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Risky Benefits and Beneficial Risks of Animal Protein

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ABSTRACT
Protein is a vital macronutrient essential for overall health, contributing to weight management, improved cardiometabolic health, and regulation of blood glucose levels, fat-free mass, and waist circumference. While animal proteins are a major dietary source, concerns have emerged linking high intake to increased risks of mortality, cancer, and cardiovascular diseases; though findings remain inconsistent and inconclusive. This review seeks to examine the key distinctions between plant and animal protein sources and critically evaluate the health implications of animal protein consumption. It also highlights current knowledge gaps and outlines future research priorities regarding the benefits and potential limitations of animal protein.

KEYWORDS
Animal food, cardiovascular disease, environment, ischemic heart disease, proteins, stroke

INTRODUCTION

Animal proteins are rich in nutrients. They supply high-quality protein and are a good source of several vitamins, minerals, long fatty acids, bioactive compounds, and trace elements, including B vitamins, Fe, Zn, Se, haem, eicosapentaenoic acid, docosahexaenoic acid, choline, carnitine, carnosine, and anserine[1-2]. Moderate consumption of animal products has been reported to reduce the risk of micronutrient deficiency and the need for supplementation, owing to their amino acid profile, high protein digestibility, micronutrient bioavailability and density, thereby contributing to dietary 'robustness'[3-4].

The importance of protein as a source of essential macronutrients cannot be overstressed. Adequate amount of protein in diets has been shown to reduce weight, improve cardiometabolic risk factors, attenuating fat free mass and waist circumference, and markers of blood glucose[5-6]. Unfortunately, higher animal protein has been implicated with increased mortality as well as disease risks such as cancer development and cardiovascular diseases[7-9], although the results have always remained unduplicated, creating suspicion about the authenticity of the claims. It has been established that there is no independent link between animal-sourced protein intake and elevated cancer risk, and there is no distinct clear association to elevated cardiovascular disease risks[10-11].

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Disease risks and protein intake often involve other factors, such as other nutrients consumed alongside the protein sources[12]. It is a complex relationship that has not been fully explored. For instance, men and women differ not only in their protein intake but also in the distribution between animal and plant protein intake. It has been noted that ladies consume about 61% of their proteins from animal proteins and dairy products, while men consume about 76% of their protein from animal and dairy sources[13-14].

A relatively recent study on the relationship between animal and plant protein intake and overall diet quality in young adults concluded that young female and male adults consuming less than 70% of their protein from animal sources had higher scores on a modified healthy eating index (HEI) compared to those consuming more than 70% of their protein from animal sources[14]. However, irrespective of protein intake sources, young male adults scored lower than female adults on the modified HEI, indicating that a lot remains to be explored about disease risks and protein sources (plant or animal).

This review aims to explore established differences between plant and animal proteins as well as to unravel the risks and benefits associated with animal proteins to provide insights into future directions for research activities involving animal protein and its limitations.

Health benefits of animal proteins: Proteins in animal and human nutrition are irreplaceable. They play essential roles in all physiological functions, and an adequate dietary intake of protein, providing nitrogen and amino acids, is needed for regular tissue turnover and functional body proteins[15]. Of particular importance in human nutrition are the essential amino acids, which the body cannot synthesize or in an adequate amount, underscoring the importance of essential amino acids in determining the quality of a protein. The quality of a protein is also determined by its ability to meet the body's requirements, expressed as an amino acid score. Amino acid score is the ratio of the content of essential or indispensable amino acids to the quantity required. However, non-essential amino acids also play important roles in the body, such as being precursors for the synthesis of other amino acids.

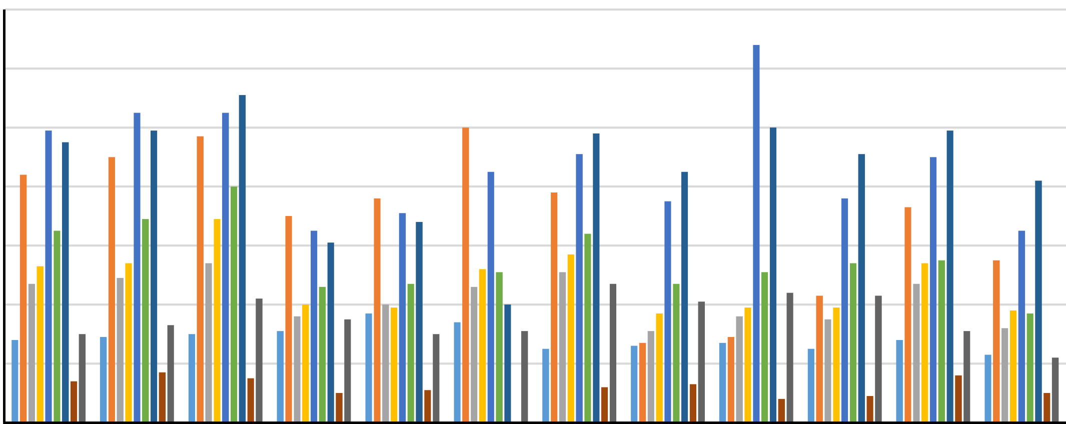
Animal proteins are superior to plant proteins in terms of essential amino acid profile and in addition, are more easily digestible than plant proteins, making them easily available for essential body functions. For instance, chicken eggs have always been used as a reference for measuring the quality (biological value) of other proteins. On the other hand, the presence of antinutritive factors (tannins, trypsin inhibitors and lectins, etc.) in plant proteins limits their bioavailability. Antinutritive factors require extensive processing of the food to reduce their impacts[16]. Plant cell walls also limit accessibility of plant proteins, being partially digested in the gastrointestinal tract of man, owing to the lack of the enzymes required for the breaking of fibers and cellulose[17,18].

Intake of animal protein has been shown to improve cognitive performance in school children average age of 7.5 years, than to total protein[19]. Animal protein intake has also been reported to be associated with higher lean body mass in women, whereas no such relationship existed for plant protein[20]. A comparison study conducted to investigate the effect of protein in combating sarcopenia and preserving muscle mass in ovariectomized rats showed that only a diet supplemented with animal protein slowed muscle decline and improved muscle structure in sedentary animals[21]. In another comparison study between soy protein and beef in middle-aged men at rest and after physical exercise, it was revealed that beef significantly induced a higher response[22].

Moderate consumption of animal products has been shown to support physical and cognitive development in children as well as reduce the risk of micronutrient deficiencies in susceptible populations (adolescents and reproductive age women[23]. About two billion people across the globe have been reported to suffer from micronutrient deficiencies, which reduction has been linked to consumption of animal proteins, resulting in improved birth weight, reduced stunted growth and cognitive development[24-26], indicating the key roles animal proteins play in alleviating protein and micronutrient deficiencies[23]. Animal proteins are richer in essential amino acids than plant proteins. Figure 1 shows the comparison of the selected animal and plant protein dietary sources in terms of amino acid pattern[27].

Animal and plant proteins: Protein in human and animal diets can be broadly classified into plant and animal protein, depending on their sources. Proteins obtained from animal products are regarded as animal proteins or animal-sourced proteins, while those from plants or crops are regarded as plant proteins or plant-sourced proteins. Both animal and plant proteins are important sources of dietary protein for humans and animals. However, they are different in some instances. Proteins may differ in their biological, chemical, functional, and nutritional characteristics depending on their source, molecular make-up, and structures[27].

Plant-sourced proteins have attracted increased consumer interest, based on concerns for ethical, sustainability, or health issues, explaining why the food industry keeps responding with many plant-sourced alternatives. Similar flavour and textual features were observed in early plant and animal proteins. However, plant proteins are inferior to animal proteins because they lack some essential amino acids, such as lysine, which thus must be supplied through other means when fed, thereby making them of lower nutritional value than animal proteins. Digestibility is also slowed or reduced for plant proteins owing to their molecular structures. Notwithstanding, they are still known to be a good protein source for humans and animals and can contribute to a balanced diet[27].



Protein sources	Cow milk	Sheep milk	Goat milk	Beef	Pork	Chicken	Whole egg	Wheat flour	Corn	Oat	Soybean	Chickpea
His	28	29	30	31	37	34	25	26	27	25	28	23
Lys	84	90	97	70	76	100	78	27	29	43	73	55
Thr	47	49	54	36	40	46	51	31	36	35	47	32
Ile	53	54	69	40	39	52	57	37	39	39	54	38
Leu	99	105	105	65	71	85	91	75	128	76	90	65
Val	65	69	80	46	47	51	64	47	51	54	55	37
AAA	95	99	111	61	68	40	98	85	100	91	99	82
Trp	14	17	15	10	11	0	12	13	8	9	16	10

Fig. 1: Amino acid pattern, mg/g protein of dietary animal and plant proteins

AAA: Aromatic amino acids (i.e., phenylalanine and tyrosine), His: Histidine, Ile: Isoleucine, Leu: Leucine, Lys: Lysine, SAA: Sulfur amino acids (i.e., methionine and cysteine), Thr: Threonine, Trp: Tryptophan, Val: Valine and n.d.: Not determined

Animal proteins are considered complete proteins because they contain all the essential amino acids that are absent or deficient in plant proteins. Animal-sourced proteins have higher nutritional quality than plant-based proteins, based on their amino acid profile, digestibility, and ability to transport other important nutrients (such as iron and calcium). Animal-sourced proteins provide adequate nutrition for humans and are essential for infants' physical and cognitive development, making animal proteins a recommended source in food and products[28]. The technological functionality, such as foaming, gelling and emulsification, which gives food its appealing texture and sensory attributes, possessed by animal protein is superior to plant-sourced protein[29]. Commonly available and most widely used animal and plant proteins, as well as emerging proteins such as insects, pseudocereals, are presented in Fig. 2a-b. Most commonly used animal-sourced proteins in human nutrition include egg, meat, dairy, and milk, with recent interest in insects.

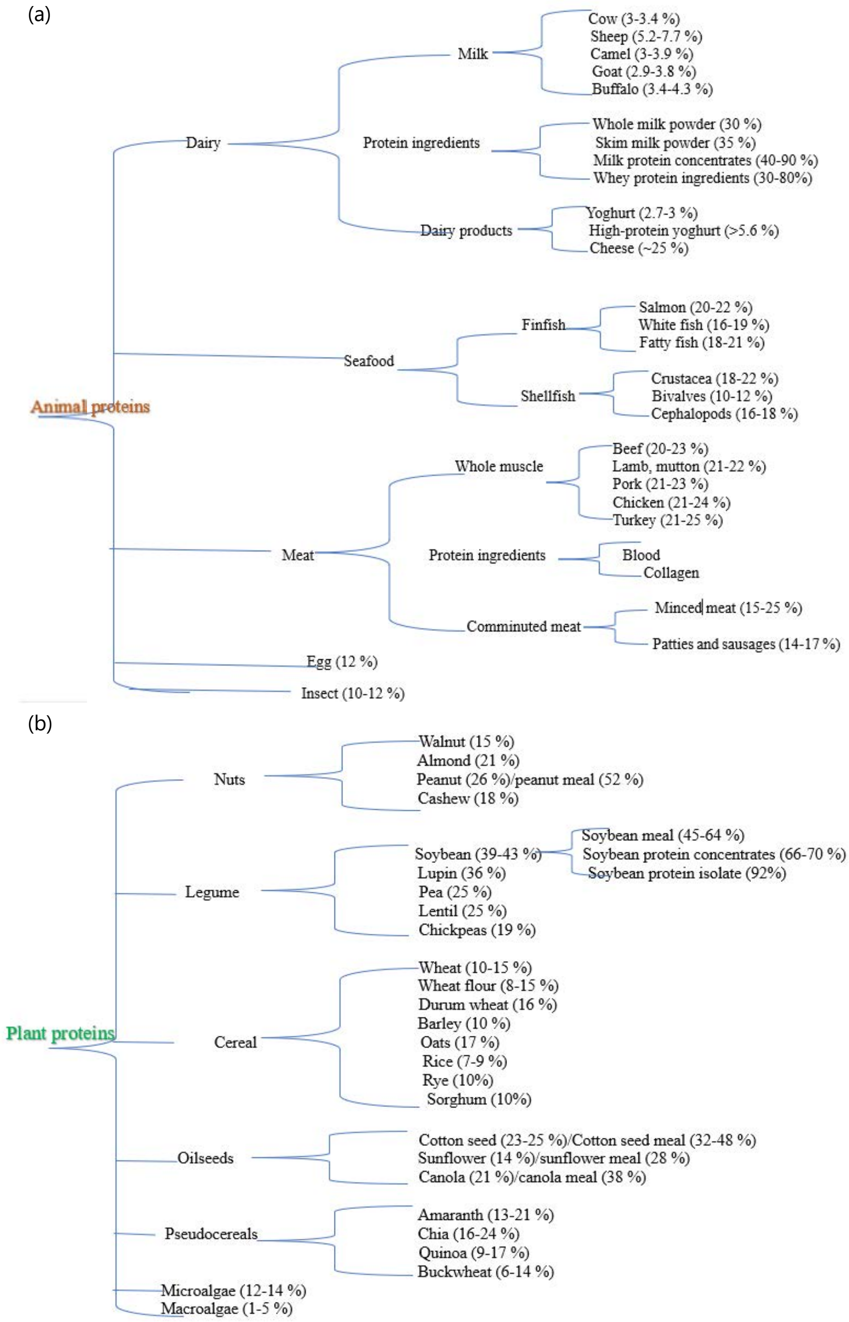


Fig. 2(a-b): Animal and plant protein contents, (a) Animal proteins and (b) Plant proteins
Values presented as percentages are protein concentrations in natural biological resources, per wet weight, except for the protein powder ingredients in per dry weight[27, 30-34]

Dairy: The data presented in Fig. 2 clearly shows that milk may contain between 3-8% protein, depending on the species of animals from which it is obtained, underscoring the influence of genetic variation, farming systems, seasonality, and feeding, which in turn may be responsible for variation in their amino acid composition. Dairy protein ingredients are extensively used in bakery products, foods for the elderly, beverages, fish products, confectionery, meat, infant dietary products, and dietetic foods. They are used in specialty products aimed at slimming, clinical and medical support, and sports nutrition[35]. Dairy proteins can be grouped into whey proteins (Approximately 20% of the total proteins from cows) and casein (80%), phosphoproteins.

Bovine milk is the most consumed globally, although non-bovine sources are also contributing a significant amount and increasing in production and consumption[36]. Caseins provide micelles in milk, which supply calcium, phosphate, and proteins in high concentrations that would otherwise be insoluble in water, thereby providing adequate nutrients for neonates. The relationship between protein and mineral components, responsible for their functional properties, has been broadly utilized for producing dairy products such as cheeses, yogurts. It has been noted that these unique technological and nutritional characteristics of caseins are difficult to replace with plant proteins[27]. Skim powder milk (about 30% protein) and whole milk powder (about 24% protein) are produced from dried skim and whole milk, respectively.

Seafood and eggs: The importance of seafood as a diverse and valuable protein source in the human diet cannot be overemphasized. Fish provides about 16% of the global animal proteins[27]. Fish, a high-protein, low-energy, and total fat, especially saturated fat protein is rich in vitamins and minerals, required for growth and development. The qualities of avian eggs include a complete supply of essential amino acids, outstanding digestibility, and high nutritional value. Over 90% of egg white dry matter is made of protein. Eggs are generally made up of about 75% water and 12% protein. Albumen (egg white) makes up about 50% of the protein in an egg. The egg yolk makes up about two-fifths of the protein, while eggshell and eggshell membrane share the remaining protein[27]. Processed egg powder ingredients and products are utilized in bakery, confectionery, and condiment products, bakeries being the largest user of whole eggs and separated yolks and whites. Egg products are used for forming abilities; for instance, egg white remains the reference for foaming properties when compared with other plant and animal protein products.

Meat: Muscle meat contains between 20 and 25% protein, and its importance in human nutrition cannot be overstressed, consisting of relatively consistent protein content across species. Comminuted and reformed foods consisting of organs, muscle, or co-products, such as burgers, minced meat and sausages, can be potentially substituted with plant-sourced protein products, where their functional properties, such as fat and water binding capacity and meat emulsion formation, can match that of plant-sourced protein products. However, their protein content is generally lower than the muscle meat cuts[27]. Also, aside possessing a complete nutritional quality based on complete essential amino acid profile, required for growth and development, meat contains additional benefits such as having essential minerals and vitamins including selenium, calcium, iron, vitamins B6, B12, and vitamin D. In meat, iron is usually present in the form of haem, which is easily and efficiently absorbed. Little wonder that moderate intake of lean meat is key to ensuring a healthy, balanced diet[37]. By the way, moderation is key in life, not just in protein consumption. Collagen, abundantly present in animals, plays important roles in connective and structural functions in blood vessels, tendons, skin, cartilage, and bone. Partial hydrolysis or heat denaturation of collagen results in the production of gelatin, a versatile meat protein ingredient commonly used in food additives, as a thickener and stabilizer as well as in soup, sauce, frozen products, coating, and edible film[27].

Insects: Insects may contain protein content ranging between 19 and 24%, depending on the species in question, their feeding source, processing method, and maturity age[27,38], concentrated in the cuticle layers (covering the epidermis) and the muscles. Insect-based proteins are used in human and animal nutrition, although the interest is just growing globally. Insect consumption may be a common practice in some regions, global interest is just growing, and processed protein ingredients may be greater potential for insects[39].

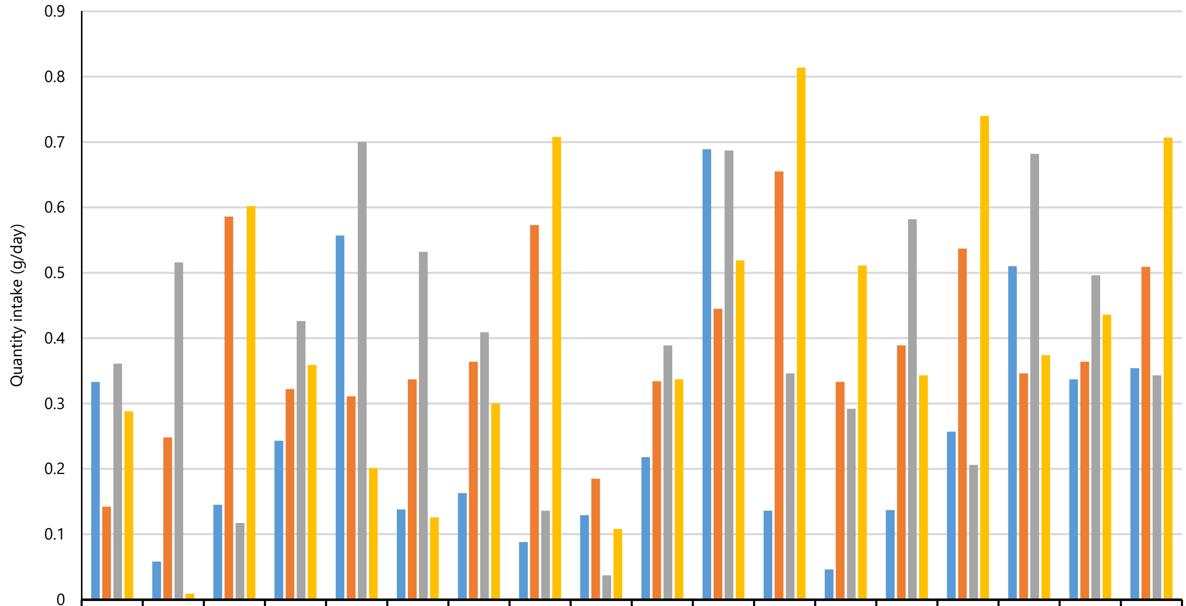
Animal-sourced and plant-sourced proteins also have different physicochemical properties/functionalities. High hydrophobicity is usually associated with plant-sourced proteins. They are less soluble and flexible than animal-sourced proteins, limiting their effective use in various food products. The limitation may be improved upon, but it may induce amino acid sidechain modifications or structural amendments, which may further reduce the bioavailability of amino acids in plant-sourced proteins[40,41]. Despite sophisticated technologies, processing techniques, and creative formulations now available, there is no effective replacement in terms of texture and mouthfeel to muscle foods, suggesting that a combination of both animal and plant proteins may be necessary as an immediate remedy to their respective limitations[42].

Proteins possess tertiary structures as a result of attractive and opposing molecular forces such as hydrogen bonding, electrostatic forces, conformational entropy, ion-pairing, van der Waals interactions, and the hydrophobic effect. Protein folding is mainly brought about by the hydrophobic effect, resulting in the compactness of globular proteins. However, animal and plant proteins are structurally different because they have different polypeptide sequences and are within different native environments[43]. They have different secondary structural characteristics and hence, different tertiary structures, influencing their performance, functional and nutritional characteristics such as forming properties, gelation, emulsification, availability of essential amino acids, accessibility to the digestive system, and fragmentation into peptides. Each protein source has several structural different classes of proteins. For instance, caseins and whey are classes of milk proteins, while caseins are disordered protein owing to low number or lack of disulphide bonds, their flexible and open structures with its constituents (β-, α S1-, α S2- and κ-caseins) forming casein micelle in milk, while whey protein (β-lactoglobulin) is a globular protein, existing as a dimer at neutral pH and as tetramers and octamers at acidic or basic pHs. Meat has three stromal, myofibrillar and sarcoplasmic muscle proteins, which are structurally different[27,44].

The relationship between the source of dietary protein intake and micronutrient intake in young female and young male adults is shown in Fig. 3. The data presented shows that plant protein intake is positively associated with vitamin E, B2, B6, folate, calcium, phosphorus, magnesium, iron, zinc, copper, selenium, sodium, and potassium intake in both sexes, while animal protein intake is positively associated with vitamins A, B2, B3, phosphorus, selenium, sodium, and potassium intake[14].

Plant proteins are limited when compared with animal proteins in terms of essential amino profile and digestibility, which may negatively impact health and development, especially for neonates and children, necessitating recommendations for improvement through processing approaches, breeding, and genetic modifications, and fortification with essential amino acids[45-47]. Figure 4 shows the modified healthy eating index for young female and male adults eating less than or more than 70% of proteins from animal sources[14].

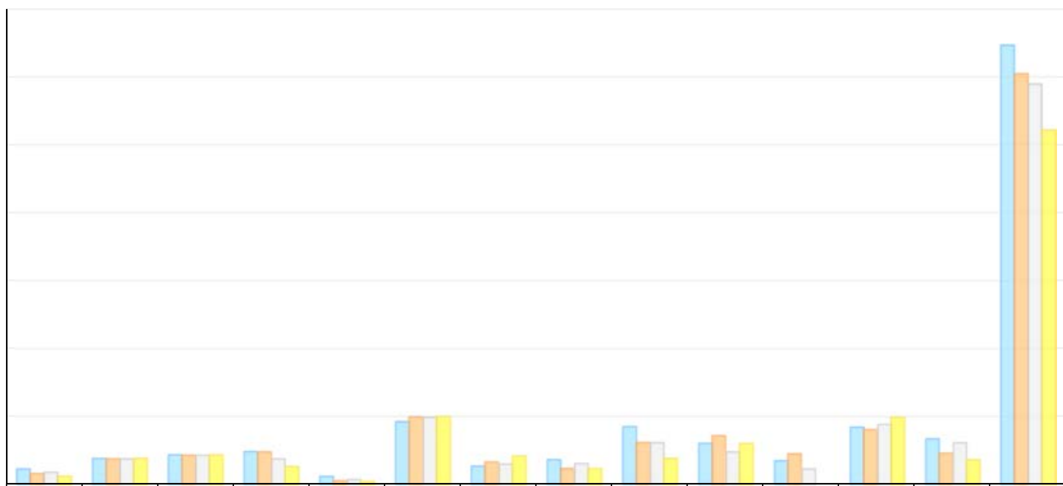
Health and disease risks of animal proteins: It may be safe to assume that the dietary benefits of animal-sourced proteins are well-known. However, consumption of animal-sourced proteins and animal agriculture are currently implicated with issues, especially in developed high-income countries. Factors fueling such issues include concerns about their impacts on climate change and environmental health, animal welfare, and human health[48].



	Vit A (mcg/d)	Vit D (mcg/d)	Vit E (mg/d)	Vit B2 (mg/d)	Vit B3 (mg/d)	Vit B5 (mg/d)	Vit B6 (mg/d)	Folate (mcg/d)	Vit B12 (mcg/d)	Ca (mg/d)	P (mg/d)	Mg (mg/d)	Fe (mg/d)	Zn (mg/d)	Cu (mg/d)	Se (mcg/d)	Na (mg/d)	K (mg/d)
APIF	0.333	0.058	0.145	0.243	0.557	0.138	0.163	0.088	0.129	0.218	0.689	0.136	0.046	0.137	0.257	0.51	0.337	0.354
PPIF	0.142	0.248	0.586	0.322	0.311	0.337	0.364	0.573	0.185	0.334	0.445	0.655	0.333	0.389	0.537	0.346	0.364	0.509
APIM	0.361	0.516	0.117	0.426	0.7	0.532	0.409	0.136	0.037	0.389	0.687	0.346	0.292	0.582	0.206	0.682	0.496	0.343
PPIM	0.288	0.009	0.602	0.359	0.201	0.126	0.3	0.708	0.108	0.337	0.519	0.814	0.511	0.343	0.74	0.374	0.436	0.707

Fig. 3: Bivariate correlations among dietary protein intake and micronutrients for young female and male adults

APIF: Animal protein intake (g/day) for female, PPIF: Plant protein intake (g/day) for female, APIM: Animal protein intake (g/day) for male and PPIM: Plant protein intake (g/day) for male[14]



	Fruits	Vitamins	Minerals	Fiber	Whole grains	Calcium	Total proteins	Plant proteins	Fatty acids	Refined grains	Sodium	Added sugar	Saturated fats	Total points
FE<70%AP	2.2	3.8	4.3	4.8	1.1	9.2	2.6	3.6	8.5	6	3.4	8.4	6.7	64.6
FE>70%AP	1.6	3.8	4.3	4.8	0.5	10	3.3	2.3	6.2	7.2	4.5	8.1	4.6	60.4
ME<70%AP	1.8	3.8	4.3	3.8	0.7	10	3	3.1	6.2	4.8	2.3	8.9	6.2	58.9

Fig. 4: Modified healthy eating index for females and males (y-axis: Animal protein (%))

FE<70% AP: Young female adults eating less than 70% of proteins from animal sources, FE>70% AP: Young female adults eating more than 70% of proteins from animal sources, ME<70% AP: Young male adults eating less than 70% of proteins from animal sources and ME>70% AP: Young male adults eating less than 70% of proteins from animal sources[14]

Disease risks: Among animal proteins, red and processed meat have been specifically implicated with non-communicable diseases, including colorectal cancer, type 2 diabetes mellitus, and cardiovascular disease[49]. On the other hand, white meat is regarded as being protective. The association of red meat and disease risks has led many global organisations to advocate for the avoidance or reduction of red meat consumption[49]. Interestingly, the debate is not won yet; the scientific literature debate is ongoing, calling for the evidence base for such recommendations, with a strong attention on the methodology used and the sources of information, as well as their weighting. It is opined that food-based dietary guidelines should be based on comprehensive and methodologically sound analysis of health benefits and harms of these classes of proteins, not leaving behind the issues of food culture, accessibility, affordability, food traditions and other factors of sustainable diets[23,50-52], until then does it seem that this issue can be effectively laid to rest. Processed meat may have been condemned too early, arising perhaps from over-dependence on observational epidemiology and risk avoidance in food policy-making[52], undermining the importance of adequate consideration for the heterogeneous nature of the type and intensity of processing of such products, which would have required holistic and multidimensional approaches[53].

The Guidance for Cardiovascular Health Related to Animal-Based Protein Foods, based on US Dietary Guidelines, can be summarized under the subcategories: Balance, variety, plant inclusion, fish and seafood inclusion, choice of lean meat and poultry cuts, and avoidance of processed meats and fried meats. It is recommended that the daily total protein food intake should be sufficient to support nutrient adequacy without compromising intake from other food groups, the protein foods should be mixed to include different subgroups and foods to support nutrient adequacy, and accommodate personal preferences, plant-based protein foods such as nuts, seeds and legumes should be included, between 2-3 servings of fish or seafood per week should be consumed, lean cuts of meat and poultry should be chosen, processed and high-temperature cooking meat and fish should be avoided[54,55].

People have often been advised when choosing animal protein foods that they should avoid processed and/or fried animal products, such as sausages and chicken nuggets[56], to avoid disease risks such as cardiovascular diseases. The risk of cardiovascular disease has been associated with animal proteins than with plant proteins. However, the functional mechanisms through which animal protein might be more toxic than plant proteins have not been fully explained and explored, and thus not yet fully understood[57,58]. It has been established that study of diet and disease risk (cardiovascular disease risks) is difficult, owing to the complex nature of cardiovascular diseases, linked with main causal components formed over years[59,60], coupled with diets being complex as well, containing several bioactive substances that may contribute to or inhibit cardiovascular diseases which are unevenly distributed across food groups and subgroups, as well as being often influenced by food production, processing and consumption patterns.

Figure 5 shows cancer development-associated agents in meat products, in raw meat products, formed during meat product processing, by contamination, modulating factors, use of processing spices, or formed during digestion as reported in literature[52,61]. Substances or agents involved in meat processing linked with cancer development and cardiovascular diseases have been documented[61-63]. However, some of the substances reported are not peculiar to animal products, even though some of them are shown to be mutagenic, genotoxic, or carcinogenic; it is not logical to singly hold them responsible for the effects of processed meat dietary intake on non-communicable diseases or cancer in general[52,64]. A lot remains to be understood about the effects of different substances in processed meat on human health[61,63].

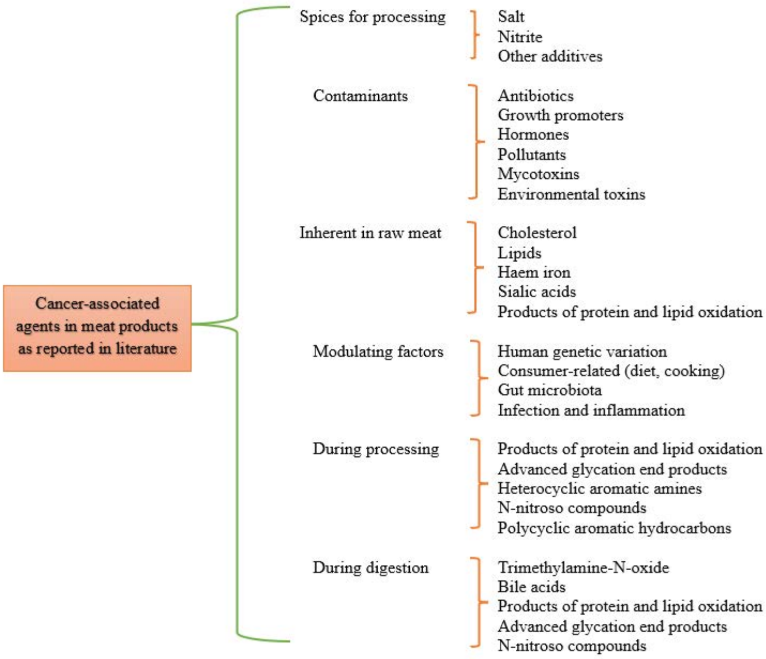


Fig. 5: Cancer-related agents in meat: Formed during processing, contamination, digestion, or influenced by spices and modulating factors[52,61]

The heterogeneous nature and inconsistent definition of meat processing contribute to the doubts cast against the results of disease-risk association of animal foods reported in the literature. Most studies that associate animal products with disease risks do not adopt a uniform definition of animal product terminologies, which may be misleading. Also, the heterogeneous nature of animal products is more often than not not taken into consideration. Lack of uniform classification of animal products[58] is a big problem in accepting the findings attributing animal products to disease risks. Processed meat has been described as further processing, which implies that the cooking of fresh meat before consumption is not regarded as processing but minimal processing. Hence, the products of such cooking are regarded as unprocessed meat products[52,65], corroborating the terms (processed and unprocessed meats) mostly used in nutritional epidemiological studies and dietary advice. Unfortunately, lack of uniform definitions of animal food terminologies and the heterogenous nature of animal foods and their products cast a big question mark on accurate assessment of their intake and relationship with disease-risks, which is regarded as one of the limitations of nutritional epidemiology, on which most of the findings associating disease-risks with animal proteins are based[52,66]. Processing techniques and processing methods, involving physical and chemical treatments and a combination of both, as well as inclusion of additives[53,67,68] are other factors that may contribute to disease risks associated with animal proteins, which are less or inadequately considered in studies making attempts to unravel the relationships between animal proteins and disease risks.

Regarding the association of animal proteins and disease risks, particularly regarding processing of meat and meat products, it has been noted for instance, using the effect of cooking on meat protein digestion and the use of nitrite in meat processing, that meat can lead to beneficial and detrimental changes in nutritional value, and may be linked with the formation of potentially harmful compounds, the nature and concentrations which are not easily investigated, owing to complex interactions among additives, ingredients, adherence to good manufacturing practices and processing techniques[52]. In agreement with previous authors, animal proteins and the effects of their processing on human health cannot and should not be generalized, and may not be as detrimental as widely perceived, that is, not to deny the possibility of the claimed risks. In addition, it should be noted that to ensure animal food safety, minimal processing of meat and meat products is required.

Several observational epidemiological studies have linked animal proteins (high consumption of red meat) with disease risks (non-communicable diseases). Low versus high dietary intake of processed or red meat was linked with decreased risk of all-cause mortality, coronary heart disease, type 2 diabetes, and colorectal cancer[69-71]. It has been observed that the increased relative risk per unit change in dietary intake, or for the lowest versus highest dietary intake group, is lower for unprocessed meat than for processed meat intake.

Several studies (meta-analysis) have also reported non-significant associations with dietary intake of unprocessed red meat, and it is worth noting that the largest effect sizes are reported for processed meat consumption and type 2 diabetes incidence, with most relative risk estimates greater than 1.2, uncommon in nutritional epidemiology[49]. How much risk a person in a group bears when compared with another person in another group is revealed by a relative risk. Of note, however, is that relative risks should not be interpreted in isolation but together with absolute risks of the event(s) in question[72]. Despite the availability of findings suggesting disease risks of animal proteins, there has not been any negative association with white meat, especially from poultry; rather, their protective potentials have been reported[73]. Interestingly, a comprehensive study (meta-analysis) reported consistent favourable relationships between dietary intake of animal proteins versus non-consumption (vegetarians and vegans) and better mental adult health[74]. The authors indicated that the more rigorous their analysis, the more the findings revealed positive and consistent results, although other meta-analysis[75,76] reported otherwise.

Several studies have linked high consumption of animal food, particularly processed and red meat, to disease risks such as obesity, diabetes mellitus, cardiovascular diseases, inflammation, and cancer development[69,77-81]. Unfortunately, the specific contribution of animal protein to the effects has not been established[82,83], as only total proteins are analyzed in many studies, while some others only differentiate between protein-rich foods without considering protein itself[15].

It is opined that nutritional epidemiology in its current form relies mainly on relatively weak methods, which requires significant improvements in scientific analysis, reporting, design and measurement[84], in addition to the potential bias in relative risk estimates limiting nutritional epidemiology, necessitating the need for more sophisticated approaches and models, since foods are not consumed in isolation[85]. Scientific literature questions the extent to which the relationship between the consumption of processed and red meat and colorectal cancer is confounded by dietary patterns[52]. A recent study, which assessed the relationship between estimated dietary protein intake and cardiovascular disease, stroke, and ischemic heart disease, revealed that neither plant nor animal protein consumption was linked with overall cardiovascular disease, ischemic heart disease, or stroke incidence[86].

Agricultural waste and animal food contamination: Animal food contamination and the generation of potential waste from animal agriculture are other concerns limiting animal protein intake, with implications on the environment and public health. Agricultural production generates large quantities of potential waste materials, which contribute to climate change and environmental pollution. Animal agriculture has been implicated in significant contributions to climate change and environmental pollution.

The agricultural sector, no doubt, is one of the main sectors generating the largest quantities of solid waste. Animal production solid wastes described as solid wastes generated from the production of livestock for whatever purposes, such as bedding/litter, animal carcasses; and food and meat processing solid wastes described as wastes produced from the processing of crop or animal products for human consumption, such as abattoir or slaughterhouses including hoofs, bones, feathers and banana peels etc., are examples of broad classification of agricultural solid wastes. Interestingly, agricultural waste materials are generated from all aspects of agriculture, but not peculiar to animal agriculture. Table 1 shows the broad classifications of agricultural solid waste[87]. The problem of waste generated from animal agriculture becoming a nuisance is largely dependent on a lack of proper awareness, improper orientation, and a

Table 1: Classification and causes or sources of agricultural solid wastes

Waste classification	Examples
Animal production	Bedding, carcasses, damaged feeders, and damaged water-trough
Food and meat processing	Hoofs, bones, feathers and banana peels
Crop production	Husks and crop residues
On-farm medical	Syringes, disposable needles, vaccine containers, or wrappers
Horticultural production	Grass cuttings and pruning wastes
Industrial agricultural	Cuttings
Chemical	Pesticide containers

governmental lackadaisical attitude in some parts of the world to effectively manage such waste. The animal producers who strive to ensure animal food security and their safety are not always to blame. In some parts of the world, agricultural practices are left in the hands of uneducated farmers with no access to adequate extension services[88-91].

In some parts of the world, the generated waste accumulates indiscriminately in open places, while they are burned indiscriminately in some other places, thereby constituting a nuisance to global health. However, researchers, including animal scientists, are advocating for the recycling of the potential agricultural wastes in order to reduce the cost of production, as well as to effectively manage the waste that otherwise would have endangered the environment and public health. Among the ongoing efforts and recommendations is the bioconversion of such wastes into non-conventional feed ingredients, including bioconversion adopting mushroom biotechnology[92-94] bioconversion of feather meal[95-97], bioconversion of poultry offal and crayfish fish wastes into poultry feed ingredients[98,99] and bioconversion of fruit wastes, oil sludge, and crop residues for feeding livestock[100-105]. Agricultural solid wastes could have negative impacts on food security, the environment, and human health. However, animal agriculture is not the only sector generating solid waste. Hence, all hands must be on deck to ensure their effective management without leading to negative impacts on animal protein intake, which has tremendous benefits for humans, significantly contributing to helping human beings overcome protein deficiencies, among other aforementioned benefits. However, animal scientists and producers should adopt the sustainable approach and be environmentally health-conscious in their practices.

The fear of synthetic antibiotics or chemical residues in animal foods has limited the consumption of animal foods. Some potential consumers have avoided animal proteins solely for this reason. Interestingly, deliberate and extensive research efforts have been focused on addressing chemical residues and contaminants in animal foods. Researchers have investigated the effect of plant-derived antibiotics as a replacement for synthetic antibiotics to minimize chemical and antibiotic contamination in animal foods[106-110]. Also, efforts are ongoing to fully understand the functional mechanism of probiotics, which are one of the current alternatives used in place of synthetic antibiotics in animal nutrition, for sustainability purposes[111,112]. Animal food safety is a concern for all and animal scientists are also making concerted efforts to ensure the safety of animal foods they produce. Studies by animal scientists have reported the beneficial effects of some feed additives such as garlic, ginger, turmeric, and their mixture in lowering low-density lipoprotein cholesterol, regarded as a risk factor for cardiovascular diseases, in animal production[113-116].

CONCLUSION

Plant proteins lack certain essential amino acids and have lower digestibility, especially affecting neonates and children. While combining different plant sources can improve amino acid profiles, challenges remain. Animal proteins provide complete amino acids and are highly digestible, but concerns around ethics, health risks, and sustainability persist. Despite technological advances, no true alternative matches the taste and texture of real meat. Red and processed meats are linked to health risks, but such claims are still debated. A balanced intake of both plant and animal proteins may help address respective limitations. Future approaches should be inclusive, culturally sensitive, and scientifically robust. With continued research and ethical practices, the benefits of animal proteins can be maximized while minimizing risks.

SIGNIFICANCE STATEMENT

This study identified the distinct nutritional profiles, health implications, and consumption patterns of plant and animal proteins, which could be beneficial for guiding dietary recommendations and shaping future nutritional policies. It highlights the nuanced effects of animal proteins, especially the differential impacts of red, processed, and white meats on health outcomes. This study will assist researchers in uncovering critical areas of protein research and dietary health relationships that have remained unexplored by many. Consequently, a new theory on the balanced integration of animal and plant proteins for optimal health outcomes may be developed.

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