantially from the specifications setup (matrix) in the feed formulation software leading to formulation errors. This technology is used to enhance precision feed formulation in relation to ME and DAA. The results can be obtained immediately after NIRS scanning of feed ingredients. Although NIRS equipment is expensive, all other costs to implement the technology can be reduced.

4.3 Feed utilisation

Effective means for dietary feed to be quantified and prepared is to perform studies of digestibility and bird growth efficiency studies. This helps in feed quality assessments. Advances made with respect to determination of feed utilisation are ever-evolving. These include: Growth assay technique, *In vivo* and *In vitro* digestibility techniques, Inert marker technique, Caecetomy and Ileotomy techniques and Ileal assay technique [16–19]. The advantages of these techniques among others are high precision data, reduction in duration and cost of experimentation, less labour-intensive, use of small feed samples, avoid use of live birds for experiments, and rapid routine feed quality assessments.

4.4 Use of novel feed ingredients

Traditionally birds are grain feeders; however, with advent of industrial processing of food for humans, a lot of by-products have been generated and research extensively for poultry feeding [20–22]. These include cereal offals, oilseed meals, brewer's dried grains, distillers dried grain with solubles (DDGS), etc. Besides, through research, lesser used feedstuffs such as barley, rye, sorghum, cassava and grain legumes are increasingly being processed for feeding [23–28]. Furthermore, other plant resources in the wild such as false yam [29] and forages [30] are being harnessed for feeding due to advances in feed processing technologies and analytical tools. The essence of using these novel feed ingredients is to serve as alternatives for conventional feed ingredients such as maize (*Zea mays*) and animal proteins (e.g. fishmeal, meat and bone meal). This is aimed at reducing feed cost or curtailing dependency on these conventional feeds, particularly in developing economies.

4.5 Use of feed additives

Feed additives are employed in poultry diets in order to improve digestive efficiency. As a consequence, poultry productivity is enhanced. Nutritional advances in feed additives include enzymes, synthetic amino acids, commercial preparations of vitamins/trace minerals, probiotics, prebiotics and toxin binders among others.

Feed enzymes are commercial enzyme products aimed at augmenting the endogenous enzymes secreted in the gut of birds when fed in the diet so as to improve availability of nutrients. Researches on enzyme usage is necessitated by wide use of vegetable proteins (e.g. legumes and oilseed meals) and some cereal grains in poultry diets.

The use of vegetable proteins was in response to a total ban on the use of animal protein sources in feeds by the European Union [31]; which hitherto was the main protein source in poultry diets due to their high digestibility. However, these vegetable proteins are characterised by high levels of anti-nutritional factors such as indigestible non-starch polysaccharides, phytic acid, tannins and alkaloids; which affect utilisation of nutrients.

Besides, some feed grains such as wheat, barley, sorghum and rye contain appreciable amounts of soluble non-starch polysaccharides that can cause very viscous gut content. Hence, the advances made in feed enzyme research culminated in the use of feed enzymes to depolymerise the soluble and insoluble pectic polysaccharides [32, 33] as well as hydrolyse phytates [34] in diets containing high levels of vegetable proteins and some cereal grains. In fact, feed enzymes prevent severe imbalances of nutrients that can remain undigested and reach the large intestine; thereby creating favourable environment for pathogens and consequent disease conditions. A good number of studies involving enzymes in poultry nutrition has

been reviewed which have demonstrated improvements in feed utilisation with enzyme supplementation [35–37].

Additional beneficial effects of feed enzymes, particularly phytase, in cereal and oilseed-based diets include the following: release of digestible phosphorus to reduce the use of expensive supplemental inorganic phosphorus (e.g. dicalcium phosphate); release of minerals such as calcium, magnesium, zinc and potassium which are complexed with the phytate molecule; and prevent excessive excretion of phosphorus in manure into the environment [34].

The bird's gut microbial ecology has implications for feed digestion and disease control. This has to do with maintenance of natural balance of beneficial and pathogenic microorganism populations in the gut. Thus, the use of antibiotics previously as feed additive tended to cause imbalance between these two groups of microbes by eliminating largely the beneficial microbes as well as cause meat contamination and resistance problems in humans [38, 39]. Hence, the introduction of probiotics/prebiotics/synbiotics (combination of pro-prebiotic) as replacement for antibiotics.

Probiotics are a culture of live microorganisms. The probiotic product may contain microbes such as *Aspergillus oryzae*, *Lactobacillus acidophilus*, *L. bulgaricus*, *L. planetarium*, *Bifidobacterium bifidum*, *Streptococcus lactis* and *Saccharomyces cerevisiae*. Some of the commercially available probiotics for poultry are Bactocell®, BioPlus 2B®, Cylactin®, *Lactobacillus acidophilus* D2/CSL®, Microfern®, Oralin®, Protexin® and Thepax®. These products promote growth of beneficial microbes which competitively exclude the pathogenic microbes [40] and may as well secrete enzymes which aid digestion of feed.

The use of prebiotics in animal nutrition post-dated probiotics with favourable effects on poultry health and meat quality [41, 42]. It has been defined recently as “a non-digestible compound that, through its metabolism by microorganisms in the gut, modulates composition and/or activity of the gut microbiota, thus conferring a beneficial physiological effect on the host” [43]. Commonly used prebiotics are mannanoligosaccharides (MOS), fructooligosaccharides and inulin. Generally, prebiotic products are resistant to attack by endogenous enzymes and therefore reach the site for proliferation of gut microorganisms, where they interfere with colonisation of the pathogenic microbes and thereby exclude them [44].

Inclusion of synthetic essential amino acids in poultry has been on the rise as a result of improving efficiency of protein utilisation. This is in line with current trend of formulating diets based on digestible amino acids in order to reduce amount of dietary protein [45]. These are DL-Methionine, L-lysine HCl, L-Threonine and L-Tryptophan. Initially, the idea was to meet first-limiting amino acids (Lysine and Methionine) requirements for poultry; however, with the need to further reduce dietary protein requirements as well as reduction in nitrogen excretion, this calls for increased use of second and third limiting amino acids such as L-Threonine and L-Tryptophan as well as the next limiting amino acids including Isoleucine, Valine and Arginine [45–48].

Advances in dietary supplementation with vitamins (water/fat soluble) and trace minerals (Zn, Cu, Mn, Se, Co, Fe) continue to be made and have brought about improvements in feed utilisation, growth performance and welfare of birds [49]. Vitamins and trace mineral supplements are vital feed additives aimed at supplying sufficient amounts that meets the needs of the biochemical systems of the cells of birds culminating in varied benefits. These benefits include enhanced mineral uptake, improved immune system, proper tissue and bone development, cellular growth as well as amelioration of oxidative stress in birds [49].

The use of toxin binders in poultry feeds has counteracted problems of mycotoxins associated with cereal grains [50, 51].

4.6 Use of nano-minerals

The use of nano-minerals in poultry nutrition is a recent concept that is gaining grounds as a result of varied application of nanotechnology in animal production systems. This has to do with alteration of particle size to few nano meters (1–100 nm) and studies reviewed so far have proved that feeding of nanoparticle improved digestive efficiency, immunity, growth rate, performance, resistance to pathogens, quality of meat and eggs in birds [52, 53].

4.7 Combating metal toxicity

Several researches have highlighted the problems of metal toxicity in poultry; which led to the establishment of nutritional guidelines on safety levels to protect both birds and humans from metal toxicity [54]. Nutritionally beneficial ones for good health but whose dietary excesses create health problems include iron, copper, manganese, zinc, etc.; whereas poisonous ones which may contaminate feeds from the environment include arsenic, mercury, lead, cadmium, vanadium, etc. [55, 56].

4.8 Production of designer eggs

Studies on dietary modification have played a major part in the production of nutritionally-improved eggs referred to as “Designer Eggs”. By way of nutritional manipulations of the cholesterol content and its fractions, lipid profile, fatty acids, amino acids and minerals can be modified to produce healthy eggs for humans [57]. This can also be done through addition of therapeutic pharmaceutical compounds [57].

4.9 Nutritional management, gastro-intestinal tract conditioning and poultry health

It's undeniable fact that achievement of productive efficiency can only be attained through nutrition if and only if the health status of birds is not compromised. Therefore, current nutritional researches are geared towards optimising poultry health and consequently their welfare. Some of these nutritional strategies with positive impact on poultry welfare have been reviewed extensively [58]. They include: manipulation of diet composition (e.g. dietary ME/CP as a way of controlling the body composition to prevent body fatness of market broilers or fatty liver haemorrhagic syndrome in layers); addition of essential fatty acids such as linoleic acid and linolenic acid to prevent lesions or supplemental fats/oils to increase dietary ME values; use of calcium and phosphorus (an approximate ratio of 2: 1), or vitamin D to prevent bone problems such rickets and tibial dyschondroplasia or cartilage abnormalities that can lead to welfare problems such as osteomyelitis and femoral head necrosis; use of major supplemental mineral like sodium/vitamin and trace mineral supplements to boost normal health and/or under adverse conditions; use of feed additives such as enzymes and probiotics discussed above (Section 4.5) to improve feed efficiency with added advantage of less sticky excreta (better litter quality with less incidence of hock burns) and control of disease causing organisms, respectively; dietary modifications to help birds cope with stress, particularly under hot climatic conditions (e.g. decreasing crude protein content, use of synthetic amino acids to increase amino acid intake, use of fat to help decrease heat increment, use of sodium supplement as bicarbonate for maintenance of blood electrolyte balance, use of vitamins such as vitamins C, E and A to help in heat and other types of stress); and physical manipulation of feed such as mash feeding and feed restriction to control growth for maintenance of good health (e.g. lower mortality, reduction in metabolic disorders, improved walking ability).

5. Future nutritional research focus

Advances in poultry breeding, emergence of new feed resources, consumer demands and climate change as well as environmental concerns have implications for future poultry nutritional research. Thus nutritional research focus, henceforth, will be influenced mostly by the following innovations:

- Feed formulation softwares and feeding programmes
- Novel feed ingredients and feed additives
- Gastro-intestinal conditioners for gut health, birds' welfare and food safety
- Modern technologies for feed processing and feeding packages
- Perinatal nutrition and epigenetic programming

6. Future research funding

A balance should be maintained between a long-term and short-term research funding. Critical challenges needed to be addressed include the following:

- Scarce research funds, particularly in developing countries
- Prioritisation of limited research funds for nutritional research
- Basic research is relatively expensive and may hamper research in developing countries
- Diversion of research funds away from researches already conducted in developed countries that are relevant for application in developing countries
- The emergence of new demands from consumers, new disease situations, requirements to thrive on different feeding programmes and environmental conditions, have created new avenues for future research
- In-country competitive research funds (i.e. coordination of research at a national level to avoid multiplicity of similar research)
- Animal welfare (e.g. hot climate, dietary manipulation, growth rate, etc.)
- Food safety [e.g. mineral residues, pathogens (*Salmonella*, *E. coli*, *Campylobacter*, etc.)]
- Limitation (in use of antibiotics)
- Disease risks
- Competition between poultry and humans for feed ingredients (e.g. maize)

7. Conclusions

Nutritional research has contributed significantly to poultry production over the years. Its role in the poultry sector is more crucial than ever before in sustaining progress made in the sector as world population continues to increase at alarming rate. The progress in nutritional research is made possible by several advanced techniques that have been developed and tested by numerous researchers both in academia and industry. The appropriateness of any techniques to be used depends on the facilities available at the research site and the cost involved. Also, there is a need to maintain balance between research that may have future usefulness (fundamental research) and that which may be used immediately (applied or practical research) through application of scientific innovations. In future, nutrition objectives will require scientists to use extensive interdisciplinary approaches.

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