Letters in Food Science & Technology

NARRATIVE REVIEW

Animal- and plant-based proteins: Amino-acid quality, digestibility, human health, functionality and environmental trade-offs-

A narrative review of current evidence

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ABSTRACT

Animal- and plant-derived proteins are major sources of dietary nitrogen and indispensable amino acids, but they differ in amino-acid pattern, digestibility, food matrix, accompanying nutrients, cost, cultural acceptability and environmental footprint. This narrative review integrates protein chemistry and digestion with evidence on muscle outcomes, cardiometabolic health, food functionality and sustainability. Animal proteins such as dairy products, eggs, fish and meat generally provide highly digestible protein and a complete indispensable-amino-acid profile; whey is rich in leucine and rapidly digested, whereas casein is digested more slowly. Plant proteins vary widely: Soy and some other legumes have useful indispensable-amino-acid profiles, while many cereal proteins are relatively low in lysine and several legumes are relatively low in sulfur amino acids. These limitations can be mitigated through dietary variety, complementary protein mixtures, food processing, fortification and adequate total intake. Protein-quality scores such as PDCAAS and DIAAS combine amino-acid adequacy with digestibility but are not interchangeable and do not represent whole-diet quality, health effects or sustainability.

Human trials show that both protein classes can support muscle adaptation when total protein and training are adequate. The most recent meta-analysis of randomised trials found a small average advantage for animal protein for muscle mass (standardised mean difference −0.20), driven mainly by non-soy plant proteins and plant-based diets (soy and milk protein did not differ), with no significant difference for strength or physical performance; a protein-matched resistance-training trial found no difference between a plant-based and a mixed diet. Plant-forward dietary patterns are commonly associated with favourable cardiometabolic outcomes, but effects depend on the foods displaced and the overall dietary pattern rather than protein origin alone. On average, many plant protein foods have lower greenhouse-gas emissions and land use than ruminant meat, although production system, processing and land-use change matter. The most defensible conclusion is that protein source should be selected by amino-acid adequacy, digestibility, food matrix, health context, affordability, preference and environmental impact, not by origin alone.

Keywords: Dietary protein; animal protein; plant protein; essential amino acids; digestibility; DIAAS; PDCAAS; muscle protein synthesis; cardiometabolic health; sustainability.

Colour key used in all figures and tables

Animal-source	Plant-source	Food & digestion	Physiology	Outcomes / caution	Modifiers / risk

Key points

- Both animal and plant proteins can meet indispensable-amino-acid needs when total protein, energy and food variety are adequate.
- In one pig-model study, all dairy proteins scored DIAAS ≥ 100, soy isolate and soy flour 75–99, and pea protein concentrate and whole-grain wheat < 75 (Figure 2) [7].
- RCT meta-analyses show a small average animal advantage for muscle mass (SMD −0.20) but no significant difference for strength or physical performance [12,13]; a protein-matched 12-week trial found no difference [14].
- Cohort data link plant protein with lower all-cause mortality (pooled effect size 0.92), but substitution and the whole food matter [17,18].
- Per 100 g protein, beef emits roughly 50 kg CO_2-eq versus about 0.4 kg for peas, yet variation within foods is large [22,24].

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1. Scope and approach

This is a narrative review intended to explain established mechanisms and prepare representative high-value reviews, meta-analyses, consensus reports and primary studies. It is not a systematic review: no exhaustive database search, duplicate screening, formal risk-of-bias assessment or preregistered protocol was undertaken. Evidence statements are therefore calibrated to study design, and causal conclusions are reserved for randomised trials where possible. Literature selection emphasised protein quality, amino-acid physiology, muscle outcomes, health associations and life-cycle assessment.

References were checked on 24th October 2026 against PubMed, PubMed Central or publisher records where these were accessible; DOIs are given for every cited work that has one. Quantitative values in the text and figures are taken from the cited abstracts or full texts; figures are schematic where stated.

2. Protein chemistry and biological roles

Proteins are polymers of amino acids linked by peptide bonds. Dietary digestion hydrolyses proteins and peptides into absorbable amino acids and small peptides, which enter portal circulation and contribute to synthesis of skeletal muscle, enzymes, transporters, antibodies, peptide hormones and other nitrogen-containing compounds. Nine amino acids are indispensable in adults because endogenous synthesis cannot meet physiological requirements: histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine [1]. Requirements differ by age, physiological state and health status. Protein also contributes to satiety, tissue repair and maintenance of nitrogen balance; it is not a substitute for sufficient energy, micronutrients or physical activity.

“Animal” and “plant” are broad categories, not uniform nutritional entities. Milk whey and casein differ in digestion kinetics; collagen is low in tryptophan and is not a complete protein; red meat, fish, eggs and dairy bring different micronutrients and accompanying fats. Similarly, soy isolate, tofu, lentils, peas, wheat gluten, oats and nuts differ markedly in amino-acid pattern, fibre, antinutritional factors and digestibility. A fair comparison must specify the food, processing, dose, comparator and outcome.

3. Sources and composition

Table 1 summarises the main protein-source groups. Fungal proteins such as mycoprotein (from *Fusarium venenatum*) are typically about 45% protein and 25% fibre by dry weight [2]. Commercially available plant protein isolates themselves differ in protein content and amino-acid composition [3], and the adequacy of protein and amino acids in vegetarian diets depends on dietary variety and energy intake [4].

Table 1. Major protein-source groups

Source group	Examples	Typical strengths	Important qualifications
Animal – dairy	Milk, yogurt, cheese, whey, casein	High digestibility; all indispensable amino acids; whey often leucine-rich; calcium and vitamin B_{12} in many foods	Lactose intolerance affects some people; saturated fat and sodium vary; milk allergy is distinct from lactose intolerance
Animal – eggs and fish	Eggs, fish, shellfish	High-quality protein; fish may provide long-chain omega-3 fatty acids; eggs provide choline and micronutrients	Allergy, food safety and sustainability vary by species and production
Animal – meat	Poultry, pork, beef, lamb	Highly digestible; supplies vitamin B_{12}, zinc and bioavailable iron in varying amounts	Processed meat should be distinguished from unprocessed meat; red/processed meat evidence and health implications are not identical
Plant – legumes	Beans, lentils, peas, chickpeas, soy	Protein plus fibre, folate, potassium and other phytochemicals; soy has a relatively balanced amino-acid pattern	Lysine is often adequate, while sulfur amino acids can be limiting; cooking improves digestibility and safety

Source group	Examples	Typical strengths	Important qualifications
Plant – cereals	Wheat, rice, oats, maize	Accessible, versatile, often affordable; cereals complement legumes in amino-acid pattern	Lysine is often the limiting amino acid; whole-grain matrix and processing affect accessibility
Plant – nuts and seeds	Peanuts, almonds, sesame, sunflower, chia	Protein with unsaturated fats, minerals and fibre	Protein density varies; amino-acid limitations and allergenicity vary
Fungal / emerging	Mycoprotein, microbial proteins	Can offer useful amino-acid profiles and lower land requirements in some systems [2]	Not botanically plant protein; products differ in processing, sodium, allergens and evidence base

Table 1. Statements are general tendencies; specific foods and products can differ substantially. Row shading follows the colour key (coral = animal, green = plant, blue = fungal/emerging).

4. Amino-acid quality and digestibility

Protein quality depends on the amount of each indispensable amino acid delivered to the body relative to requirements and on how much is digested and absorbed. A limiting amino acid constrains the use of the other amino acids for protein synthesis; surplus amino acids cannot be stored as a dedicated protein reserve and are metabolised, with nitrogen largely excreted as urea. Cereals are commonly lysine-limited, whereas legumes may be relatively limited in methionine plus cysteine. Combining legumes and cereals across the day can improve the overall indispensable-amino-acid pattern; they need not always be consumed in the same mouthful (Figure 1). Soy is an important exception to overly broad claims that all plant proteins are low quality.

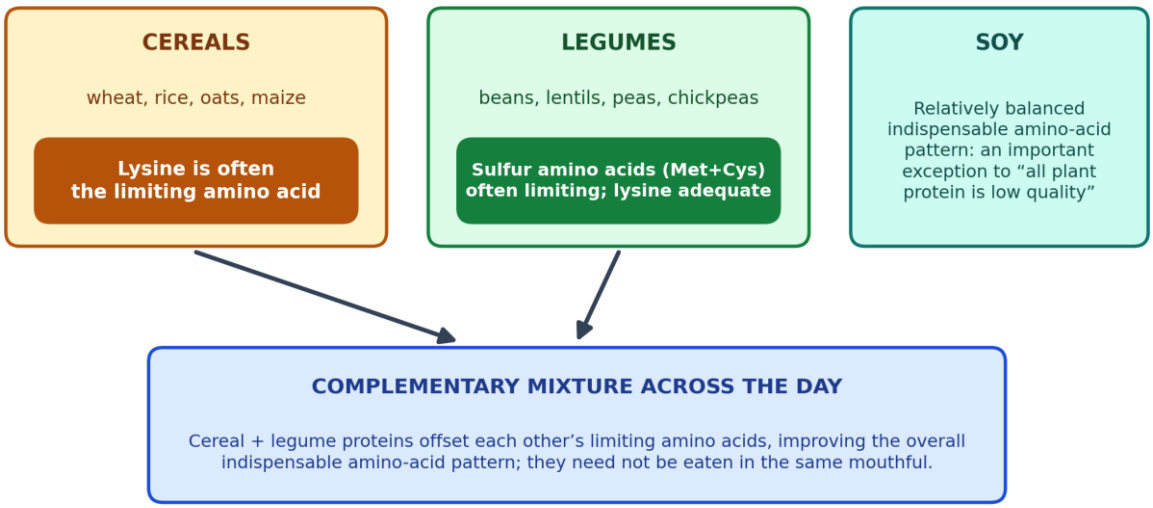


Figure 1. Limiting amino acids in cereals and legumes, and how complementary mixtures improve the overall pattern. Schematic; soy shown separately because its pattern is comparatively balanced.

PDCAAS (protein digestibility-corrected amino acid score) uses the limiting indispensable amino-acid score multiplied by fecal protein digestibility and traditionally truncates values at 1.0. DIAAS (digestible indispensable amino acid score) uses ileal digestibility of individual indispensable amino acids and does not truncate scores in the same way [1,5]. DIAAS is conceptually more sensitive to amino-acid-specific digestibility, but human ileal data are limited and values depend on the food and processing. Neither score by itself predicts long-term health, ecological footprint or the quality of the whole diet; a recent review also notes that diets high in whole-food plant proteins may require greater total protein and energy intakes to offset lower protein quality [6].

Table 2. Selected differences in protein-quality assessment

Feature	PDCAAS	DIAAS
Digestibility basis	Fecal protein digestibility	Ileal digestibility of individual indispensable amino acids
Amino-acid specificity	Limiting amino-acid score adjusted by overall digestibility	Each indispensable amino acid corrected for ileal digestibility
Score ceiling	Traditionally truncated at 1.0	Not truncated at 1.0
Key limitation	Fecal digestibility may overestimate amino-acid availability; truncation hides differences among high-scoring foods	Data and standardised human measurements remain limited; score does not capture whole-diet effects

Table 2. Adapted from FAO and DIAAS methodological reviews [1,5].

Measured values illustrate the spread. In a pig-model study of eight foods, all four dairy proteins (whey protein isolate, whey protein concentrate, milk protein concentrate, skimmed milk powder) reached DIAAS ≥ 100; soy protein isolate and soy flour fell in the 75–99 "good quality" band; and pea protein concentrate and whole-grain wheat scored below 75 (Figure 2). PDCAAS-like values were higher than DIAAS for skimmed milk powder, pea concentrate, soy isolate, soy flour and wheat, indicating that fecal-based scoring can overestimate quality [7]. Another analysis of 17 protein sources found considerable DIAAS variation within the same protein source, and showed that potato, soy and pea proteins can complement other plant proteins in simulated mixtures [8].

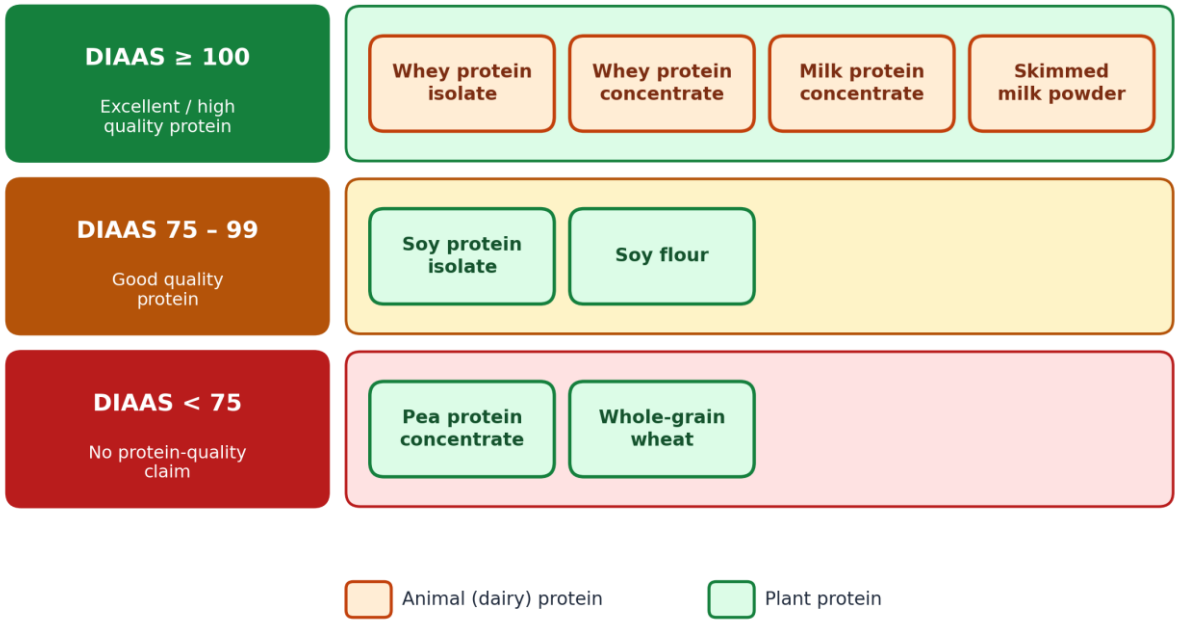


Figure 2. FAO DIAAS claim categories applied to eight foods tested by Mathai et al. [7]. Standardised ileal digestibility was determined in pigs; categories refer to the scoring patterns used in that study and will differ with age group, method, processing and product. Coral = animal (dairy); green = plant.

5. Digestion, absorption and muscle-protein synthesis

After gastric and pancreatic proteolysis, amino acids and small peptides are absorbed by intestinal transporters. Postprandial aminoacidaemia supplies substrate and acts as a signal for muscle protein synthesis. Leucine is an important nutrient signal for mTORC1-associated anabolic signalling, but leucine alone cannot sustain synthesis without the other indispensable amino acids. Exercise sensitises muscle to amino acids, while ageing, inactivity, illness and energy deficit can reduce anabolic

responsiveness. Protein dose, meal distribution, total daily intake, food matrix and exercise therefore modify the apparent source effect.

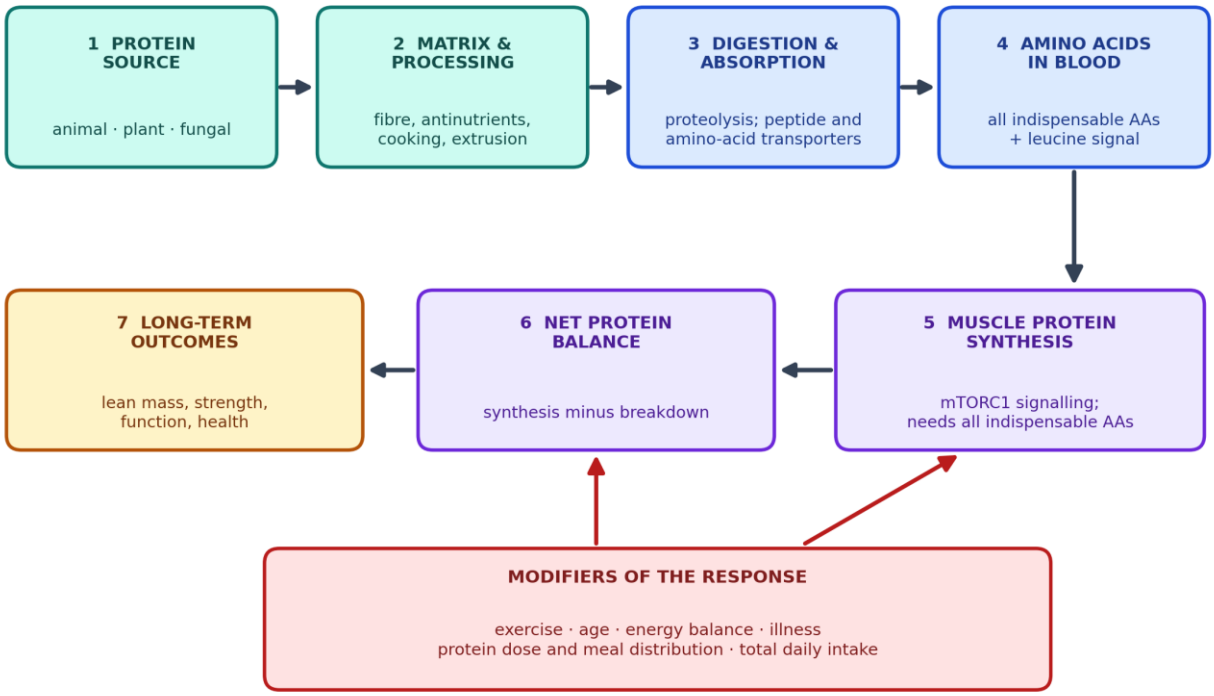


Figure 3. Mechanistic framework linking protein source, digestion, amino-acid availability and long-term muscle outcomes. The diagram is conceptual and does not imply that source alone determines outcome.

Whey is typically rapidly digested and leucine-rich; casein tends to form a gastric curd and yield a slower amino-acid appearance profile. These kinetic differences are real but should not be interpreted as proving that one protein is always better for long-term health. Acute studies of soy and wheat protein have shown a lower muscle-protein-synthetic response than several animal proteins, which has been attributed to lower digestibility and greater splanchnic extraction of plant-derived amino acids, although few plant proteins have been studied and strategies exist to augment their anabolic properties [9]. Plant proteins may have lower digestibility because of cell walls, fibre, protease inhibitors, phytate and other matrix effects. Soaking, fermentation, germination, cooking, extrusion and isolation can alter these factors, with the direction and magnitude depending on the ingredient and process. Heating is beneficial for many legumes but excessive heat can reduce availability of some amino acids, notably lysine through Maillard reactions. Improving the amino-acid composition of the diet can compensate for the lower anabolic potential of some plant proteins [10], and the relevance of protein quality to resistance-exercise adaptation has been debated [11].

6. Muscle mass, strength and physical performance

Evidence from acute tracer studies, supplementation trials and meta-analyses is not entirely uniform. Figure 4 summarises the three key studies. Lim et al. pooled 16 randomised trials and found no overall effect of protein source on absolute lean mass or muscle strength, although percent lean mass favoured animal protein, particularly in adults younger than 50 years [12]. A later systematic review and meta-analysis by Reid-McCann et al. (2025), including 30 trials in the muscle-mass meta-analysis, reported a small average advantage for animal protein (standardised mean difference −0.20 for plant versus animal; 95% CI −0.37 to −0.03), with substantial heterogeneity [13]. The effect was present in adults younger than 60 years but not in those aged 60 years or older (SMD −0.05; 95% CI −0.32 to 0.23). It was also food-specific: soy and milk protein did not differ (SMD −0.02; 17 trials), whereas non-soy plant proteins (rice, chia, oat, potato; SMD −0.58; 5 trials) and plant-based diets (SMD −0.51; 7 trials) performed less well than animal comparators (Figure 5). No significant difference was found for muscle

strength (14 trials) or physical performance (5 trials), and no trial examined sarcopenia as an outcome [13].

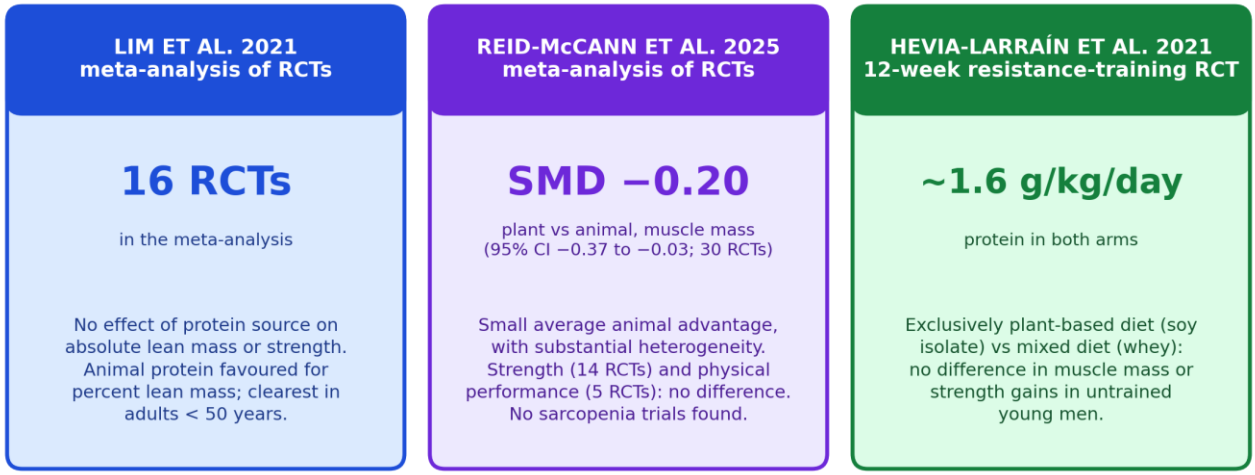


Figure 4. Evidence at a glance: three key studies on protein source and muscle outcomes [12–14]. SMD = standardised mean difference; RCT = randomised controlled trial.

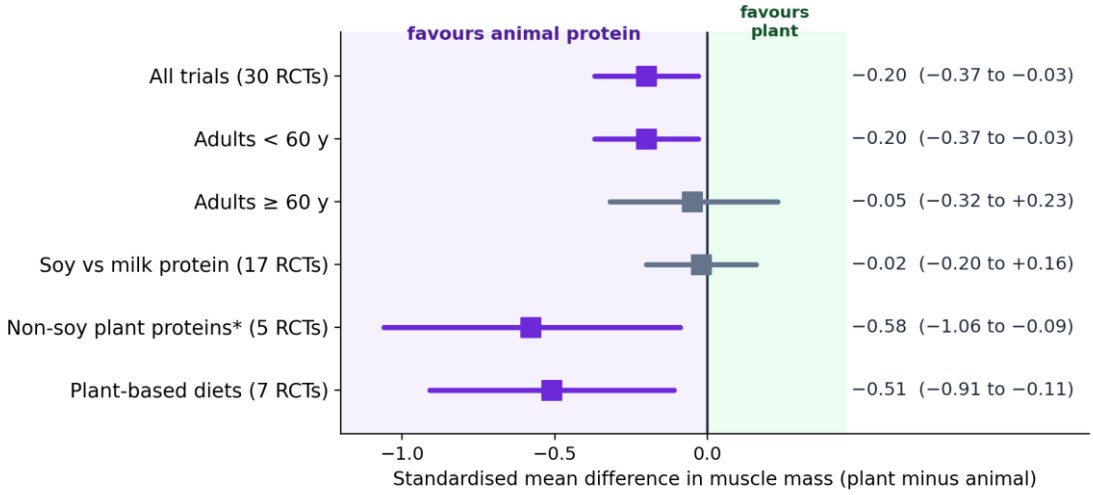


Figure 5. Pooled standardised mean differences in muscle mass, plant versus animal protein, from Reid-McCann et al. [13]. Negative values favour animal protein; purple = 95% CI excludes zero, grey = CI includes zero. *Rice, chia, oat and potato protein.

These results do not justify a blanket conclusion that plant protein cannot support muscle. A protein-matched, 12-week resistance-training trial in untrained young men found that an exclusively plant-based diet (plant foods plus soy protein isolate) and a mixed diet (with whey supplementation), each providing about 1.6 g protein/kg/day, produced no different gains in muscle mass or strength [14]. The wider evidence base includes heterogeneous plant proteins, doses, populations, training protocols and comparators; many studies provide total protein above the minimum requirement, potentially narrowing differences. Adequate total protein, a diverse indispensable-amino-acid supply, sufficient energy and progressive resistance exercise are central.

For older adults or people with poor appetite, choosing a protein-dense, digestible food and distributing protein across meals may be practical [15,16]; much of the supporting evidence is observational and from high-income countries [15], and the effect of plant-rich diets on appetite in older adults remains uncertain [16]. Individual needs should be assessed clinically in kidney disease or other relevant conditions.

Table 3. Key trials and meta-analyses on protein source and muscle outcomes

Study	Design and population	Main finding	Reading
Lim et al. 2021 [12]	Systematic review; 16 RCTs in meta-analysis; adults	No effect of source on absolute lean mass or strength; animal protein favoured for percent lean mass, especially in adults < 50 y	Small, outcome-dependent difference
Reid-McCann et al. 2025 [13]	Systematic review; 30 RCTs for muscle mass (14 strength; 5 performance)	Muscle mass SMD −0.20 (95% CI −0.37 to −0.03); soy = milk (SMD −0.02); non-soy plant protein −0.58; plant-based diets −0.51; no strength or performance difference; no sarcopenia trials	Food-specific; soy comparable to milk
Hevia-Larraín et al. 2021 [14]	12-week resistance-training RCT; untrained young men; ~1.6 g protein/kg/day in both arms	Plant-based diet (soy isolate) and mixed diet (whey) produced no different gains in muscle mass or strength	Adequate total protein narrows differences

Table 3. SMD = standardised mean difference (negative values favour animal protein in [13]); RCT = randomised controlled trial.

7. Cardiometabolic and broader health outcomes

Health effects are best interpreted in the context of the food replacing another food. Animal and plant protein sources come with different nutrient clusters (the "protein package"), and associations with cardiometabolic risk vary markedly by the type of animal protein [17] (Figure 6). Replacing processed meat or some red meat with legumes, nuts, soy foods or whole grains changes not only protein source but also fibre, unsaturated fat, sodium, haem iron and other compounds. In a systematic review and dose-response meta-analysis of prospective cohorts, higher total protein intake was associated with lower all-cause mortality (pooled effect size 0.94; 95% CI 0.89–0.99) and higher plant protein intake with lower all-cause mortality (0.92; 95% CI 0.87–0.97); each additional 3% of energy from plant protein was associated with about 5% lower all-cause mortality, whereas animal protein was not significantly associated with cardiovascular or cancer mortality [18]. Such associations are subject to residual confounding and dietary-pattern clustering, which limit causal attribution to protein itself. Soy foods have been reviewed separately for clinical and epidemiological outcomes [19], and some authors argue that unprocessed red meat can be included within healthful dietary patterns [20]. Fish, yogurt, eggs and unprocessed poultry are not nutritionally equivalent to processed meat, and animal foods should not be treated as a single exposure.

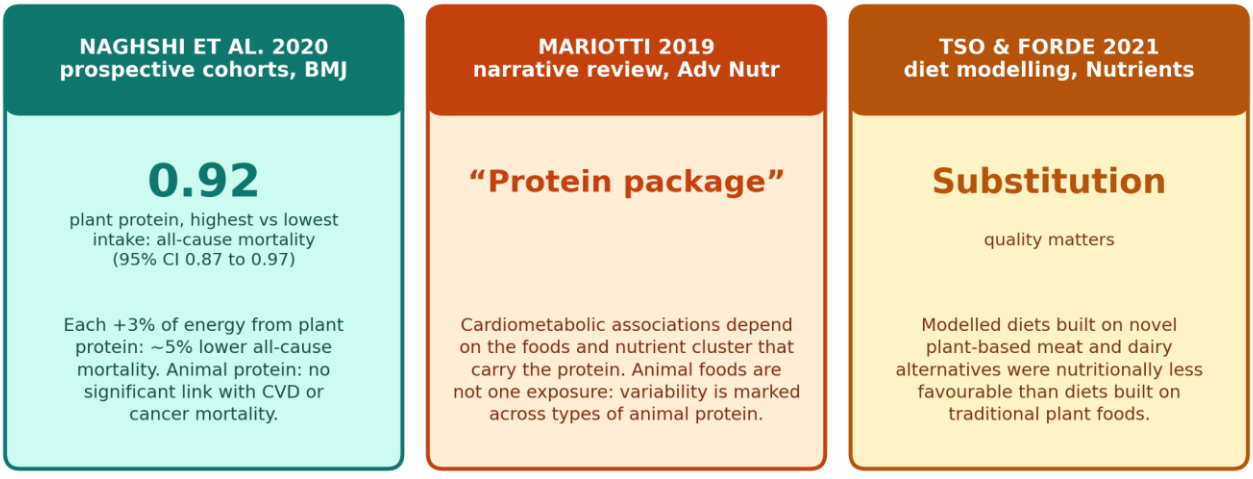


Figure 6. Evidence at a glance for cardiometabolic outcomes and substitution [17,18,21]. Effect sizes for Naghshi et al. are pooled effect sizes (highest versus lowest intake).

Potential mechanisms for plant-forward patterns include soluble fibre and fermentation products, unsaturated fats, lower energy density, phytochemicals, and replacement of foods rich in sodium or saturated fat. Mechanisms associated with animal foods include highly bioavailable vitamin B12, haem iron and zinc, while high intake of processed meat may also entail sodium, nitrite and other exposures. Substitution quality matters: a dietary-modelling study found that diets built on novel plant-based meat and dairy alternatives were nutritionally less favourable than diets built on traditional plant foods [21]. The net effect depends on the food, amount, processing, cooking method, baseline diet and individual risk profile; protein source alone is an incomplete causal explanation.

8. Environmental sustainability and food systems

Life-cycle assessments commonly find that legumes and many other plant protein foods have lower greenhouse-gas emissions and land use per unit of protein than ruminant meat. Using global averages from Poore and Nemecek, producing 100 g of protein from beef (beef herd) emits about 50 kg CO_2-equivalent, compared with about 11 kg for cheese, 5.7 kg for poultry, 2 kg for tofu and 0.4 kg for peas (Figure 7) [22,23]. Within a food, the range is wide: for dairy and beef cattle combined, high-impact producers released about 12 times as many greenhouse gases as low-impact producers [22]. A review of 52 life-cycle assessments reached a similar conclusion, with the most climate-friendly protein sources up to 100 times lower in carbon footprint than the least climate-friendly, differences being mainly attributable to production system; land occupation ranged from negligible for seafood to over 2,000 m² per kg protein for extensive cattle farming, versus about 30 m² for poultry [24].

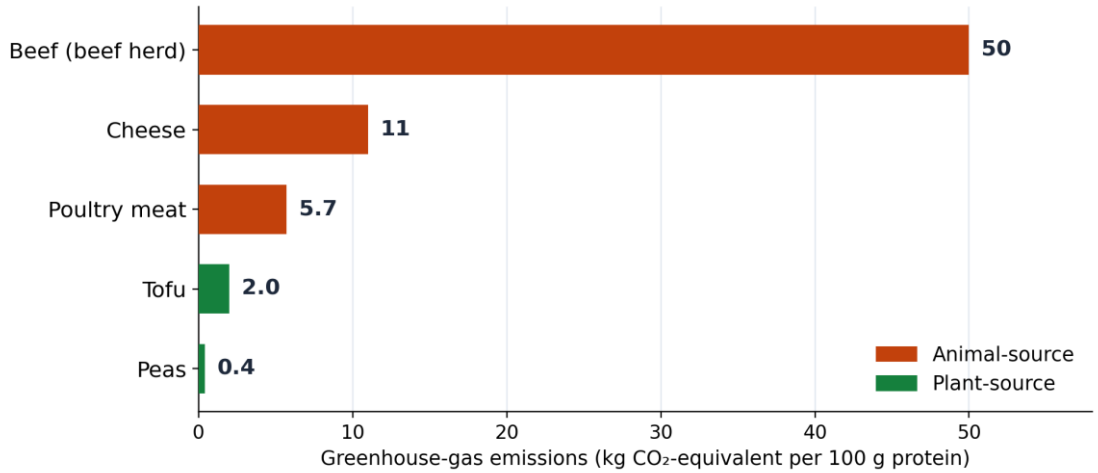


Figure 7. Greenhouse-gas emissions per 100 g protein for five foods. Values are the rounded global averages reported by Poore and Nemecek [22] and reproduced by Our World in Data [23]; later dataset updates differ slightly (for example, cheese ≈ 8–11 kg). Producer-level variation within each food is large.

Cattle and sheep can have high impacts because of enteric methane, feed production and land requirements, although they may use non-arable land and produce co-products. Poultry, eggs, dairy, pork, aquaculture and wild-caught fish differ from ruminant meat and from each other. Plant foods also vary due to fertiliser, irrigation, land-use change, processing, refrigeration, transport and food loss. Water scarcity-weighted impact is not equivalent to total water use, and environmental conclusions depend on the functional unit (per kg food, per kcal, per gram protein or per nutrient delivered). Strategies and constraints for meeting future protein demand are reviewed in [25,26].

Thus “plant-based is always sustainable” is too simple, just as “local is always lower impact” is too simple. Substitution matters: replacing a high-impact food with a lower-impact protein while maintaining nutritional adequacy generally offers a clearer environmental pathway than evaluating a food in isolation. Social factors - including affordability, cultural dietary patterns, farmer livelihoods and access to fortified foods - also matter, and sustainable healthy diets are framed internationally around health, environmental and sociocultural dimensions together [27].

9. Food technology and functionality

Protein functionality arises from molecular structure, charge, hydrophobicity, solubility, aggregation and interactions with water, lipids and other ingredients. Heat can denature globular proteins and expose hydrophobic regions, promoting gelation or aggregation; pH near the isoelectric point often reduces solubility; salts alter electrostatic interactions; high pressure, extrusion and fermentation can modify structure and texture. Whey proteins can form heat-induced gels, caseins stabilise emulsions, and plant proteins can be used in beverages, meat analogues, foams and emulsions, but solubility and flavour may require formulation [28–30]. Plant-based foods often need fortification with micronutrients such as calcium, zinc and vitamin D to approach the nutrient content of the animal foods they replace [28]. Functional performance is not identical to nutritional quality: an isolate may perform well technologically while still needing assessment for amino-acid adequacy, digestibility, sodium, allergens and processing effects [21,29].

10. Mechanistic synthesis

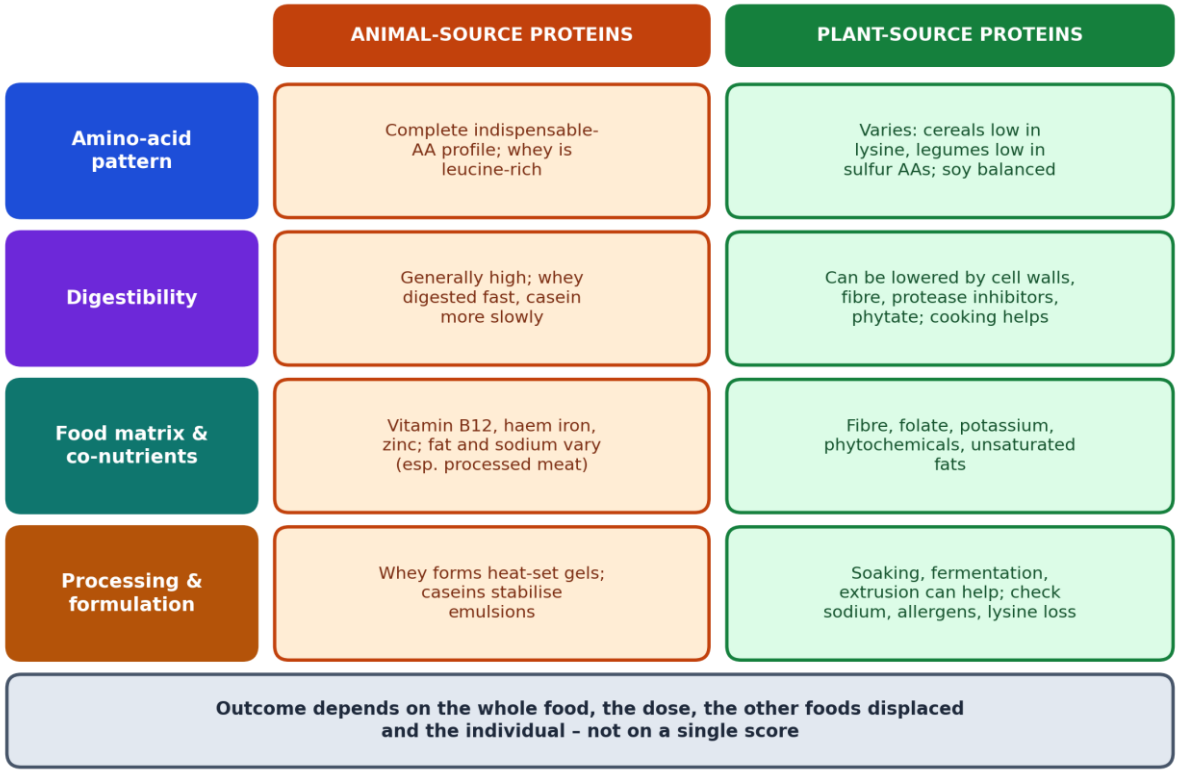


Figure 8. Factors influencing protein quality, summarised qualitatively for animal- and plant-source proteins. The diagram describes tendencies reported in the text, not measured values or a universal ranking; soy, mycoprotein and processed isolates can differ substantially.

Figure 8 summarises the factors involved. Mechanism summary: (1) amino-acid composition sets the potential indispensable-amino-acid supply; (2) matrix and processing influence release and digestion; (3) absorbed amino acids provide both substrate and signalling; (4) exercise, age, energy balance and illness modify tissue response; and (5) long-term health and sustainability depend on the whole food and dietary pattern. These links are biologically plausible and supported to varying degrees, but they should not be collapsed into a single score.

11. Practical synthesis

Table 4. Practical principles

Prioritise adequacy	Meet individual protein and energy needs rather than focusing only on source labels.
Use variety	Legumes, soy foods, whole grains, nuts and seeds can complement one another; mixed diets may also include dairy, eggs, fish or meat according to preference.
Consider processing	Cooking legumes improves safety and often digestibility; fermentation and other processes may improve functionality and reduce some antinutritional factors.
Compare like with like	Match total protein, energy, exercise, food matrix and comparator when interpreting studies.
Use whole-food context	Fibre, fats, sodium, micronutrients and degree of processing influence health beyond protein grams.
Personalise when needed	Food allergies, lactose intolerance, kidney disease, malnutrition risk, pregnancy, athletic training and older age can change practical recommendations; clinical conditions warrant individualised advice.

12. Limitations and research priorities

Major uncertainties include limited head-to-head trials of diverse whole foods; short trial duration; inconsistent protein doses and outcome measures; underrepresentation of older, frail and culturally diverse populations; and imperfect translation from acute muscle-protein-synthesis measures to long-term function. DIAAS values derived in pigs approximate but do not replace human ileal data, and cohort associations remain vulnerable to confounding. Research should compare whole-food dietary patterns and matched protein doses, report amino-acid composition and digestibility, stratify by age, sex and exercise, measure clinically meaningful outcomes, and integrate nutritional adequacy with life-cycle assessment. DIAAS values for cooked mixed meals and commonly consumed foods require further standardised data.

13. Conclusions

Animal and plant proteins both contribute indispensable amino acids and can support health. Animal proteins often have higher digestibility and a favourable indispensable-amino-acid pattern, while plant foods contribute fibre and other beneficial components and often have lower environmental impacts. Soy and several processed plant proteins can narrow quality differences; complementary food combinations and adequate total intake further improve plant-based adequacy. Human evidence suggests a small average animal-protein advantage for some muscle-mass outcomes, concentrated in non-soy plant proteins and plant-based diets, while strength and performance differences are not significant and the certainty is constrained by heterogeneous trials. The scientifically sound approach is food-specific and context-dependent: evaluate amino-acid quality, digestibility, whole-food composition, health endpoints, affordability and environmental impact together.

Declarations

1. Use of AI-Assisted Tools: AI-assisted tools were used during the preparation of this manuscript for organising scientific information, developing the review structure, improving language and readability, and refining the presentation of scientific concepts. The author(s) critically evaluated, verified, and edited all AI-assisted content and take full responsibility for the accuracy, originality, scientific integrity, interpretation of the cited evidence, and final content of the manuscript.

2. Funding: The author(s) received no specific financial support, research grants, or sponsorship from any government, private, commercial, industrial, or non-governmental funding agency for the preparation of this narrative review.

3. Conflict of Interest: The author(s) declare that they have no financial, commercial, institutional, personal, or professional conflicts of interest that could have influenced the preparation, interpretation, or presentation of this manuscript.

4. Ethical Approval: Ethical approval was not required for this narrative review because it is based exclusively on previously published scientific literature, research reports, and publicly available information. No experiments involving human participants or animals were conducted as part of this work.

5. Informed Consent: Not applicable. This manuscript does not involve the recruitment of human participants, collection of personal information, or use of identifiable patient data.

6. Data Availability Statement: No new experimental data were generated or analysed during the preparation of this review. All information discussed is derived from previously published research articles, scientific databases, institutional reports, and other publicly accessible sources, which are appropriately cited in the manuscript.

7. Author Contributions: The author(s) contributed to the conceptualization, visualization and development of the review, identification and collection of relevant scientific literature, examination of animal- and plant-based protein sources, evaluation of amino-acid composition and protein quality, assessment of digestibility and bioavailability, analysis of nutritional and health implications, investigation of functional and technological properties, evaluation of environmental impacts, manuscript preparation, critical revision, and approval of the final version.

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The author also acknowledges the scientific and industrial communities involved in the development and processing of protein-rich foods, including dairy products, eggs, meat, fish, pulses, legumes, cereals, oilseeds, nuts, seeds, and emerging alternative protein sources. Their research has contributed to understanding protein functionality, solubility, emulsification, gelation, foaming, texture development, food formulation, and technological applications.

The author further recognises the contributions of researchers investigating the relationships between dietary protein consumption and human health, including muscle development and maintenance, metabolic health, cardiovascular health, healthy ageing, and nutritional adequacy across different population groups.

Grateful acknowledgement is also extended to scientists and institutions examining the environmental implications of protein production, particularly greenhouse gas emissions, land and water requirements,

biodiversity, resource utilisation, food-system sustainability and the potential of alternative protein sources to support environmentally responsible food production.

Finally, the author acknowledges the valuable contributions of national and international research institutions, scientific databases, academic publications and publicly accessible reports consulted during the preparation of this narrative review.

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