

Importance of Animal Agriculture for Human Health and Well-being

Planet Earth is endowed with several million animal species. Domesticated animal-farming provides food (milk, meat, eggs), materials (wool, hide) and work (draught) that are of ultimate use for human welfare. Animal agriculture plays an important role in providing high-quality complete protein, and the consumption of high-quality animal protein and other nutrients plays an important role in the well-being of consumers for their growth, development and health. Especially, the demand for animal-sourced proteins are expected to increase tremendously (in view of ageing population) for supporting optimal human growth and mitigating sarcopenia in the elderly (meat is an excellent source of quality protein: 17–20% in chicken, mutton and beef; 11–15% in pork). Thus, animal agriculture plays an important role in providing animal-sourced food as part of a healthy diet for humans and other consumers, while contributing to scientific, economic and social developments worldwide (Wu 2022). This chapter is written lucidly (hopefully) for lay readers to understand science on meat consumption comprehensively as well as in a comprehensible manner without scientific jargon and nuances of scientific writing.

ANIMAL NUTRITION AND THE CONSUMERS OF ANIMAL PRODUCTS

Farm animals (pregastric as well as postgastric fermenters), especially ruminants, have inherent capacity (due to the microbial fermentation in their digestive tract) to convert the low-quality feedstuffs and forages into high-quality protein and highly bioavailable minerals in the diet of humans and other consumers. For this transformation to happen efficiently, they need to be fed as per their dietary requirements for nutrients such as energy, amino acids, lipids, carbohydrates, minerals, vitamins and water in their different life stages. Thus, farm animals are biological transformers that convert materials not consumed by humans into high-quality foods. Hence, adequate nutrition of farm animals is crucial to showcase their productivity potential as per genetics and sufficient provision and optimum utilisation of dietary AAs and other nutrients need to be ensured in their daily ration for production of proteins.

Animal products including fish are used principally as food for human beings and also used to feed other animals, while the byproducts of the egg and meat industry

are primarily used to feed companion animals (cats and dogs) and to a little extent in the diets of farm animals (e.g. meat and bone meal). The necessity for healthy companion animals don't need emphasis as they contribute to the well-being of their owners. Milk byproducts are used to make milk replacers for young animals reared away from their mothers.

THERE IS A CLOSE LINK BETWEEN ANIMAL AND HUMAN NUTRITION

As mentioned earlier, animal proteins are complete proteins and meet the needs of amino acids for human consumption. Further, animal-sourced foods provide nutrients that are absent in plant-sourced-foods. These include: (1) several unique nutrients such as taurine, carnosine, anserine and creatine (antioxidant nutrients), (2) nonproteinogenic nutrients that possess antioxidative properties and are crucial for energy metabolism in tissues, and (3) animal products are sources of highly bioavailable essential minerals such as iron, zinc, copper, manganese and selenium and vitamins.

Because of the unique source of animal products, it is paramount to feed animals well and improved animal nutrition can enhance the quality of foods for human beings and other consumers. Further, wool (textile fibre; cysteine-rich α -keratin proteins) produced by sheep and other animals (including cashmere and mohair from goats) is used to manufacture clothes and related daily life products. This indicates a close link between animal and human nutrition.

CONTRIBUTION OF ANIMAL PRODUCTS TO HUMAN REQUIREMENTS

The contribution of animal products to world food supplies is summarised in Table 1.1. In general, as people get richer, they tend to increase their consumption of animal products because of their richness in nutrients and taste as well as texture, while vegetable diets are often considered as bland and unexciting. Meat and milk consumption in selected countries are furnished in Table 1.2 and contribution of animal

Table 1.1: Contribution of various food groups to world food supplies (FAO)

<i>Food group</i>	<i>Energy (%)</i>	<i>Protein (%)</i>
Cereals	47	43
Roots, tubers and pulses	7	10
Nuts, oils, vegetable fats	10	4
Sugar and sugar products	8	2
Vegetables and fruits	6	7
All plant products	78	66
Meat	8	15
Eggs	1	2
Fish	1	5
Milk	5	11
Other	1	1
Animal fats	2	0
All animal products	18 (one-sixth of energy)	34 (one-third of protein)
Other foods	5	0

Table 1.2: Meat and milk consumption in selected countries (kg/head/year) (FAO)*

<i>Country</i>	<i>Beef</i>	<i>Sheep meat</i>	<i>Pigmeat</i>	<i>Poultry meat</i>	<i>Total meat</i>	<i>Milk</i>
USA	36.2	0.4	27.6	50.0	114.2	254.7
Argentina	55.5	1.6	10.9	38.7	105.1	199.0
France	23.8	3.3	33.0	22.9	83.0	241.3
UK	18.1	4.5	25.8	31.6	80.0	232.2
China	5.1	0.9	38.4	13.2	57.6	32.7
Nigeria	2.3	2.7	1.5	1.7	8.2	7.9
India	0.8	0.6	0.3	1.9	3.6	84.5
Bangladesh	1.3	1.3	0	1.4	4.0	21.9

* Figures quoted for milk consumption generally include the milk equivalent of milk products.

Table 1.3: Contribution of animal products to human diets (FAO 2008)*

	<i>Energy (MJ/day)</i>				<i>Protein (g/day)</i>
	<i>Meat and offal</i>	<i>Milk and eggs</i>	<i>Animal fats</i>	<i>Total animal</i>	<i>Total animal^a</i>
World	0.96	0.60	0.25	1.81	29
Spain	1.89	1.27	0.30	3.46	70
UK	1.96	1.52	0.64	4.12	59
USA	1.92	1.71	0.46	4.09	74
Argentina	2.12	1.01	0.30	3.43	57
China	1.96	0.48	0.19	2.63	37
Japan	0.74	0.72	0.15	1.61	51
India	0.09	0.31	0.24	0.64	10
Kenya	0.33	0.60	0.03	0.96	15
Nigeria	0.15	0.08	0.02	0.25	8

^a Includes fish

* Figures quoted for milk production generally include the milk equivalent of milk products.

products to human diets are furnished in Table 1.3. The sources of meat consumed (i.e. the animal species) differ considerably between countries (Table 1.2) and over the world as a whole, one-third of the meat consumed comes from poultry, one-third as pig meat, and one-fifth as beef.

When the figures presented in Tables 1.1 and 1.2 are translated into nutrient intakes for individual countries, it has been revealed that there are substantial departures from the world averages of about 2.0 MJ of energy and 29 g of protein per person per day (Table 1.3). In the developed countries of Europe (3.46, 4.12) and North America (4.09), and also in pastoral countries (Australia and Argentina; 3.43), animal products supply about 4 MJ of energy per day. Their contribution of protein is about 65 g per day. In India, animal products supply only 0.64 MJ and 10 g of protein per day. In Nigeria (and in many of the countries of West and Central Africa), the contributions of animal products are very small. In Kenya, they are greater because there is more pastoral agriculture. The main factor determining the intake of animal products is the wealth of the human population, but this factor is modulated by additional factors such as the availability of alternative sources of food and the religious beliefs and social customs of consumers.

MAJOR NUTRITIONAL ADVANTAGES IN MEETING HUMAN'S REQUIREMENTS PARTLY FROM ANIMAL PRODUCTS

The non-essentiality of animal products for human beings is demonstrated by the continued existence of vegetarianism and, and more particularly, veganism. This fact emphasises that all the nutrients required can be met by foods, which need not be of animal origin. There are, however, several major nutritional advantages in meeting the human's requirements partly from animal rather than entirely from plant sources. These are as follows:

1. Animal products supply nutrients in proportions closer to those required by man. Let us see the requirement of lysine, essential amino acid and the content of it in 100 g protein of different foods (i.e. lysine:protein ratio). A growing child requires 2 g of lysine and 30 g of total protein per day - a ratio of 6 g lysine per 100 g protein. A good-quality plant protein such as that of the soybean has a lysine:protein ratio of 6.4 (2.8 for rice protein), but animal protein in milk has even more favourable ratio of 8.2. Thus, animal proteins are valuable for supplementing the proteins of staple foods such as cereals by supplying lysine and other essential amino acids, and this is particularly important for growing children.
2. There is one essential nutrient, vitamin B₁₂ (cyanocobalamin) that is virtually absent from plant derived foods. This is synthesised by microorganisms and is present in animal products. Vegans in particular have to ensure that they have a supply of this nutrient from a supplementary source such as yeast.
3. Animal products are also good sources of other vitamins, especially vitamin A, thiamine, riboflavin and niacin. They are also an important source of iodine.
4. Further, nutrients from animal products are more accessible for digestion than those of plant-derived foods because of two reasons. One being that plant cell walls impede digestion in the stomach and small intestine, and although they may be digested and released in large intestine with nil to doubtful absorption. Second reason is that some minerals in plant tissues are bound in compounds that resist digestion, an example being phosphorus in phytates. Animal products are free from phytates and others, and thus good sources of the minerals such as iron, calcium and zinc.

Though human beings have no specific need for animal products, these products are better sources of some important nutrients (e.g. iron and vitamin B₁₂) compared to plant products. The iron in vegetables and cereals is inorganic and is available to a lesser extent due to the presence of phytates, phosphates and oxalic acids, which combine with iron and form insoluble salts.

OBJECTIONS TO THE USE OF ANIMAL PRODUCTS

Objections to the use of animals to provide human food are now strongly focussed on environmental concerns, while the ethical objections are not discussed here. See later 'Is this meat eating really necessary?'

Plant production is far more efficient in terms of edible energy and protein per acre of land than animal production. The efficiency of conversion of plant products to edible animal products varies from about 2 to 18% for energy and from 4 to 26% for protein,

and the least values being represent meat production from ruminant animals. Consistently increasing demand for animal products and the consequent overgrazing can destroy plant communities, and the demand for additional grazing can cause deforestation. Forest lands may be cleared for growing crops to meet the demand for food and feed crops to meet the demand for raising primarily ruminant animals for animal products. However, the chief concerns are the contribution to climate change of fossil fuel energy used to support livestock production systems, and the methane produced by ruminants. Methane is considered to be a more dangerous greenhouse gas than carbon dioxide.

DIRECT NUTRITIONAL OBJECTIONS TO ANIMAL-DERIVED PRODUCTS

The direct nutritional objections to animal-derived foods arise mainly due to the food-borne diseases they cause, presence of saturated fats and lack of fibre.

1. **Foodborne diseases:** Farm animals may harbour organisms such as pathogenic bacteria and intestinal parasites that may be transmissible to human beings through the consumption of their products (The Merck Veterinary Manual 2016). See later for details related to zoonotic diseases.
2. **Saturated fats:** Some of the supposedly valuable nutrients in animal products—fats, in particular—have been implicated in the causation of certain life-style diseases of human beings and other consumers such as heart disease, stroke. The science related to lipid transportation (lipoproteins), fatty acids and lipid metabolism are dealt in detail later in this chapter.
3. **Lack of fibre:** The other negative point is meat lacks fibre. Hence, transit time of faecal matter in the intestines is increased leading to altered bacterial flora. Lack of fibre also causes constipation; colon cancer is also attributed to this.

Thus, animal products present hazards to consumers from foodborne diseases and from the saturated fats they contain and the lack of fibre.

The following practices help in overcoming the negative aspects of meat: Remove skin in case of chicken meat, trim away all excess fat with other carcasses; pressure cooking/microwave cooking; eat plenty of vegetables, fruits, whole grain to obtain fibre and vitamin C; limit consumption to 60–75 g/day for 3 days in a week. So, meat is good if eaten in moderation and cooked rightly.

The Merck Veterinary Manual (11th edn, 2016) lists 150 zoonotic diseases, which are transmissible from animals to man (known collectively as zoonoses), but the majority of these are transferred by contact or bites or are carried by wild animals. The foodborne diseases of man that arise from farm animals form a relatively small, but nevertheless important and are summarised in Table 1.4. The infection of human beings with these diseases can be minimised: (1) by the regular use of anthelmintics to restrict intestinal parasites, (2) by the slaughter of infected stock to restrict or eradicate bovine tuberculosis. The milk-borne disease tuberculosis can be controlled since the pasteurisation (heat treatment) of milk is designed to kill tuberculosis bacilli and other bacteria and (3) by following strict hygienic practices in slaughterhouses and food stores. Appropriate cooking of meat and boiling of milk are also important in the control of zoonoses.

Table 1.4: Some important diseases transmissible in food from farm animals to human beings

<i>Disease</i>	<i>Causative organism</i>	<i>Source of infection</i>
Bacteria		
Brucellosis (undulant fever)	<i>Brucella abortus</i>	Cattle (milk)
	<i>B. melitensis</i>	Goats, sheep
Campylobacter enteritis	<i>Campylobacter</i> spp.	All farm animals
Clostridial disease (enterotoxaemia)	<i>Clostridium perfringens</i>	Domestic animals
Coliform infections	<i>Escherichia coli</i>	Poultry, pigs and cattle
Listeriosis	<i>Listeria monocytogenes</i>	All farm animals
Salmonellosis (food poisoning)	<i>Salmonella</i> spp.	Poultry, pigs, cattle
Streptococcal infections	<i>Streptococcus pyogenes</i>	Cattle (milk)
Tuberculosis	<i>Mycobacterium bovis</i>	Cattle (milk)
Protozoa		
Sarcocystosis (cyst formation)	<i>Sarcocystis suis hominis</i>	Pigs and cattle
Cryptosporidiosis (diarrhoea)	<i>Cryptosporidium parvum</i>	Cattle
Toxoplasmosis	<i>Toxoplasma gondii</i>	Meat and Milk
Cestodes, trematodes and nematodes		
Fascioliasis (liver fluke)	<i>Fasciola hepatica</i>	Cattle and sheep
Tapeworms	<i>Echinococcus</i> and <i>Taenia</i> spp.	Cattle, sheep and pigs
Trichinosis (cyst formation)	<i>Trichinella spiralis</i>	Pig
Prion disease: Bovine spongiform encephalopathy in livestock	Prions	Cattle

Source: The Merck Veterinary Manual, 11th edn, 2016, Whitehouse Station, NJ, Merck and Co.

In-feed antibiotic growth promoters have been used in intensive livestock systems to restrict infections, but their routine administration is now prohibited or discouraged because of the danger of producing antibiotic-resistant organisms leading to anti-microbial resistance.

Of the diseases listed in Table 1.4, the most important in developed countries are the enteric infections from *Campylobacter*, *E. coli* and *Salmonella* organisms (foodborne diseases).

The protein derivatives known as prions cause the fatal neurological condition in cattle and other animals known as a transmissible spongiform encephalopathy (TSE). The bovine form of this (BSE) is known as 'mad cow disease' and can be transmitted to human beings through the consumption of nerve and other tissues. In human beings, the disease is known as variant Creutzfeldt-Jakob disease (vCJD) and causes a fatal paralysis. The control and elimination of BSE in cattle has required a ban on the inclusion of animal residues in feeds and the slaughter of any infected animals.

In addition to the foodborne diseases, viruses infecting animals, such as those causing bird and swine influenzas, may be transmitted to human beings.

Saturated fats associate with atherogenesis and thrombogenesis: Saturated fats are associated with diseases of the circulatory system and are characterised by damage to the arterial walls (atherogenesis) and the formation of blood clots (thrombogenesis). If clots form in the blood vessels and impede the blood supply to the heart muscle, they cause coronary heart disease; if they block the vessels supplying the brain, they

cause stroke; if they block the vessels of the lungs, they cause pulmonary embolism. The affected individuals either die or become severely disabled.

CHOLESTEROL (LDLc) AND n-3 FATTY ACIDS

Lipid transport system employs lipoproteins—high-density lipoproteins (HDL), low-density lipoproteins (LDL) and very low-density lipoproteins (VLDL). Lipoproteins are the link between fatty deposits in the circulatory system and dietary fats. The concentrations of lipoprotein forms in blood are used to assess the risk of heart attacks and strokes. High-risk factors are high concentrations of LDL and VLDL. Conversely, high concentrations of HDL indicate a low risk. A high concentration of blood cholesterol, especially that associated with low-density lipoproteins, (LDLc), is also regarded as a high-risk indicator.

One of the most important dietary factors regulating serum cholesterol levels is the ratio of polyunsaturated fatty acids (PUFA) to saturated fatty acids (SFA). The SFA increase and the PUFA decrease cholesterol levels, except for the trans PUFA, which have a similar effect to the SFA. A ratio of 0.5–0.9 SFA: PUFA is considered to be satisfactory.

Different families of PUFA affect lipid metabolism in different ways. Thus, the n-6 or ω -6 acids significantly decrease serum cholesterol levels and have a minor effect only on triacylglycerol levels, whereas the n-3 or ω -3 acids have a minor effect on serum cholesterol but significantly lower triacylglycerol levels. The n-3 or ω -3 acids may be regarded as having a more beneficial effect compared to the n-6 or ω -6 acids. The n-3 fatty acids have a further beneficial effect in that they inhibit the transformation of the ω -6 acids to their eicosanoid products.

In between the SFA and PUFA are the monounsaturated fatty acids (MUFA), such as octadecenoic (oleic, 18: 1) acid, which are regarded as neutral or possibly beneficial to blood lipoproteins.

RECOMMENDED RATIO AMONG SFA, MUFA AND PUFA FOR GOOD HEALTH

Views on the health risks of SFA have been modified in recent years but the World Health Organization and other bodies recommend that SFA should provide no more than 10 percent of dietary energy intake. Other recommendations are that SFA: MUFA: PUFA should be in the proportions of 10:10:10. Only plant lipids have the suggested 10:10:10 ratio. The fats of terrestrial animals have a predominance of saturated fatty acids. Thus, in milk fat the ratio SFA:MUFA:PUFA is 8.5:3.3:0.3, and in meat, it is 8.3:8.3:2.0.

Ratio between n-6 Fatty Acid and n-3 Fatty Acid

Diets have changed with the advent of civilisation. Now humans eat less roughage (fibre) and more processed foods. It has been recommended that the ratio between n-6 FA and n-3 FA is as close to 1:1 as possible, which is of prehistoric man's diet. Now the ratio is as bad as 13:1 in some countries to 20 to 30:1 in several others. It is considered desirable to have a balance in the diet of n-6 to n-3 PUFA: the recommended maximum ratio is 4:1.

The n-6 and n-3 fatty acid contents (%) and n-6: n-3 ratio of certain oils are furnished here: canola oil 20.0, 9.3 and 2.2; maize oil 59.5, 1.0 and 59.5; fish oil 1.5, 21.4 and 0.1; linseed oil 12.7, 53.3 and 0.2; olive oil 9.6, 1.0 and 9.6; groundnut oil 33.0, 0.5 and 66.0; sunflower oil 67.3, 1.1 and 61.2 and soybean oil 54.2, 7.7 and 7.0.

NEED TO PRODUCE LOW-FAT MEAT AND MILK AND THEIR PRODUCTS

The figures given above demonstrate the difficulty—perhaps even the impossibility—of meeting the guidelines for fat consumption with a diet containing a high proportion of animal products. The preferred strategy of those who wish to meet the guidelines of WHO seems to be a reduction in intake of animal fat but no reduction in consumption of the other constituents of animal products. Hence low-fat meat and milk and their products are preferably to be used in the diet.

Animal nutritionists, in association with animal breeders, have come out to maintain the acceptability of animal-derived foods by modifying their lipid constituents. For this, animals are selected for leanness and are fed to give maximal growth of muscle; further, they are slaughtered when immature so that they have less fat. As it is known that diet can modify the body composition, it is possible to modify the constitution of body fats via their diet in case of pigs and poultry. So, the proportions of n-3 and n-6 PUFA can be changed. But in case of ruminants, dietary fatty acids are biohydrogenated in the rumen leading to saturated fat deposition in their body tissues. Low-fat milk and milk products are made by removing the fat content and such products are available in the market like toned milk, double toned milk, etc. Pigs selected to be ultralean have metabolic problems, and all pigs rely on subcutaneous fat to provide insulation against a cold environment (McDonald et al textbook).

MODIFYING THE FATTY ACID COMPOSITION OF MEAT AND MILK FATS

There has been much interest in modifying the fatty acid composition of meat and milk fats: (1) to have greater content of healthful fatty acids and (2) to bring about a more general increase in PUFA.

The first one is to increase the proportions of the long-chain PUFA, specifically eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), both n-3 fatty acids. The increase of n-3 PUFA can be achieved by increasing the proportion in dietary lipids of alpha linolenic acid, which is the precursor of EPA and DHA. Changing the diet of ruminants from conserved forages and concentrates to feeding fresh forages increases the intake of alpha linolenic acid and, despite rumen hydrogenation of PUFA, this increases the proportion of long-chain PUFA in meat and milk fats, and also lowers the n-6: n-3 ratio.

The second one is to bring about a more general increase in PUFA. With non-ruminants, some change in the ratio of PUFA to SFA can be achieved by dietary manipulation. With ruminants, however, it is possible to some extent by feeding rumen-protected specific supplements of PUFA, so that the PUFA are protected them from hydrogenation in the rumen.

RED MEATS ARE PRONE TO CAUSE CANCER

It has been found that red meats (i.e. beef, mutton and pork) increase the risk to consumers of contracting colorectal cancer; red meats are also associated—although less certainly—with other cancers (e.g. of the lung and pancreas). The risk is reportedly increased if the meat is processed, for example, by smoking or by cooking at very high temperatures (which gives rise to carcinogens such as heterocyclic aromatic amines).

CONJUGATED LINOLEIC ACID IS A BENEFICIAL FATTY ACID

It has been reported that conjugated linoleic acid (CLA) or more precisely as cis-9, trans-11 octadecadienoic acid (or the 10, 12 isomer) has a beneficial role in the body. This acid has been shown in animal trials to be antiatherogenic and anticarcinogenic, and also to limit obesity and stimulate immune function. Humans do not have the ability to synthesise CLA and must obtain it through the diet. CLA is produced in the rumen as an intermediate in the bacterial hydrogenation of unsaturated fatty acids present in the diet (hence its alternative name of rumenic acid), but it may also be synthesised in animal tissues. It is, therefore, present in both milk and meat from ruminants. Ruminants given foods that contain relatively high concentrations of unsaturated fatty acids, such as young pasture herbage, PUFA-rich vegetable oils such as sunflower, rapeseed and linseed oils produce fats with particularly high contents of CLA.

PROTEIN NUTRITION AND METABOLISM HAS BEEN AN ACTIVE RESEARCH AREA IN ANIMAL NUTRITION

All animals have dietary requirements for energy, amino acids (AAs), lipids, carbohydrates, minerals, vitamins and water in their life cycles (NRC 2002, Wu 2018). All nutrients interact with each other and with the environment to influence growth, development and health of animals. Grazing ruminants without protein or mineral supplements exhibit suboptimal growth and lactational performance (Govoni et al 2019).

Likewise, nonruminants (e.g. swine and poultry) fed typical maize- and soybean meal-based diets without dietary supplementation with deficient AAs cannot achieve their maximum genetic potential for growth and egg production. Thus, because protein is the most abundant dry matter component in growing animals (e.g. about 65–67% in skeletal muscle on the dry matter basis) and a major nutrient in human foods (e.g. meat, eggs and milk) and feedstuffs for animal diets, protein nutrition and metabolism has been an active research area in animal nutrition over the past century (Baker 2008, Bergen 2007, Firkins et al 2007).

Compelling evidence indicates that animals (including humans) have dietary requirements for proteinogenic AAs that are not synthesised *de novo* (e.g. leucine and lysine) and proteinogenic AAs that are synthesised *de novo* in animal cells (e.g. glutamate, glutamine, glycine and proline). Some of the AAs, known as functional AAs in nutrition, participate in and regulate key metabolic pathways to improve the health, survival, growth, development, lactation and reproduction of animals.

Adequate nutrition is crucial for preventing and treating metabolic disorders (including metabolic diseases) and infectious diseases in all species of animals.

Compared with humans, farm animals are at greater risks for infections by pathogens such as bacteria, fungi, parasites and viruses. Thus, maintaining a healthy gut is essential to the survival, growth and reproduction of the animals (Ren et al 2020). Since the 1950s, sub-therapeutic levels of feed antibiotics have been included in conventional diets to improve the growth performance and feed efficiency of swine and poultry. However, due to the development and spread of bacteria resistance to antibiotics, feed antibiotics have been banned in many countries since 2006.

At the organ level, the small intestine is not only the terminal site for nutrient digestion and absorption, but also intimately interacts with a diverse community of intestinal antigens and bacteria to influence gut and whole-body health. Understanding the species and metabolism of intestinal microbes, as well as their interactions with the intestinal immune systems and the host intestinal epithelium can help to mitigate antimicrobial resistance and develop prebiotic and probiotic alternatives to in-feed antibiotics in animal production.

Animal byproduct feedstuffs are abundant sources of amino acids, bioactive peptides, energy and highly bioavailable minerals and vitamins. Hence, they are effective for improving the growth, development, health, feed efficiency and survival of livestock and poultry, as well as companion and aquatic animals. This knowledge is essential to ensure sufficient provision of animal protein for humans, while helping reduce greenhouse gas emissions, minimise the urinary and faecal excretion of nitrogenous and other wastes to the environment and sustain animal agriculture (including aquaculture).

IS MEAT EATING REALLY NECESSARY?

Let us hear from 'paleoanthropology and nutrition' experts.

Meat production consumes many times more resources, especially from ruminant animals because of incomplete digestion and transformation of feed into tissue due to microbial fermentation. Some 77% of the world's arable land is used for meat and milk production, even though animal products provide only about 18% of the world's caloric needs. We see today that high meat consumption shortens the lives of many people and can contribute to numerous diseases such as diabetes, cancer and cardiovascular ailments. It would therefore do us good to significantly reduce our meat consumption. Humans have been around for about 2.5 million years. For at least 2.4 million years, people have been eating animals. This fact is evidenced by cut traces on fossil animal bones, surviving stone tools and analysis of our ancestors' teeth. Is this meat eating really necessary?

BRAIN IS THE EVER-GROWING ORGAN OF THOUGHT

Brain volume of *Homo habilis* and *Homo rudolfensis* was still about 750 cubic centimeters and *Homo erectus* already had up to 1250 cubic centimeters. Today, *Homo sapiens* even has a brain volume of 1100 to 1800 cubic centimeters. The human brain is an enormously expensive organ. Although it accounts for only a few percent of total body mass, it consumes a good fifth of total energy. Hence, it is argued since meat is a high-nutrient dense food, it is needed to humans. But experts from such diverse fields as paleoanthropology and nutrition are questioning these ideas.

We are constantly evolving: Human evolution is not locked but instead constantly developing. What was true for our ancestors is not necessarily still true today. For example, food's availability, composition and preparation have changed enormously since early humans acquired a taste for meat. Modern breeding methods have significantly increased the nutrient content in plant foods. And over time, we have learned to cook our food so that it is easier to digest and nutrients are more accessible.

We are victims of our own success: We now have become so good at processing food that—for the first time in human evolution—many people eat more calories than they can burn in a day. “After millennia of food scarcity, we have been living in food abundance for almost 70 years (in certain parts of the world). Our bodies cannot handle that,” says Hans Hauner, professor of nutritional medicine at the Technical University of Munich. In the course of their evolution, humans have always consumed what was available to them,” Hauner explains. “Humans, unlike many other animals, are able to extract from different food sources in their environment what ensures their survival.”

Our muscles can burn carbohydrates, but likewise metabolize fatty acids. In the same way, our brains can also switch from a sugar-based diet, at least in part, to a ketogenic diet. The question remains whether we still need animal proteins and the micronutrients contained in meat today. As nutritionist Hauner points out, “Today there are quite competitive sportsmen who nourish themselves through a purely vegetarian or vegan diet. So, you can also optimally supply your muscles and brain with vegetable proteins.”

Paleoanthropologist Kindler, meanwhile, believes that tastes and food sources are “handed down and more of a social issue than one of physiological evolution or instinct.” So, if people were to return more to the diet of their ancestors, eat more local fruits and vegetables, and eat significantly less meat, it would be good news for their health—and for our planet. Balanced, healthy diet with some amount of meat, dairy and other animal products is valuable.

CONTRIBUTION OF NANOTECHNOLOGY TO GREATER EFFICIENCY IN ANIMAL NUTRITION AND PRODUCTION

Traditional Methods of Feed Supplementation vs. Nanotechnology

Traditional methods of feed supplementation typically involve the delivery of additives through bulk feed or premixed formulations. However, they often face challenges such as limited bioavailability due to inefficient absorption, susceptibility to degradation during storage and processing and a lack of control over release kinetics, leading to potential wastage and uneven absorption. Altogether this affects the cost-effectiveness and efficacy of traditional methods leading to inefficient utilization. In contrast, nanotechnology offers significant advantages in feed supplementation. Nanomaterials serve as carriers for precise and targeted delivery, enhancing bioavailability and nutrient absorption through nanoencapsulation. These provide enhanced stability and protection of bioactive compounds, as well as controlled release mechanisms for sustained and precise delivery (Wang et al 2018). Moreover, nano-based feeds enable targeted delivery to specific organs, cells, or biological barriers, optimising efficacy and minimising environmental impact through minimised wastage and efficient utilisation (Nile et al 2020).

Nanotechnology has the potential to positively impact the challenges faced by the animal production sector by enabling: (i) the development of enhanced feed formulations with enhanced nutritional profiles and bioavailability that optimise animal diets, improve feed conversion ratios and mitigate resource inefficiencies; (ii) advanced disease management using nanomaterial-based drug delivery systems to deliver therapeutic agents and vaccines, with the potential to reduce disease burdens and minimise reliance on conventional antibiotics and antimicrobials, which ultimately impact on the antimicrobial resistances problems; (iii) sustainable production systems by minimising the environmental footprints and ecological impacts associated with animal agriculture through efficient nutrient utilisation, waste generation reduction and environmental pollutants mitigation. This has resulted in increased productivity and the creation of products with greater nutritional value, quality and safety.

While providing an overview of the current state of the art regarding nanotechnology solutions applied in feed, Almeida CF et al (2024; JAPAN 108: 1430–1452) also dealt the risks and opportunities from nanotechnology in animal nutrition and production to help researchers and livestock producers. Nanotechnology products are successful because of their unique physicochemical properties due to their increased surface area. As a consequence, nanomaterials exhibit improved surface reactivity, stability, bioactivity, bioavailability and controlled drug release. Several types of nanomaterials have been used and reported in the literature for the feed sector. These include inorganic nanoparticles, polymeric nanoparticles, mesoporous nanoparticles, polymeric micelles, solid lipid nanoparticles, liposomes, micelles and nanospheres.

The development of nanotechnology products for feed must consider the challenges raised by biological barriers in the animal gastrointestinal system. One of the first steps in the development of nanomaterials must be to define the target animal, since the gastrointestinal systems of ruminants, poultry or pigs have chemical and physical specificities (Fig. 1.1).

Oral administration of nanomaterials benefits from ease of administration, feasibility of solid formulations and decreased immune response. However, nanomaterials must be able to overcome the environmental and mechanical degradation characteristic of animal gastrointestinal systems to reach their targets, usually the intestine (Meng et al 2018). In the intestine, the nanomaterial faces a physical barrier that regulates intestinal permeability and microbiota, which prevents the spread of microorganisms, toxins and foreign substances into the circulatory system (Gray et al 2021, Meng et al 2018). Hence, factors such as nanomaterial composition, size, shape, solubility, chemical charge and loading should be tailored according to the animal and biological target to ensure a prolonged residence time in the gastrointestinal tract, avoiding intestinal clearance mechanisms, increasing tissue penetration and distribution, efficient cell uptake and effective delivery to target sites (Abd El-Ghany 2019).

The application of nanotechnology in the feed sector is mainly focused on two areas, namely nutritional feed additives and the development of vaccines. In each case, the aim has been to improve productivity through growth performance and the reduction of the impact of disease and ultimately diminish costs. Most studies evaluated the beneficial use of nanomaterials in the poultry sector to improve the performance of the animals. Four types of nanomaterials were identified, nanominerals, nanoparticles, nanoemulsions and nanocapsules.

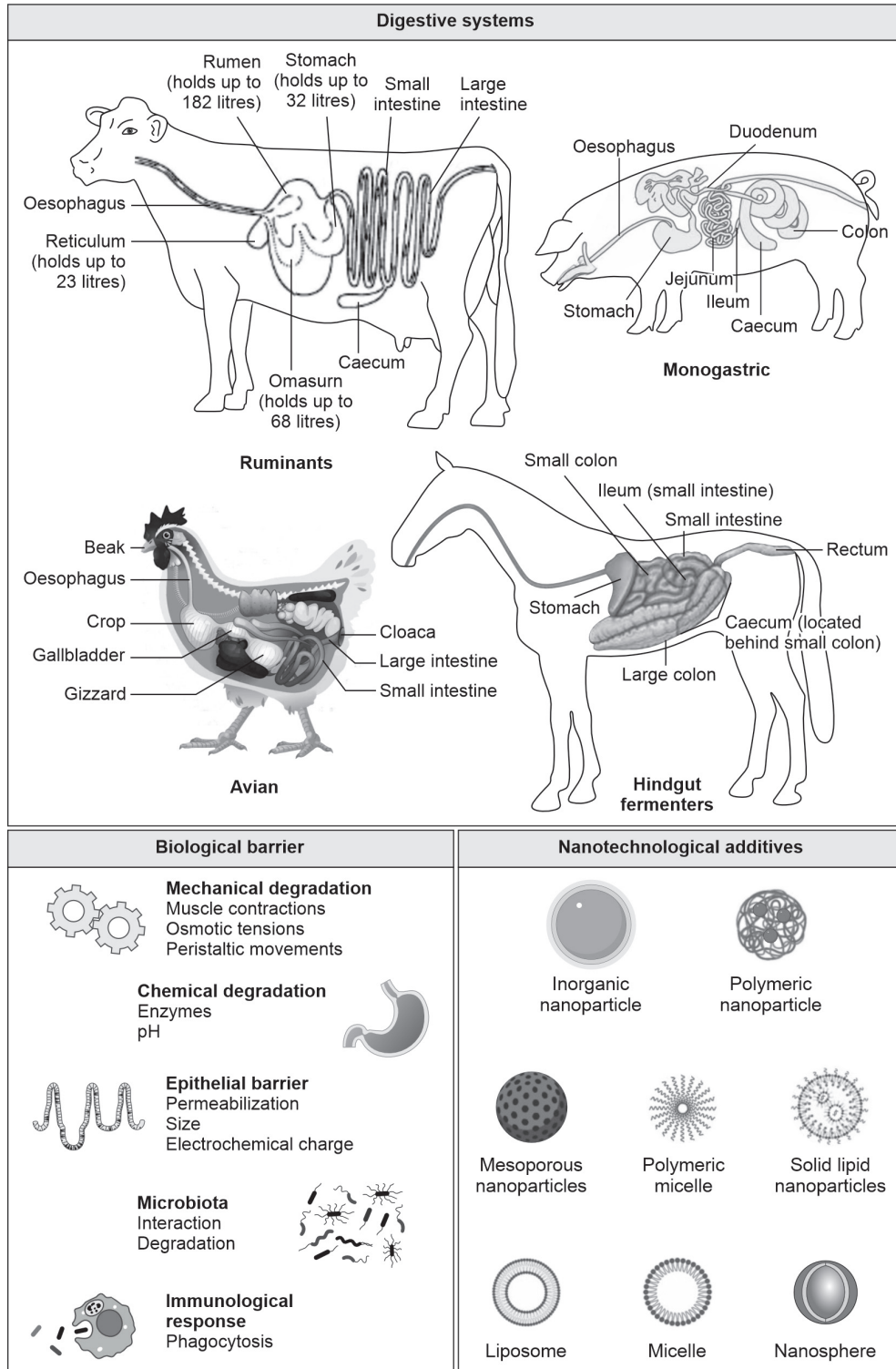


Fig. 1.1: Nanosystems developed to overcome the biological barriers of the gastrointestinal system of animals. **Source:** Almeida CF et al (2024; JAPAN 108: 1436).

1. Nanominerals

Nanominerals (nanoparticles derived from inorganic materials): small size, high surface area, good homogeneity and physical reactivity contribute to increased bioavailability. Their use as feed additives improves the growth performance, immune response, digestive function, microbiota homeostasis and reproductive performance in poultry and livestock (Swain et al 2015). Compared to the block form, nanominerals require the administration of small doses, resulting in reduced feed costs and minimised environmental impact due to the excretion of lower mineral levels (Gopi et al 2017, Reddy et al 2020, Swain et al 2015). Furthermore, nanominerals can be used as an alternative to antibiotics as growth promoters, circumventing the issue of antibiotic resistance and the elimination of antibiotic residues in final products, without the risk of transfer to humans (Zheng et al 2017). The nanominerals of interest include nanozinc, selenium, nanosilver, chromium, copper and nanoclay.

Nanoclay, nanomaterial that consists of very thin layers of clay minerals, act as carrier of essential minerals such copper, selenium, and chromium. It can be used to improve the feed efficiency, growth performance, egg production and quality and health status of poultry.

2. Nanocapsules

A nanocapsule is a hollow core-shell particle capable of encapsulating various substances. This nanomaterial can protect the substances encapsulated from degrading and release them in a controlled manner. In the animal nutrition sector, nanocapsules have been, mainly, used to encapsulate feed additives and ensure their delivery on the animal digestive tract in a targeted and sustained manner. They can also be used to improve the absorption, stability and efficacy of a range of feed additives. These improvements are achieved because nanocapsules protect the encapsulated substances from degradation by environmental factors such as light, oxygen, pH or enzymes; or because they increase the solubility and bioavailability of substances that are poorly soluble in water, such as lipophilic compounds (Gopi et al 2017).

Naturally occurring bioactive molecules are being explored to improve feed quality and as alternative to antibiotic growth promoters (AGP). Nanocapsules have been used to overcome these drawbacks and thus improve the applicability of the biological activity of natural compounds in the feed sector. For example, curcumin nanocapsule administration potentiates the antioxidant effect of this natural compound, as three times lower doses achieve the same results as free curcumin. The encapsulation of graviola leaf extract, garlic extract, peppermint, basil oil or cumin essential oil also improve the antimicrobial and antioxidant properties of these natural compounds. This enhances their applicability as feed additives to optimise growth, gastrointestinal integrity and economic efficiency in livestock and poultry.

Moreover, the application of nanocapsules to potentiate the action of probiotics has been investigated on the poultry sector. The nanoencapsulated *Bacillus amyloliquefaciens* reveal promising results and can be used as feed additive to improve the performance and gut health of broiler chickens with efficacy against *Campylobacter jejuni* colonisation (Ismail et al 2023). The use of nanoencapsulated probiotic and prebiotic as a novel feed additive for growing rabbits also gave improved gut health, immunity and growth performance; the nanocapsules improved the gut microflora

balance by increasing the population of *Lactobacillus* and *Bifidobacterium* and decreasing the population of *Escherichia coli* and *Clostridium perfringens* (Hashem et al 2021).

Chitosan (chitosan is a natural polysaccharide derived from the shells of crustaceans, such as shrimp and crab) has been the polymer used, in majority of studies, to encapsulate bioactive molecules with potential as feed additives in livestock and poultry nutrition. Chitosan is biodegradable, biocompatible, non-toxic, thus suitable for animal consumption and environmental safety. It has been demonstrated that nanocapsules of chitosan can protect natural bioactive compounds and minerals from harsh conditions in the rumen or stomach of animals and guarantee the proper delivery on the small intestine intact and exert their beneficial effects. Moreover, chitosan nanocapsules have been successfully applied on the development of vaccines against salmonellosis in poultry. Both oral and in ovo administration of chitosan-adjuvanted salmonella vaccines were able to induce both humoral and cellular immunity against *Salmonella* spp. and reduce its shedding and organ invasion.

3. Nanoparticles

In addition to nanocapsules, **solid nanoparticles of chitosan** have been reported to enhance the nutritional value of animal feed. For example, chitosan nanoparticles alone or in combination with zinc improved the growth performance, humoral immunity, gut microbiota and immune response of weaned pigs due to their higher stability, solubility and bioavailability compared to conventional forms (Xu et al 2020, Zhang et al 2021b).

The nanosized form of vitamin D₃ showed higher bioavailability, stability and solubility than micro-vitamin D₃. The growth performance, bone quality, calcium and phosphorus absorption and vitamin D status of broiler chickens was improved after the administration of nano-vitamin (Sheikhsamani et al 2022). Moreover, nanoparticles of vitamin C administered in combination with nanomineral zinc oxide alleviate the negative effects of heat stress on the growth performance, immune response, intestinal morphology and blood constituents of broiler chickens (Bahrapour et al 2021).

4. Nanoemulsions

A nanoemulsion is a colloidal system that consist of droplets, with less than 100 nanometers, of one liquid dispersed in another liquid. Because of their small size, nanoemulsions have some special properties, such as kinetically stability, optically transparent, high surface area and tunable rheology. Nanoemulsions have been used in animal nutrition to improve the bioavailability, stability and efficacy of various feed additives. They can enhance the absorption of lipophilic compounds, such as vitamins, essential oils and fatty acids in the gastrointestinal tract of animals. Nanoemulsions can also protect the active ingredients from degradation by environmental factors, such as light, oxygen and pH. Furthermore, nanoemulsions can modulate the release of the encapsulated compounds in a controlled manner, depending on the needs of the animals.

Some studies have shown the benefits of using nanoemulsions in animal nutrition. The administration of nanoemulsion containing essential oil from natural sources, for example, eugenol, thymol, peppermint, coriander, enhanced the growth performance, immune response and intestinal health of chickens and rabbits. A nanoemulsion

containing ω -3 fatty acids was found to increase the content of beneficial fatty acids in the meat and eggs of poultry animals (Abbasi et al 2019). Similar results were described for nanoemulsified vegetable oil and betaine. Based on the results, nanoemulsion could be used as an effective feed additive for broiler chickens under cyclic heat stress to improve their growth traits and meat characteristics (Abudabos et al 2021).

CONCLUSIONS ON NANOTECHNOLOGY CONTRIBUTIONS

Feed costs alone represent 60 to 70% of costs in animal production for human consumption. So, economising on feed can improve profits from animal farming. Nanotechnology offers potential to increase productivity by creating higher-quality and safer products. The feed sector has benefited from the use of nanosystems to improve the stability and bioavailability of feed ingredients. The use of nano-based feed products can reduce the cost of animal production by improving nutrient utilisation, reducing feed wastage, increasing feed conversion, improving animal immunity and disease resistance and reducing the use of antibiotics and other chemicals. Several research studies have been published supporting the role of nanominerals, nanocapsules, nanoparticles and nanoemulsions as feed additives, showing clear evidence of their potential as growth promoter, immunity enhancer or antimicrobial agent.

Nanotechnology additives are being touted as an alternative to increase feed efficiency, reduce the cost of animal nutrition, protect animal and human health and to improve safety and environmental factors. Nevertheless, further studies are needed to ensure that the application of nanoparticles in animal feed is safe for animals, the environment and humans. Therefore, the regulatory framework for nanoproducts is constantly need to be updated with appropriate legislation to avoid the potential hazards of nanotechnology application in feed (Almeida et al 2024).

Bibliography

- Abbasi F, Samadi F, Jafari SM, Ramezanpour S and Shams Shargh M 2019. Ultrasound-assisted preparation of flaxseed oil nanoemulsions coated with alginate-whey protein for targeted delivery of omega-3 fatty acids into the lower sections of gastrointestinal tract to enrich broiler meat. *Ultrasonics Sonochemistry*, 50, 208–217.
- Abd El-Ghany WA 2019. Nanotechnology and its considerations in poultry field: An overview. *Journal of the Hellenic Veterinary Medical Society*, 70, 1611–1616.
- Abudabos AM, Suliman GM, Al-Owaimer AN, Sulaiman ARA and Alharthi AS 2021. Effects of nano emulsified vegetable oil and betaine on growth traits and meat characteristics of broiler chickens reared under cyclic heat stress. *Animals: An Open Access Journal from MDPI*, 11(7), 1911.
- Bahrampour K, Ziaei N and Esmaeilpour OA 2021. Feeding nano particles of vitamin C and zinc oxide: Effect on growth performance, immune response, intestinal morphology and blood constituents in heat stressed broiler chickens. *Livestock Science*, 253, 104719.
- Baker DH 2008. Animal models in nutrition research. *J Nutr* 138:391–396.
- Bergen WG 2007. Contribution of research with farm animals to protein metabolism concepts: A historical perspective. *J Nutr* 137:706–710.
- Firkins JL, Yu Z and Morrison M 2007. Ruminant nitrogen metabolism: Perspectives for integration of microbiology and nutrition for dairy. *J Dairy Sci* 90 (E Suppl): E1–E16.
- Gopi M, Pearlin B, Kumar RD, Shanmathy M and Prabakar G 2017. Role of Nanoparticles in Animal and Poultry Nutrition: Modes of Action and Applications in Formulating Feed Additives and Food Processing. *International Journal of Pharmacology*, 13, 724–731.

- Govoni KE, Reed SA and Zinn SA 2019. Poor maternal nutrition during gestation: Effects on offspring wholebody and tissue-specific metabolism in livestock species. *J Anim Sci* 97:3142–3152.
- Gray P, Jenner R, Norris J, Page S and Browning G 2021. Antimicrobial prescribing guidelines for poultry. *Australian Veterinary Journal*, 99, 181–235.
- Hashem NM, Hosny NS, El-Desoky NI and Shehata MG 2021. Effect of Nanoencapsulated Alginate-Synbiotic on Gut Microflora Balance, Immunity, and Growth Performance of Growing Rabbits. *Polymers*, 13(23), 4191.
- He W and Wu G 2020. Metabolism of amino acids in the brain and their roles in regulating food intake. *Adv Exp Med Biol* 1265:167–185.
- Ismail H, Ibrahim D, El Sayed S, Wahdan A, El-Tarabili R M, El- Ghareeb W R, Alhawas BA and Alahmad B 2023. Prospective application of nanoencapsulated bacillus amyloliquefaciens on broiler chickens' performance and gut health with efficacy against campylobacter jejuni colonization. *Animals: An Open Access Journal from MDPI*, 13(5), 775.
- Meng H, Leong W, Leong KW, Chen C and Zhao Y 2018. Walking the line: The fate of nanomaterials at biological barriers. *Biomaterials*, 174, 41–53.
- Nile SH, Baskar V, Selvaraj D, Nile A, Xiao J and Kai G 2020. Nanotechnologies in food science: Applications, recent trends, and future perspectives. *Nano-Micro Letters*, 12, 45.
- Ren WK, Bin P, Yin YL and Wu G 2020. Impacts of amino acids on the intestinal defensive system. *Adv Exp Med Biol* 1265:133–151.
- Sheikhsamani E, Golian A and Zerehdaran S 2022. The bioavailability and effects of nano-vitamin D₃ and micro-vitamin D₃ on performance and bone characteristics in broiler chickens. *Poultry Science Journal*, 10, 203–213.
- Swain PS, Rajendran D, Rao SBN and Dominic G 2015. Preparation and effects of nano mineral particle feeding in livestock: A review. *Veterinary World*, 8, 888–891.
- Wang L, Wang Y, Hao Y and Rui Y 2018. Effects and advantages of nanomaterials in agricultural production. *Fresenius Environmental Bulletin*, 27, 7911–7920.
- Wang J, Zanghi M, Xu J and Kim WK 2021. Evaluation of using magnetic nanoparticle attached phosphorus species as supplemental phosphorous source in broiler diet. *Journal of Applied Poultry Research*, 30(3), 100169.
- Wu G 2021. *Amino acids: Biochemistry and nutrition*, 2nd edn. CRC Press, Boca Raton, Florida.
- Wu G 2022. Recent Advances in Animal Nutrition and Metabolism (Advances in Experimental Medicine and Biology volume 1354) edited by G Wu pages 1–9. Published by Springer Nature Switzerland AG.
- Xu Y, Mao H, Yang C, Du H, Wang H and Tu J 2020. Effects of chitosan nanoparticle supplementation on growth performance, humoral immunity, gut microbiota and immune responses after lipopolysaccharide challenge in weaned pigs. *Journal of Animal Physiology and Animal Nutrition*, 104, 597–605.
- Zhang M, Hou G, Hu P, Feng D, Wang J and Zhu W 2021b. Nano chitosan-zinc complex improves the growth performance and antioxidant capacity of the small intestine in weaned piglets. *British Journal of Nutrition*, 126, 801–812.
- Zheng K, Setyawati MI, Leong DT and Xie J 2017. Antimicrobial gold nanoclusters. *ACS Nano*, 11, 6904–6910.

Further Reading

- National Research Council (NRC) 2002. *Scientific Advances in Animal Nutrition*. National Academies Press, Washington, DC.
- Wu G 2018. *Principles of Animal Nutrition*. CRC Press, Boca Raton, Florida.