Nutritional Value of Plant Proteins

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The quality and nutritional value of dietary proteins are determined by the quantity, digestibility and bioavailability of essential amino acids (EAA), which play a critical role in human growth, longevity and metabolic health. Plant-source protein is often deficient in one or more EAAs (e.g., branched-chain amino acids, lysine, methionine and/or tryptophan) and, in its natural form, is less digestible than animal-source protein. Nevertheless, dietary intake of plant-source protein has been promoted because of its potential health benefits, lower cost of production and lower environmental impact compared to animal-source protein. Implementation of dietary strategies that improve both human and planetary health are of critical importance and subject to growing interest from researchers and consumers.

Keywords: plant proteins ; nutrition ; humans

1. Introduction

Dietary protein is an important macronutrient that plays a critical role in human health and longevity [1]. All 20 amino acids (AA) are required, in adequate amounts, for tissue protein synthesis and maintenance of normal metabolic function [1][2][3][4]. The nine essential amino acids (EAA) are particularly important as they cannot be synthesised in human cells at sufficient rates to meet metabolic demand (MD), so must be obtained from dietary protein sources [1][2][3][4]. Recommended dietary allowance (RDA) for protein for adults is currently ~0.8 $g \cdot kg^{-1} \cdot d^{-1}$, but is higher for populations with greater MD (e.g., infants, children, pregnant/lactating women, athletes) [5]. In developing regions, protein malnutrition is a major issue [6][7], whereas in developed regions protein intake is generally sufficient and discussions are based on whether higher protein intakes positively or negatively impact health and fitness [1][8].

Over the last 60 years, the per capita global protein consumption has increased [9], but rapid population growth and climate change threaten food security, and human and planetary health [6][10][11][12][13]. In response, scientists and politicians have encouraged a transition away from animal- to plant-sourced foods as a means to meet sustainable development goals (SDGs) [10][11][12][13]. However, the affordability, validity and nutritional adequacy of plant-based diets have been questioned [14][15][16].

Plant crops are the primary harvesters of solar energy acting as a cost and energy-efficient nutrient-rich sink—and a valuable source of protein, carbohydrate, essential vitamins and minerals [17]. Hence, by necessity or choice, plant foods and plant-based diets have been popular throughout human history, with large segments of the population adopting them because of personal, ethical, religious or philosophical beliefs. Consequently, we deem it pertinent to evaluate and review dietary strategies that can be used to enhance the nutritional value of plant-sourced protein (PSP) for human consumption.

2. Protein Quality

In addition to the protein RDA, the quality of the protein must be considered as it is inextricably linked to RDA and protein adequacy. Protein quality is based on the ability of the protein to deliver the individual EAAs in sufficient amounts to meet requirements. Indeed, several studies have reported differences between isonitrogenous PSP and ASP, showing that PSP is utilised with a lower efficiency, implying that PSP is lower-quality than ASP [18].

Quantitative assessment of dietary protein quality was devised to reflect postprandial bioavailability of the EAAs in relation to requirements, determined by the content and profile of EAA and the true ileal digestibility of the protein. Although several methods exist to evaluate protein quality, the digestible indispensable amino acid score (DIAAS) has been adopted by the World Health Organisation (WHO)/Food and Agriculture Organisation (FAO)/United Nations University (UNU) [19][20]. The DIAAS is calculated as the mg amount of digestible EAA in 1 g of dietary protein (mixed or single-source) divided by the mg amount of the digestible EAA in 1 g in an ‘ideal’ reference protein [19][20]. For foods susceptible to damage from processing, digestible reactive (bioavailable) Lys is used rather than total digestible Lys [19]. The lowest scoring EAA is the DIAAS and the first limiting EAA (LEAA). Consequently, for the EAR of protein (0.66 g·kg^{-1}·d^{-1}) the DIAAS represent the fraction of the minimum daily requirement of the first LEAA consumed. Thus, 0.66 g·kg^{-1} of protein with a DIAAS of 1.0 will, in theory, supply 100% of the minimum daily requirements of the first LEAA and all other EAAs [19][20]. If the protein has a DIAAS of >1.0 the protein is considered 'excellent/high' quality, >0.75 'good' quality and <0.75 no protein quality claim can be made. Generally, ASP is considered 'excellent' quality, whilst PSP, in its natural form, is generally considered 'low' quality with most scoring <0.75 (Table 1).

Table 1. Global plant protein supply (% total plant protein intake), digestibility and digestible indispensable amino acid score (DIAAS) range. CP, crude protein; whey protein concentrate (WPC) and whole milk powder (WMP) are provided as animal protein references. Leu, leucine; Lys, lysine; SAA, sulphur amino acids (methionine and cysteine); Trp, tryptophan. First limiting amino acid is in bold. [a] World Health Organisation (WHO)/Food and Agriculture Organisation (FAO)/United Nations University (UNU) adult indispensable amino acid (IAA) reference pattern as mg IAA·g protein^{-1} (Leu, 66; Lys, 57; SAA, 27; Trp, 8.5) [19].

Plant Source	Global Supply %	Protein % Mass	CP True Ileal Digestibility %	DIAAS [a]			
				Leu	Lys	SAA	Trp
Wheat [19][21][22][23][24][25][26]	32	11–17	71–94	0.82–1.06	**0.20–0.54**	0.64–1.51	1.15–1.62
Rice [21][22][23][25][26][27]	21	8–9	73–90	0.84–1.17	**0.37–0.73**	0.40–2.11	0.84–2.29
Maize [21][22][26][27]	8	7–9	70–76	1.31–2.01	**0.48–0.54**	0.68–1.46	0.70–1.04
Pulses [21][24][23][26][27][28]	5	22–30	78–90	0.97–1.16	1.05–1.53	**0.46–0.85**	0.78–1.82
Beans [21][26][27][28]	3	23–25	58–83	0.72–1.09	0.93–0.98	**0.49–0.60**	0.76–1.86
Potatoes [26][27]	3	2–3	52–58	0.34–0.39	0.42–0.46	0.38–0.77	0.49–1.42
Soya [21][24][26][27]	3	12–43	68–88	1.14–1.39	1.10–1.25	**0.93–1.12**	2.04–2.11
Sorghum [21][23][26]	2	10–11	65–83	1.58–1.79	**0.26–0.29**	0.54–0.97	0.57–1.05
Groundnuts [21][26][27]	2	26	77–91	0.84–0.94	**0.38–0.52**	0.58–0.98	0.74–1.58
Millet [21][25][26]	1	8–17	80–90	1.70–1.73	**0.07–0.10**	0.62–1.17	0.77–1.82
WPC [21][24][26][27]	N/A	80–85	95–98	1.91–1.98	1.80–2.41	1.99–2.00	2.99–3.40

Plant Source	Global Supply %	Protein % Mass	CP True Ileal Digestibility %	DIAAS [a]			
				Leu	Lys	SAA	Trp
WMP [19][21][26]	N/A	28	96	1.62	1.54	1.43	1.82

In the main cereal crops, Lys is the first LEAA, and the sulphur-containing amino acids (SAA: Met and Cys) are usually the first LEAA in the legume crops, although there are exceptions where Trp (e.g., haricot beans, split yellow peas, chickpea, pinto beans) or Lys (black-eyed peas) is the first LEAA (Table 1), but it should be noted that PSPs also have lower branched-chain amino acid (BCAA) (Ile, Leu, Val) and Trp scores than most ASPs (Table 1) [7][17]. In the last decade, some new and novel high-quality PSPs have been identified and researched (e.g., fungi, pseudo-cereals, aquatic plants and algae), however, they are yet to be commercially cultivated for human consumption [29].

Protein RDA is based on high-quality protein intake (i.e., DIAAS > 1.0) [19][20], but for lower-quality proteins (i.e., DIAAS < 0.75) a larger quantity of protein would have to be consumed to meet protein/AA requirements. For example, if dietary protein consumption was entirely dependent on three main cereal staples (i.e., wheat, rice and maize), the DIAAS (based on a weighted mean average (Table 1)) would be ~0.5 (LEAA: Lys). Consequently, to meet minimum requirements for Lys, the EAR of protein would need to double (i.e., >1.3 g·kg^{-1}·d^{-1}). However, in most instances fold increases in PSP intake would not be necessary to meet requirements as normally multiple different dietary PSPs and ASP are consumed [9]. Nevertheless, it is necessary to consider protein quality alongside RDA, particularly for populations with higher MD and thus, EAA and protein requirements (e.g., infants, children, pregnant, elderly, physically active, athletes) acute and/or chronic disease (e.g., pneumonia, gastrointestinal infection, cachexia/sarcopenia) limited access to a variety of PSPs and/or consuming insufficient quantities of food and protein in general [5][6][7][18][30][31].

As the DIAAS is calculated per gram of protein, comparative evaluation of the DIAAS between different protein sources is conducted on an isonitrogenous basis [19]. Consequently, the DIAAS fails to consider that, in their natural form, plant-sourced foods typically have a lower protein density (i.e., unit of protein mass per unit of product mass) and higher caloric density (i.e., kcal per unit of protein mass) compared to animal-source foods [4]. For example, to provide a 0.3 g·kg^{-1} of protein (i.e., a meal-sized serving), the caloric equivalent for soybeans would be higher than poultry meat despite having similar DIAAS (3.4 kcal·kg^{-1} vs. 1.9 kcal·kg^{-1}) [21]. Animal-source foods with low protein density (e.g., whole milk at 3–4% protein) would also have higher caloric equivalents (4.9 kcal·kg^{-1}), but score markedly better than low-quality, low-density plant foods (e.g., 14.6 kcal·kg^{-1} for wheat flour and 13.9 kcal·kg^{-1} for groundnuts). In most instances, consuming greater amounts of PSP to compensate for inferior protein quality is not always feasible and may negatively impact health (e.g., obesity, metabolic syndrome, malnutrition and gastrointestinal distress due to overconsumption of calories, carbohydrate, dietary fibre and antinutrients). Therefore, it is pertinent that we review dietary strategies that enhance the quality of PSP [32][33][34][35].

3. Summary and Conclusions

The nutritional value of PSP related to human protein/AA requirements is highlighted and discussed. Increasing the RDA >1.0 g·kg^{-1}·d^{-1} may be a simple and effective strategy to offset protein/AA deficiencies in PSP, however, in practice, this strategy may not always be practicable or efficacious—particularly for those who rely on a limited variety of PSPs by necessity, not by choice. In developed regions, increasing intake of PSP should be little concern as dietary strategies such as protein complementation, supplementation and fortification of PSP with EAA can be implemented to help meet protein/AA requirements. This is fortunate as increased pressure to find sustainable food sources has led to a trend away from animal- to plant-source foods and plant-based diets. At present, it appears that there is ample room to improve sustainable intensification of animal-source food production, whilst simultaneously increasing in the intrinsic nutritional value of plant-source foods via GEd or processing methods. This dual approach will favourably impact global nutrition and the health of both current and future generations, but remains a significant scientific and technological challenge.

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