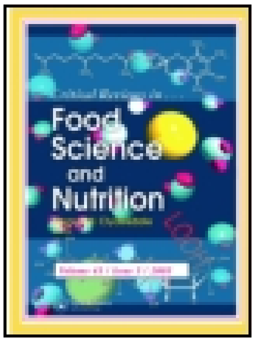

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Review: Amino acid concentration of high protein food products and an overview of the current methods used to determine protein quality

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ABSTRACT

Quality of the dietary protein in foods rather than amount of dietary protein may be of greater importance from a human health and wellness standpoint. Various systems are in place to determine the value of dietary protein. Protein digestibility-corrected amino acid score (PDCAAS) and digestible indispensable amino acid score (DIAAS) are the two major protein standards used to determine the completeness of proteins by their unique concentration and digestibility of indispensable amino acids. The purpose of this review was to provide a comprehensive comparison of the amino acid concentration of high protein foods and provide the current status of the use and practicality of the PDCAAS and DIAAS system. This review builds upon previous research analyzing the total nutrient density of protein-rich foods and expands scientific research investigating the quality of proteins. In summary, the average sum of indispensable amino acids for meat and fish products is much more consistent than that of non-meat and plant-based food products. However, some non-meat products have relatively similar amounts of indispensable amino acids on a similar serving size basis. The overwhelming aspect of determining protein quality is that greater research is needed to determine protein digestibility of food products.

KEYWORDS
Dietary protein; amino acid concentration; protein quality; protein digestibility

Introduction

Nutrient density alone does not provide adequate insight into quality of protein consumed in foods. It is important to look into the amino acid concentration of food products in order to obtain an accurate measurement of protein quality. Amino acid concentration can provide insight into how efficiently a food product will be able to supply the amino acid requirements of an individual (Caire-Juvera, Vázquez-Ortiz, & Grijalva-Haro, 2013). Caire-Juvera (2013) analyzed the amino acid concentration of foods that are commonly consumed in Northwest Mexico and concluded that amino acid concentration of food products can enhance national food databases by providing more insight into protein quality (Caire-Juvera et al., 2013). The USDA released a national food nutrient database (which included amino acid concentration of food products) in August of 2015, yet very few scientific articles have made use of this database with inference to current trends in food and nutritional science. A review conducted by Bohrer (2017) evaluated nutrient density and nutritional value of meat and non-meat foods high in protein, yet this review was limited in depth with regards to protein quality. Thus, the first aim of this review was to focus on the amino acid concentration of meat and non-meat foods high in protein.

In addition to the concentration of amino acids in foods, it is also important to look into the digestibility of indispensable and dispensable amino acids in high protein foods. Protein quality is typically measured using biological assays or chemical analysis (Bender, 2014). These biological assays are capable of providing great insight into the protein value of foods (Schaafsma, 2000). The protein digestibility-corrected amino acid score (**PDCAAS**) was adopted by the US Food and Drug Administration in 1993 as the preferred method of determination of protein quality and is calculated using the following formula: PDCAAS (%) = (mg of limiting amino acid in 1 g of test protein) / (mg of same amino acid in 1 g of reference protein) * fecal true digestibility (%) * 100 (Schaafsma, 2000). The Food and Agriculture Organization of United Nations has developed and recommends the use of the digestible indispensable amino acid score (**DIAAS**) to determine protein value; however, there are often challenges with collecting the true digestibility of foods consumed by humans. Thus, the second aim of this review was to discuss the digestibility of amino acids of meat and non-meat foods high in protein and the current utilization of protein digestibility scoring systems being used to assess protein quality.

The role of individual amino acids in the diet

Indispensable amino acids

Amino acids that are considered to be indispensable in the human diet cannot be produced endogenously from the diet and must be derived from food products or other forms of exogenous consumption.

Tryptophan

Dietary tryptophan is nutritionally significant although it is usually less significant than other amino acids. Tryptophan can

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be converted into two important metabolites – nicotinamide (vitamin-like properties because of its ability to replace dietary niacin) and the neurotransmitter serotonin (Shibata, 1995; WHO/FAO/UNU Expert Consultation, 2007). Serotonin has a variety of physiological functions, in terms of affective disorders (Imeri, De Simoni, Giglio, Clavenna, & Mancia, 1994), potent effector of mood and behavior (Mousseau, 1993), and pain perception (Russell et al., 1992). All the above reasons make tryptophan a highly important biological molecule. The requirement of dietary tryptophan is 4 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007).

Threonine

Threonine is highly significant for synthesis of mucin and maintenance of intestinal integrity (Bertolo, Chen, Law, Pencharz, & Ball, 1998). Furthermore, threonine is related to immune function, protein phosphorylation and O-linked glycosylation, as well as the synthesis of glycine (Wu, 2009). The requirement of dietary threonine is 15 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007).

Lysine

Lysine is an indispensable amino acid because it cannot be synthesized by mammals and its main role is to participate in protein synthesis (Tomé & Bos, 2007). Moreover, the supplementation of L-lysine can significantly enhance the calcium absorption of gut and the filtered calcium resorption of kidney (Civitelli et al., 1992; Fürst, 1993). The requirement of dietary lysine is set at 30 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007).

Methionine

Methionine plays an important role in formation of products which require single carbon transfers (Massey, Blakeslee, & Pitkow, 1998). As a product of methionine, S-adenosylmethionine is in high energy affecting on the formation of choline (Zeisel, Carolina, Hill, Carolina, & Blusztajn, 1994). Choline is an important part of other high energy metabolic intermediates, such as cytidine diphosphocholine (COP-choline) (Zeisel et al., 1994). Methionine not only has a significant role in choline synthesis (Zeisel et al., 1994), but also in detoxification in the liver (Marchesini et al., 1992; Seyoum & Persaud, 1991). The requirement of dietary methionine is 10.4 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007).

Phenylalanine

Phenylalanine and its metabolite tyrosine play an indispensable role in the initial metabolic steps of dopamine synthesis (Massey et al., 1998). Deficiency of phenylalanine leads to increased dopamine synthesis finally resulting in adverse effects on mental tasks (Zello, Pencharz, & Ball, 1990). It has been reported that phenylalanine is used to determine the synthesis of protein in visceral tissue (Southorn, Kelly, & McBride, 1992). The requirement of dietary phenylalanine is 25 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007).

Histidine

Kriengsinyos et al. (2002) observed that hemoglobin concentrations were adversely affected when individuals were fed histidine-free diets. Thus, histidine is considered to be an indispensable amino acid (WHO/FAO/UNU Expert Consultation, 2007). Histidine is involved in the modulation of oxidative DNA degradation and affects various organisms and physiological systems (Massey et al., 1998). The chemical messenger – histamine, a possible neurotransmitter in brain (Okahara, Murakami, Yamamoto, & Yata, 1995), is a significant metabolite of histidine (Massey et al., 1998). The dietary requirement of histidine is 10 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007).

Isoleucine

Although isoleucine is not produced in animals, it is stored in high quantities. As an indispensable amino acid, isoleucine cannot be synthesized in the human body and must be ingested in diet (Rose, Wixom, Lockhart, & Lambert, 1955). Isoleucine is associated with synthesis of glutamine and alanine and balance among branched-chain amino acid (Wu, 2009). The requirement for dietary isoleucine is 20 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007).

Leucine

Leucine is used to form sterols in adipose and muscle tissue (Rosenthal, Angel, & Farkas, 1974). Furthermore, leucine is branched-chain amino acid balance, glutamate dehydrogenase activator, and flavor enhancer (Wu, 2009). The requirement of dietary leucine is 39 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007).

Valine

The major function of valine is synthesis of glutamine and alanine and balance among branched-chain amino acid (Wu, 2009). The requirement of dietary valine is 26 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007).

Dispensable amino acids

Cystine

The dietary requirement of cystine is 4 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007). Interestingly, about 30% of the requirement for methionine can be replaced by cystine, so it can also be considered in some cases as an indispensable amino acid along with the nine aforementioned indispensable amino acids (WHO/FAO/UNU Expert Consultation, 2007).

Tyrosine

The dietary requirement of tyrosine is 25 mg/kg per day (WHO/FAO/UNU Expert Consultation, 2007). Both phenylalanine and tyrosine can be classified as aromatic amino acids. Phenylalanine is nutritionally indispensable while tyrosine is a metabolic product of the former catabolism. Thus, tyrosine is dependent on sufficient phenylalanine to meet the needs for these two amino acids (WHO/FAO/UNU Expert Consultation, 2007). Tyrosine is not an indispensable amino acid, as long as the requirements for phenylalanine are met and there is the necessary enzymes activity converting phenylalanine into tyrosine (Bhagavan, 1992). Nevertheless, when a deficiency or genetic defect happens to the system, tyrosine turns into an indispensable amino acid (Massey et al., 1998). The function of tyrosine is associated with protein phosphorylation, nitrosation, and sulfation (Wu, 2009). Furthermore, tyrosine is the precursor for the synthesis of dopamine, epinephrine, norepinephrine, and thyroid hormones (Wu, 2009).

Arginine

Arginine is indispensable only in high anabolic activity, such as the tissue growth of childhood (Massey et al., 1998). Arginine has an important role in regulation of blood pressure (Gokce, 2004), healing of injuries (Stechmiller, Childress, & Cowan, 2005), immune function, and the release of hormones (Tapiero, Mathé, Couvreur, & Tew, 2002).

Alanine

Alanine is a dispensable amino acid and can be synthesized by the human body. The functions of alanine include inhibition of pyruvate kinase and hepatic autophagy, gluconeogenesis, transamination, and glucose–alanine cycle (Wu, 2009).

Aspartic acid

Aspartic acid was found in the neuroendocrine tissues of invertebrates and vertebrates (A. D'Aniello, 2007). In terms of function, aspartic acid is involved in the development of the human nervous system (Hashimoto et al., 1993), visual activity (D'Aniello et al., 2005), and has a role in neurotransmission (Chen et al., 2005).

Glutamic acid

Glutamic acid is used in the biosynthesis of proteins (Levintow, Eagle, & Piez, 1957). It is a dispensable amino acid and can be synthesized in the human body (Hou, Yin, & Wu, 2015). Moreover, glutamic acid is an important neurotransmitter in the vertebrate nervous system (Meldrum, 2000) and serves as the precursor for the synthesis of other neurotransmitters, such as gamma-aminobutyric acid (GABA) (Hettema et al., 2006). Glutamic acid is associated with healthy brain development and function in human body (Hettema et al., 2006).

Glycine

Glycine is a precursor to proteins, a biosynthetic intermediate (Nelson & Cox, 2005), and a neurotransmitter (Liu & Zhang, 2000). It has been reported that glycine can improve sleep quality (Yamadera et al., 2007).

Proline

The principal function of proline is related to collagen structure and function, neurological function and as an osmoprotectant (Wu, 2009).

Serine

Serine is significant in metabolism because it is involved in the synthesis of purines and pyrimidines (Wu, 2009). Serine is the precursor to some amino acids such as glycine and cysteine (Wu, 2009). D-Serine is a signaling molecular in nervous system, peripheral tissues and organ (Liu, Hill, Arhem, & Von Euler, 2001; Takarada, Hinoi, Takahata, & Yoneda, 2008; Ma, Huang, Chen, & Lee, 2008). Additionally, serine also plays a role in gustatory sensation (Kawai, Sekine-Hayakawa, Okiyama, & Ninomiya, 2012).

The concentration of amino acids in high protein food products

Indispensable amino acids

The average indispensable amino acid amount for beef products and fish products evaluated in this review was 8.13 ± 0.98 g and 8.44 ± 0.96 g, respectively. While, the average indispensable amino acid amount for non-meat products evaluated in this review ranged from 0.80 g (broccoli) to 8.65 (great northern beans). Overall, meat and fish products were consistently higher in terms of total indispensable amino acid concentration compared with plant-based food products, yet some plant-based food products, particularly ones high in total protein concentration, were roughly equivalent in total indispensable amino acid concentrations. Some sources of non-meat foods were high in total indispensable amino acids (eggs, nuts, great northern beans, and black beans) and some sources of non-meat foods were very low in total dispensable amino acids (milk, broccoli, green peas, spinach, pinto beans, lima beans, kidney beans, and tofu).

Dispensable amino acids

The average dispensable amino acid amount for beef products and fish products evaluated in this review was 11.08 ± 1.32 g and 10.92 ± 1.26 g, respectively. While, the average indispensable amino acid amount for non-meat products ranged from 1.38 g (spinach) to 17.99 g (peanuts). Overall, meat and fish products were consistent in terms of dispensable amino acids, while some sources of non-meat foods were high in total dispensable amino acids (nuts, great northern beans, and black beans) and some sources of non-meat foods were low in total dispensable amino acids (milk, broccoli, spinach, pinto beans, tofu).

Digestibility of amino acids

There are many factors that affect digestibility, including intrinsic factors in the nature of food protein and the cell wall, dietary factors (such as dietary fiber and polyphenols), and chemical reactions (such as the combination of lysine and cross-linkages) (National Research Council, 1989). However, limited research on the digestibility of specific amino acids in proteins has been conducted. Amino acid score is a method to determine if a protein with absorbed dietary nitrogen can meet all nine of the indispensable amino acids requirement at the safe dietary level of humans or other animals (WHO/FAO/UNU Expert Consultation, 2007). Furthermore, protein digestibility should be considered for accurate estimation of the capacity of protein to meet physiological requirement, beside the amino acid score (National Research Council, 1989). Both amino acid score and protein digestibility determine the values for PDCAAS and DIAAS.

Determination of protein value

The PDCAAS is a chemical method introduced by the FAO/WHO in 1989 to assess protein quality and was adopted by the US Food and Drug Administration in 1993

(Boye, Wijesinha-Bettoni, & Burlingame, 2012). It is calculated by multiplying the lowest amino acid score by the true fecal crude protein digestibility factor (Boye et al., 2012). The amino acid score is obtained by dividing concentration of the first limiting indispensable amino acid in the test protein by the concentration of that specific amino acid in a reference scoring pattern (Schaafsma, 2000). This pattern is usually based on children, because they require more amino acids and better protein quality in their diet (FAO/WHO, 1991). However, there are other age group patterns which would cause changes in the amino acid score, and subsequently the PDCAAS (FAO/WHO, 1991).

PDCAAS is considered the go-to method for protein quality evaluation in the diets of regular, healthy individuals due to its speed, low cost, and theory (Schaafsma, 2012). However, it still has four main disadvantages (Schaafsma, 2012). First, PDCAAS are capped at 1.0 or 100% as it does not make sense for the body to use more than what have been absorbed (Schaafsma, 2012). This means that foods such as milk (full cream, pasteurized) and eggs (lyophilized powder), which normally would have a score of 1.27 and 1.01, respectively, would be noted as 1.0 (Boye et al., 2012). The truncation of scores mean that it does not accurately estimate the importance of proteins in a mixed diet (Schaafsma, 2000). A solution proposed to this would be to create another protein quality index that determines the ability to which a protein can balance diets that are short of one or more indispensable amino acid (Schaafsma, 2012). Secondly, it is difficult to determine whether the current reference scoring patterns that are being used can actually lead to an accurate interpretation of protein value as the patterns are based on the minimum amino acid requirements in one's diets (Schaafsma, 2012). It would be better if the patterns were based on optimum requirements of the general population, separated into several age groups (Schaafsma, 2012). Thirdly, the true faecal digestibility that is being used to calculate the PDCAAS score does not cover the whole picture in terms of total digestibility (Schaafsma, 2012). In fact, some amino acids are absorbed in the intestines, and thus the true ileal protein digestibility should be used and compared with the current method to conclude which is the better measurement. This could be done through an in vitro method (Schaafsma, 2012). Finally, the crude protein digestibility factor (on the basis of nitrogen digestibility) used in PDCAAS calculations can be inaccurate in determining protein quality as individual amino acid digestibility, which are undoubtedly different, are not used and considered (FAO, 2013; Rutherfurd, Fanning, Miller, & Moughan, 2015).

Based on previous publications, it has been found that meats from animal sources, along with fish products have PDCAAS scores of 1 or values close to 1. This high number signifies that these foods have protein and amino acids that are of high quality (Marangoni et al., 2015). Plant based foods such as beans on the other hand have scores around 0.5 and 0.6, significantly less than animal-derived products. This shows that their protein composition is incomplete and/or the foods are harder to digest (Marangoni et al., 2015). In addition, plant sourced foods commonly have anti-nutritional factors that prevents digestion and therefore more needs to be consumed to reach ideal protein requirements in diets (Schaafsma, 2012). The PDCAAS are not able to include this into the calculation, and thus some of these scores are actually higher than they actually are (Schaafsma, 2012).

The Food and Agriculture Organization of United Nations has developed the DIAAS back in 2013 as the recommended new method to determine protein value (FAO, 2013). DIAAS was proposed to address the limitations of the PDCAAS mentioned above and to improve on the usefulness of an amino acid score (FAO, 2013). This method factors in both the individual amino acid concentration and its digestibility at the end of the small intestine, determined best with human models and if not, with pig or rat models, respectively (Rutherfurd et al., 2015). It is calculated by dividing mg of digestible dietary indispensable amino acid in 1 g of the dietary protein by mg of the

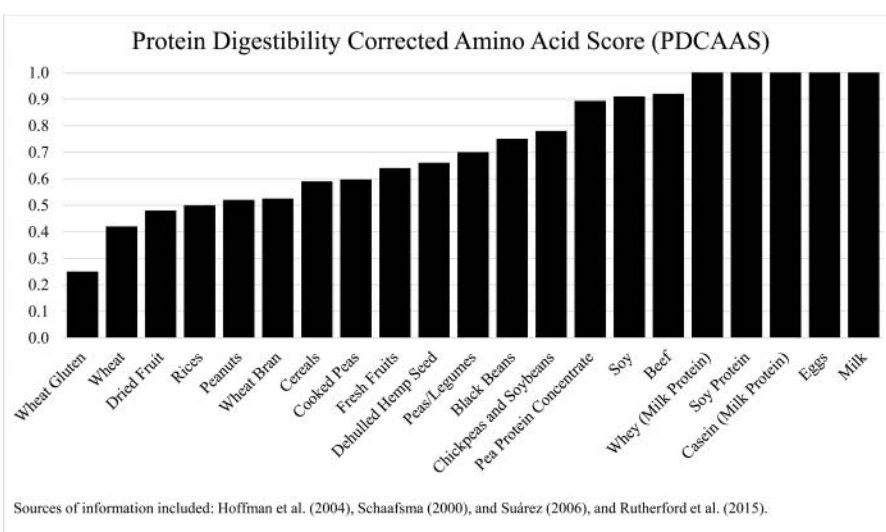

Figure 1. Estimations of protein digestibility corrected amino acid score (PDCAAS) of different sources of high protein foods. (Various sources were used for this information).

same dietary indispensable amino acid in 1 g of the reference protein (FAO, 2013). This calculation allows a more specific inference regarding if the amount of dietary protein in one's diet is enough to provide indispensable amino acids that are necessary for metabolism (Martens, Tan, Mattes, & Westerterp-Plantenga, 2014). Additionally, DIAAS can be used for mixed diets, and because they are not truncated, these scores allow differentiation among excellent or very good sources of dietary protein (FAO, 2013). While the DIAAS has the capability of providing comprehensive information on the quality of protein in foods, expensive techniques are required to calculate digestibility of amino acids (in vitro gastrointestinal models or animal models). More research on digestibility of common human foods as well as comparisons between inter-species models are still needed for reference (FAO, 2013).

Although few DIAAS values have been calculated for foods, Stein (2016) was able to determine the scores for 21 commonly used foods in human nutrition. DIAAS values for cereal grains were relatively low, ranging from 0.29 (sorghum) to 0.77 (dehulled oats). Dairy proteins (i.e. casein, milk protein concentrate, skim milk powder, whey protein concentrate, and whey protein isolate) had values ranging from 124 to 139, which were very high (Stein, 2016). Finally, DIAAS values were close to 1 for legume based products such as soy flour and soy protein isolates (Stein, 2016). However, pea protein concentrate had a lower DIAAS value of 0.73. Overall, it can be estimated that animal sourced protein would have higher DIAAS values but the limiting amino acid would differ among groups of food.

Minekus (2015) described the usefulness of the TNO Gastro-Intestinal Model (TIM) to determine the protein quality of food products. The TIM is a multi-compartmental model designed to realistically simulate conditions of the lumen of the gastro-intestinal tract and has a wide range of uses in nutritional sciences. The TIM has the capability to measure the true digestibility of the protein (digestibility at the end of the small intestine). This makes this particular modelling system very useful to determining protein quality of many different types of food products. However, this particular research and testing still needs to be conducted and the knowledge needs to be transferred to a greater magnitude.

Conclusions

The purpose of this review was to present readers with information of the amino acid concentration of high protein foods and the current status of the use and practicality of the PDCAAS and DIAAS system. It is important for individuals to consume adequate dietary protein during all stages of life, particularly to meet the requirements for indispensable and dispensable amino acids from a health and wellness standpoint. Thus, an accurate measurement of dietary protein quality is necessary. Additionally, if an amino acid scoring system is going to be effectively used to determine protein quality, more research is warranted to further the amount of information available.

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