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Refining Ounce-Equivalents Using the EAA-9 Approach for Protein Scoring and Dietary Guidance

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Title Page

Title

Refining Ounce-Equivalents Using the EAA-9 Approach for Protein Scoring and Dietary Guidance

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Author contributions

SMF and DKL project conception; SMF and DKL development of overall research plan and study oversight; EMR performed data analysis and statistical analysis; SMF, EMR, and DKL wrote the paper; SMF had primary responsibility for final content.

All authors have read and approved the final manuscript.

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Running title

Protein Equivalents for Plant and Animal Foods

Abbreviations and definitions

Dietary Guidelines, Dietary Guidelines for Americans; EAA, Essential Amino Acid; SR Legacy, USDA National Nutrient Database for Standard Reference, Legacy Release.

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Research Snapshot

Research Question: How can USDA dietary guidance for protein food substitutions be improved to align with the unique metabolic functions and requirements of the nine essential amino acids (EAAs), especially with the growing shift towards plant-based foods?

Key Findings:

This study underscores the non-interchangeable nature of EAAs and challenges generic use of total protein as a surrogate for amino acids in dietary recommendations. It utilizes the RDAs for the individual EAAs to demonstrate the limitations of the USDA protein ounce-equivalents for meeting dietary protein and EAA needs. The study characterizes the importance of a nutrient-based understanding of protein quality and demonstrates use of the newly developed EAA-9 Equivalence servings as a tool and resource for evaluating protein quality and developing nutrient-rich diets.

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Structured Abstract

Background:

The USDA Protein Food Ounce-equivalents are designed to identify plant sources of protein foods and provide serving size substitutions. While the ounce-equivalent concept is simple, it fails to generate equivalent exchanges for protein or essential amino acids (EAAs).

Objective:

To accurately define the EAA content of USDA protein food ounce-equivalents, to develop a more accurate food exchange list, and to evaluate the EAA-9 protein quality framework as a tool for determining precise EAA-equivalent substitutions.

Design:

The USDA National Nutrient Database (SR Legacy) and the EAA-9 protein quality model were used to evaluate the validity of the USDA Protein Food ounce-equivalents for creating equivalent protein and EAA substitutions. The EAA-9 framework then established EAA-9 Equivalence serving sizes to meet EAA requirements.

Main Outcomes:

EAA composition in protein foods was assessed. EAA-9 Equivalence servings were developed.

Analysis Performed:

EAA composition was calculated for USDA protein food ounce-equivalents. EAA-9 scores were calculated for protein foods and compared using an egg's EAA composition as a standard.

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MyPlate Kitchen Recipes were used to apply USDA protein food ounce-equivalent exchanges and EAA-9 equivalence servings.

Results:

The USDA protein food ounce-equivalents are not equivalent in protein or EAAs with the disparity ranging from one ounce-equivalent of chicken breast with 9.1 g of protein and 4.0 g of EAAs to one ounce-equivalent of almonds with 3.0 g of protein and 0.9 g of EAAs. Using the USDA serving of one egg as a standard for comparing protein food groups, less than 15% of beans, peas, and lentils and 0% of nuts and seed ounce-equivalents achieve the EAA composition of an egg. EAA-9 Equivalence servings are truly equivalent, with each serving providing a reliable and interchangeable protein source. The EAA-9 Equivalence servings have been calculated and are now available for all USDA SR Legacy foods with a complete EAA profile, offering a resource for exchanges that ensure EAA requirements are met.

Conclusions:

Creating ounce-equivalent substitutions for protein foods requires creating food exchanges that assure EAA requirements are met. The USDA Protein Food ounce-equivalents provide inadequate guidance for balancing EAA requirements.

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Introduction

Translating nutrition research into practical dietary advice is a complex endeavor. One of the most challenging examples is communicating the dietary requirements for the 20 amino acids that constitute our daily protein intake, some of which are categorized as dispensable while others are considered indispensable or essential amino acids (EAAs). Each EAA has unique dietary requirements, yet amino acid requirements are typically characterized as a single, collective protein requirement. However, all proteins and all protein-containing foods are not equivalent and do not provide the same balance of EAAs. The challenges and complexities of understanding EAA needs become more significant with the increased use of plant-based proteins.

To address the complexity of providing adequate protein using diverse plant and animal foods, the USDA created the concept of protein food ounce-equivalents as a tool to help professionals and consumers comply with dietary guidelines.[1] The USDA protein food ounce-equivalents are widely used as a basis for replacing animal-based protein foods with plant foods while maintaining dietary patterns that meet federal regulatory standards.[2,3] The USDA defines one ounce-equivalent of protein as 1 ounce of cooked lean meat, poultry, or seafood; 1 egg; 1/4 cup of cooked beans, peas or lentils; ¼ cup (about 2 ounces) of tofu; 1 ounce tempeh, cooked; 1 tablespoon of peanut butter; or 1/2 ounce of nuts or seeds. The USDA MyPlate website provides a table listing protein foods as one ounce-equivalents.[4] The 2020-2025 Dietary Guidelines for Americans (Dietary Guidelines) further reinforced the current ounce-equivalents approach.[1]

Current USDA protein food ounce-equivalents inaccurately represent protein and EAA contents.

Although the concept of ounce-equivalents offers a simple method for identifying protein-rich foods when creating meals, the designated protein food ounce-equivalents are not equivalent in either protein quantity or quality reflecting lack of recognition of EAA requirements. This issue has been highlighted in previous publications.[5–8]

The serving sizes selected for ounce-equivalents were not designed to be truly equal in protein quantity or quality or to adequately reflect amino acid composition. Instead, servings were determined based on common usage and the composition of overall calories, fat, and protein, with the primary goal of avoiding overconsumption of calories and fat rather than meeting dietary protein or EAA requirements.[9,10]

Evaluating the protein and EAA contents for some of the USDA ounce-equivalent food groups highlights the inconsistency. For example, 1 egg, 1 tablespoon peanut butter, and ½ ounce of almonds are recommended as ounce-equivalents.[4] While the ounce-equivalent designations for these three foods are roughly equivalent in total calories, they differ greatly in protein quality. Total protein for egg, peanut butter, and almonds contain 6.3g, 3.9g, and 3.0g total protein respectively. They differ even more in EAA composition, providing a respective 2.8g, 1.0g, and 0.9g of total EAAs.[11]

We recently created a new scoring framework, EAA-9, as a tool for better understanding protein quality and for use in evaluating food choices and meal creation.[12,13] EAA-9 scoring produces a transparent, scalable, and additive approach to evaluating the potential of multi-ingredient foods and meals to meet EAA requirements. This framework produces a score that serves 4 distinct yet connected functions. The EAA-9 scoring framework (1) enables comparison of protein quality among different foods; (2) allows for personalization based on EAA needs associated with age, metabolic conditions, and physical activity; (3) expresses protein quality as a simple

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percentage of EAA requirements; and (4) ultimately yields a score that reflects the fulfillment of EAA recommended dietary allowances (RDAs).

The objectives of this study are to evaluate the use of USDA protein food ounce-equivalents, to evaluate their application in creating diets that prioritize protein quality to meet EAA requirements, and to provide a resource of protein food exchange servings that are truly equivalent in EAAs and ensure protein quality is accounted for in dietary guidance. This study employs the EAA-9 scoring model to assess the adequacy of current USDA protein food ounce-equivalents and to evaluate these serving recommendations in the context of USDA Dietary Guideline Recommendations using MyPlate Kitchen Recipes.[14] Leveraging the EAA-9 score, the study develops the concept of EAA-9 Equivalence servings, specifically designed to serve the needs of healthcare professionals in creating EAA complete plant-based diets. This updated and comprehensive resource of EAA-9 Equivalence servings ensures that when used, specifically in creating plant based diets, EAA content of foods is truly equivalent and enables each food to serve as a reliable and interchangeable protein source.

Methods

Mapping USDA ounce-equivalent protein foods to SR Legacy foods with EAA profiles

The USDA National Nutrient Database for Standard Reference, Legacy Release (SR Legacy) was used to evaluate the amino acid profiles associated with the USDA protein food ounce-equivalence concept by comparing foods with known EAA composition.[11] The USDA SR Legacy food composition data were downloaded from FoodData Central (FDC) (in JavaScript Object Notation [JSON] format on 5/27/2022) to obtain foods with complete EAA profiles. As described by FDC, these EAA values may differ in accuracy because they are derived from multiple sources including direct analyses, calculations, and published literature. Next, protein foods were identified from MyPlate *Ounce-Equivalent of Protein Foods* table,[4] which provides 104 foods with ounce-equivalent descriptions (such as “1-ounce cooked lean beef” and “¼ cup of baked beans”). A Registered Dietitian Nutritionist (RDN) mapped these 104 protein food descriptions to equivalent SR Legacy foods based on description and nutritional composition, mappings were cross checked by a second RDN. Nearly half of the generic USDA protein food descriptions (48 out of 104) were each mapped to multiple specific SR Legacy foods. For example, the USDA protein food description “Tofu” was mapped to similar SR Legacy foods such as firm tofu, silken tofu, or freeze-dried tofu. This mapping accommodates the generic nature of USDA protein food categories and the specificity of SR Legacy foods.

Evaluating EAA Composition and USDA MyPlate Kitchen Recipes using the EAA-9 score

To evaluate use of the USDA protein food ounce-equivalents and demonstrate the application of the EAA-9 scoring framework for creation of EAA-9 Equivalence servings, three representative USDA MyPlate Kitchen Recipes were selected from the MyPlate website,[14–17] with each meal designed to align with the standard healthy American dietary pattern.[1] A trained RDN performed protein food ounce-equivalent exchanges following the guidelines outlined on the USDA MyPlate protein food description web page.[4] Protein food ounce-equivalents were chosen by replacing animal-based protein foods, including dairy products,[18] with plant-based alternatives while maintaining the recipe's flavor and intended meal characteristics. The goal was to create an appetizing alternative that reflects how a dietitian typically uses ounce-equivalent substitutions in practice. The amino acid composition of plant-based dairy alternatives that were not present in the SR Legacy database were collected from FoodData Central Foundation foods (downloaded in JSON format on 8/25/23).[19]

Identification of a protein food standard for defining EAA-9 Equivalence serving sizes

Translating the RDA for protein or for EAAs into serving sizes for diverse foods requires selecting a reference food. For the purpose of this analysis, we chose to use a 50 g chicken egg that is considered a standard serving size within the USDA guidelines and represents a one ounce-equivalent serving. Historically, eggs have been considered a representation of a "perfect protein" food due to their nutritional characteristics.[20–23] Eggs are notable for their high density and ideal balance of EAAs and ease of digestibility.[21] It is worth emphasizing that while we have chosen an egg as the standard for our calculations, other high quality proteins such as 1 ounce of chicken breast or 1 ounce of salmon could be used as standards when calculating EAA-9 Equivalences.

Calculations of EAA-9 scores and EAA-9 Equivalence serving sizes

The EAA-9 score is based on comparison with the RDA requirements for each of the EAAs using the EAA-9 framework. Using the EAA-9 score for an egg as the standard, one serving (i.e., one egg) represents ~15% of the daily EAA requirements. That EAA-9 score can then be used in an additive approach to meet EAA requirements and evaluate protein quality for individual foods or complete meals.

Figure 1 illustrates calculation of the EAA-9 score and, subsequently, the EAA-9 Equivalence serving size for an egg and peanut butter. The egg, with its balanced EAA profile, was used as a standard serving size for calculating the EAA-9 Equivalence serving size for peanut butter. The calculation steps are presented below.

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1. *Calculate the EAA-9 score*. The EAA-9 scoring method defines the amount of each EAA in a select serving of food as the percentage of its RDA and then expresses the food score as a single percentage for the most limiting EAA. This example uses the RDA for the EAAs as defined by the National Academies for Science.[24] However, the EAA-9 framework is designed for personalized nutrition with flexibility in selection of higher or lower requirements for any individual amino acid.

2. *Calculate the EAA-9 Equivalence serving size for an individual food*. This example illustrates the calculation for peanut butter using an egg as a standard for comparison. For each food, the EAA-9 score represents the lowest percentage score among the 9 EAAs. For an egg, the limiting amino acid is histidine, and a single egg provides 15.77% of the daily RDA. Because the score is based on the most limiting EAA, the score guarantees that the food exceeds that percentage for the other 8 EAAs. The limiting amino acid in peanut butter is lysine and the USDA ounce-equivalent of 1 Tbsp provides 4.04% of the daily RDA for the EAAs. The USDA ounce-equivalents of peanut butter has an EAA-9 density of approximately one-fourth of an egg. To be equivalent to an egg, the serving size for peanut butter needs to be increased to 4 Tbsp.

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Development of an EAA-9 Equivalence Servings Table as a Resource for Dietary Planning

EAA-9 Equivalence serving sizes were determined for all foods in the SR Legacy database that had non-zero values for all 9 EAAs (including the conditionally essential EAAs cysteine and tyrosine) and protein; these scores were then used to calculate EAA equivalent serving sizes. Values are provided as both the exact calculated EAA-9 Equivalence serving sizes and rounded to the nearest practical serving size for use in diet creation. The calculated EAA-9 Equivalence servings are available for immediate use and download on Mendeley Data (https://doi.org/10.17632/xwwsmncckr.4).[25]

Results

Amino acid profiles mapped from SR Legacy to USDA protein food ounce-equivalents

In total, 93 USDA protein foods were included in this analysis relating to a total of 532 SR Legacy amino acid profiles. Of the original 104 USDA protein foods, 11 could not be mapped to an equivalent SR Legacy food and were therefore not included in this analysis. These foods were: pork lunch or deli meat, cooked bear meat, cooked moose meat, cooked opossum meat, cooked venison meat, cooked pheasant, cooked quail, cooked hake, cooked sole, canned freshwater trout, and canned herring. Servings provided in household measurements (e.g., tablespoon, cup, or patty) were converted into standard metric values (weight in grams) for calculating amino acid profiles. The list of protein foods and corresponding SR Legacy mappings can be found on Mendeley Data (https://doi.org/10.17632/xwwsmncckr.4).[25]

Evaluation of macronutrient content of USDA protein food ounce-equivalents

Table 1 illustrates the differences in macronutrient content for foods spanning the USDA ounce-equivalent food groups. While the calorie content of the ounce-equivalents is similar across food groups, the protein and EAA contents vary greatly. An ounce-equivalent of animal-derived food provides more than 6.0 g of protein and more than 2.8 g of EAA, while the plant-foods provide less than 5.0 g of protein and less than 2.0 g of EAA. The differences in the ounce-equivalents ranged from chicken breast with 9.1 g of protein and 4.0 g of EAAs to almonds with 3.0 g of protein and 0.9 g of EAAs. The relative EAA concentration in the food groups also varies, with the animal proteins ranging from 40.3% to 44.6% and the plant proteins ranging from 26.2% to 41.2%.

Comparison of EAA-9 scores for USDA protein food ounce-equivalents to the EAA-9 score of a standard egg

For a comparison of the USDA protein food ounce-equivalents, protein foods were categorized according to the USDA-designated food groups and then compared with the EAA-9 score of the egg standard.[4] **Figure 2** illustrates that the USDA ounce-equivalents are not equivalent for EAA within food groups, especially in the case of plant sources of protein. For instance, 0% of nuts and seed ounce-equivalent foods provide the equivalent EAA composition of a standard egg.

Evaluating EAA Composition of USDA MyPlate Kitchen Recipes through EAA-9 score

MyPlate Kitchen Recipes are designed to encourage food choices emphasized in the Dietary Guidelines for Americans.[14] Following USDA protein food exchange recommendations, substituting animal foods with plant-derived protein foods leads to a decrease in the EAA-9 score. **Figure 3** provides examples from three MyPlate Kitchen Recipes to illustrate changes associated with substituting cow's milk, chicken breast, or cheese with soy milk and beans respectively.

Examining Figure 2 in detail, the first column represents plant and animal protein foods from the original MyPlate Kitchen Recipes. The EAA-9 score indicates that the protein foods from these recipes exceeds the minimum EAA requirements and provides 141% of the RDA. The second column demonstrates use of the USDA protein food ounce-equivalents to substitute animal protein foods for plant protein foods. While the calories remain similar (602 to 620 kcals), the

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EAA content drops from 141% to 63% of recommendations. In the third column, when EAA-9 scores are used to match the EAA content of the original MyPlate Recipes, the plant-based protein substitutions require increasing both total protein and total calories.

Healthy vegetarian diets often address the EAA imbalance by using complementary protein foods. An example of complementary plant proteins would be the combined use of beans and rice. Beans are legumes limiting in methionine but adequate in lysine, while rice is a grain limiting in the EAA lysine but is adequate in methionine.[26] Hence a 50/50 combination would serve to, at least in part, provide complementary proteins. This example is provided in **Figure 4.** While rice and beans represent complementary proteins, rice has low EAA density (i.e., EAAs/serving) reducing both total EAAs and total protein compared to the kidney beans alone. Ultimately, although those complementary proteins create a better balance of EAAs, the plant-based meal still requires more total protein and more total calories to meet EAA requirements. Full nutrient composition and mappings of foods in MyPlate Kitchen Recipes are provided on Mendeley Data (https://doi.org/10.17632/xwwsmncckr.4).[25]

Expansion and Implementation of EAA-9 Equivalence Servings

The EAA-9 Equivalence formula allows us to directly evaluate the EAA composition of any food and to generate comparative serving sizes for meal creation. Unlike the USDA ounce-equivalents framework which fixes the serving size based on calories, saturated fat, added sugars, and sodium in addition to protein content [27], the EAA-9 Equivalence servings standardize the EAA content based on the EAA RDAs and then defines serving size, total protein and calories. **Table 2** provides a representative list of USDA protein foods. For meats and fish, the USDA ounce-equivalents and EAA-9 Equivalence servings are relatively similar, with the EAA-9 Equivalences having slightly lower serving sizes and calories. However, plant-based protein food sources require serving sizes two to four times larger than the USDA ounce-equivalents to achieve EAA-9 Equivalence. The calories required to obtain EAA-9 Equivalence for USDA protein foods ranges from 22 calories for haddock to 647 calories for walnuts. **Table 3** provides a select list of practical EAA-9 Equivalent serving sizes, designed to be easily implemented into dietary planning.

The EAA-9 Equivalence formula was applied to all SR Legacy foods with non-zero values for all EAA and protein (n=4,735). This comprehensive list of both exact and practical (rounded) EAA-9 Equivalence serving sizes are available as open access for viewing and download on Mendeley Data (https://doi.org/10.17632/xwwsmncckr.4).[25]

Discussion

Although all amino acids serve as fundamental building blocks for the formation of new proteins, it is important to recognize that each EAA also has unique metabolic functions with optimum intake defined beyond the minimum requirement for building new proteins.[12] Each EAA is a unique nutrient in the same way each vitamin is unique, and like vitamins the minimum intake to prevent deficiency is not necessarily the optimum for health. Prevailing consumer-oriented dietary guidelines, including the USDA MyPlate recommendations, tend to oversimplify the role of amino acids by treating them as interchangeable components within the broader category of "protein-rich foods." Consequently, the critical concept that amino acids are distinct nutrients with diverse functions has not been adequately integrated into current nutritional recommendations. While this may not affect individuals who consume animal protein, the disregard for protein quality becomes problematic for those following plant-based or vegan diets.

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This study underscores the limitations of the USDA ounce-equivalents for characterizing protein sources, particularly when transitioning from animal-based to plant-based proteins. National Health and Nutrition Examination Survey (NHANES) data document that Americans who select more plant-based diets decrease both the quantity and quality of protein intake.[28] Table 1 illustrates that use of the existing USDA ounce-equivalent system would be expected to further dilute the EAA content and protein quality of the American diet.

Metabolic evaluation of USDA protein food ounce-equivalents

Failure to recognize the EAA compositions of these “ounce-equivalent” foods creates potential for metabolic dysregulation. Although the health risks of long-term suboptimal EAA intakes remain largely unknown, this is at least in part because dietary surveys generally obscure changes in EAA intakes by focusing solely on total protein. Future research needs to recognize the physiologic and metabolic roles of individual EAA. Recent studies highlight potential metabolic risks associated with use of the USDA protein ounce-equivalents for dietary guidance.[7,8,29]

Park et. al.[7] investigated the anabolic responses to consumption of USDA defined ounce-equivalents of protein food sources. The study concluded that the metabolic response to protein intake varied based on the source of protein consumed. Consuming ounce-equivalents from animal-based protein sources resulted in a significantly greater gain in whole-body net protein balance (the difference between protein synthesis and breakdown) compared to ounce-equivalents from plant-based protein sources, with nearly a 5-fold difference observed between eggs and almonds. The magnitude of the whole-body net anabolic response was directly correlated with the EAA content of the protein food source and was reflected in post-meal changes in plasma EAAs. The authors concluded that the "ounce-equivalents of protein food

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sources as expressed in the Dietary Guidelines are not metabolically equivalent."[7] More recently, Connolly et al. evaluated the effects of consuming USDA ounce-equivalent portions of pork, eggs, black beans, or almonds on postprandial EAA bioavailability in both young and older adults.[8] The study revealed that consuming recommended portions of animal-based protein sources, such as meat, poultry, and fish, resulted in a greater availability of EAAs compared to consuming the same ounce-equivalent quantity of plant-based protein sources, such as legumes or nuts. The authors concluded that ounce-equivalent portions of animal and plant-based protein foods as defined by the USDA do not provide the same EAA content or produce equivalent postprandial bioavailable EAA for either young or older adults.[8]

These findings were extended by Pinckaers et al.,[29] who evaluated the muscle protein synthesis response of older adults to ingestion of an omnivore versus a vegan meal designed to be isocaloric and isonitrogenous. Each meal provided 600 kcal and 36 grams of protein, and the meals were similar in total fiber, carbohydrates and fat. The vegan meal consisted of high-quality plant proteins including quinoa, chickpea, soybeans and broad beans presented as a "protein bowl" meal while the omnivore meal consisted of beef (flank steak), green beans and potatoes. The omnivore meal produced a 127% greater post-meal increase in plasma EAAs and approximately a 50% greater anabolic response in muscle protein synthesis. These authors concluded that in whole food meals while the dietary protein amount was the same, the post-meal anabolic response was not equivalent for the plant and animal protein foods.

USDA ounce-equivalents have far-reaching impacts

The use of ounce-equivalents in the field of nutrition and public health is widespread and deeply integrated into dietary guidelines. The USDA protein food ounce-equivalents play a pivotal role in federal regulations concerning nutrition and public health. They are used not only in the

Dietary Guidelines but also in establishing the nutritional requirements for various federal nutrition programs, including the National School Lunch Program and the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC).[2,3,30] Furthermore, these ounce-equivalents are used by insurance providers, such as Medicare and Medicaid, for defining reimbursement guidelines for nutrition care.[31] In clinical settings, medical professionals and Registered Dietitian Nutritionists prescribe specific amounts of protein foods to patients with conditions such as chronic kidney disease or diabetes, relying on the USDA ounce-equivalents.[32] In the unique case of kidney disease, the goal is to consume adequate EAAs from food while keeping total protein no higher than the required amount. This is a difficult task when total protein alone is used as a proxy. Additionally, the USDA protein food ounce-equivalents are a vital component of the Healthy Eating Index (HEI), a tool used to evaluate the overall quality of an individual's diet based on adherence to federal dietary guidelines.[33] These examples showcase the extensive reliance on the USDA protein food ounce-equivalents for practical dietary guidance, impacting virtually every individual in the United States in some capacity.

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Limitations

This study highlights the differences in EAA density between animal and plant-derived foods, but how should this knowledge be translated into practical food recommendations? What is the EAA target for a single serving size? For the purpose of this study, we used one egg as a standard for evaluating serving sizes. An egg is a high-quality protein food that provides 15.77% of the RDA for EAAs per serving. Alternative selections could have been 1 ounce of beef sirloin, salmon, or chicken breast (Table 2) with EAA-9 scores of 16.25%, 18.0%, and 24.9%, respectively. Using these three EAA-dense protein foods as the serving size standard (Figure 2) generates EAA-9 Equivalence serving sizes for peanut butter of 4.02, 4.46, and 6.16

tablespoons, respectively. The selection of an egg as the standard is a conservative choice that provides reasonable guidelines for food substitutions (Table 3). Future research on personalized nutrition needs to address optimal EAA requirements and nutrient density, considering age, gender, physical activity, and health status, to fully understand true food equivalences for EAAs and other essential nutrients. In this study, the EAA-9 scoring framework was used to determine EAA-9 equivalences, which reflect a food's ability to meet EAA RDAs. The decision to set the EAA-9 score to meet the RDA (rather than the EAR) was based on standard practice for nutrition labeling, per FDA guidelines, representing the minimum amount required to prevent deficiency in 97.5% of the population which emphasizes the importance of protein quality in dietary planning.[34]

Conclusion

This study recognizes the critical role of EAAs as distinct metabolic nutrients and implements a more practical understanding of protein quality for food choices. Our goal was to incorporate EAAs into the protein food ounce-equivalent concept, offering nutrition professionals a valuable resource of EAA equivalent servings to support a protein quality focus in dietary planning. Despite protein historically serving as a proxy for EAAs in dietary guidelines, advancing understanding of amino acid metabolism underscores the necessity of considering EAAs individually for accurate dietary recommendations, beyond total protein. The need for an accurate protein food exchange system that accounts for protein quality is increasingly critical as more people incorporate plant-based foods into diets. Professionals and consumers alike require support to ensure they can achieve adequate protein and EAA intake to maintain optimal nutrition. In this study, the EAA-9 scoring framework was used to evaluate USDA MyPlate Kitchen Recipes, revealing limitations in current guidelines and showcasing EAA-9's versatility in assessing foods, meals, and diets. Finally, we applied the EAA-9 protein quality

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scoring framework and adjusted USDA ounce-equivalent measures to achieve true protein equivalence to create the EAA-9 Equivalence serving sizes. EAA-9 Equivalence serving sizes are accurate dietary protein exchanges and the resource of calculated servings (all around 15%) can be used additively to meet EAAs needs, offering a scoring system where the sum of EAA-9 Equivalence servings reaching 100% signifies meeting all nine EAA RDAs. All practical EAA-9 Equivalent serving sizes can be accessed and are available for download at Mendeley Data (https://doi.org/10.17632/xwwsmncckr.4). This study highlights EAAs' significance and advocates for their full integration into protein scoring and dietary guidance, enhancing the precision and effectiveness of dietary recommendations.

Data Availability Statement:

The data that support the findings of this study are available in Mendeley Data at https://doi.org/10.17632/xwwsmncckr.4.[25] These data were derived from the following resources available in the public domain: MyPlate Protein Foods,[1] SR Legacy,[11] MyPlate Recipes,[15–17] FoodData Central Foundation Foods,[19] and the 2005 Dietary Reference Intakes.[24]

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Figure legends

Figure 1: Calculating the EAA-9 score and EAA-9 Equivalence serving size [a, b,]

a. Step 1. The EAA-9 score is expressed as a percentage, representing the lowest quantity of an essential amino acid (the limiting amino acid) in relation to its RDA. This example illustrates the EAA requirements for a 70 kg adult,[24] and the limiting amino acids are histidine for the egg (fdc_id:171287) and lysine for the peanut butter (fdc_id:174294).
b. Step 2. The EAA-9 Equivalence serving size for peanut butter is calculated as a ratio of the EAA-9 score for the standard egg compared with the score for peanut butter. The ratio reflects that peanut butter provides ¼ of the EAAs contained in the egg and the EAA-9 Equivalence serving size is 4 Tbsp.

Figure 2: Comparing EAA-9 scores: USDA protein food ounce-equivalents versus a standard egg

a. The 0% intercept represents the EAA-9 score of a standard chicken egg. Foods below the egg intercept have an EAA-9 score lower than the standard egg (15.77%).
b. Of the 532 SR Legacy foods, 9 were categorized into multiple groups (such as chicken deli meat which is in both "Meats" and "Poultry"). Additional variability within food groups can be attributed to the mapping of generic protein food ounce-equivalents to specific SR Legacy food profiles. For example, the "Egg" protein food group includes eggs from different species (e.g. chicken, quail, etc…), egg whites, and different cooking preparations (e.g. scrambled, poached, etc…).

Figure 3: Protein Food Substitutions applied to MyPlate Kitchen Recipes

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a. Three MyPlate Kitchen Recipes [15–17] illustrate how total protein, calories, and the EAA-9 score change when applying USDA ounce-equivalents and EAA-9 Equivalence serving size substitutions. MyPlate Kitchen recipes are designed to encourage food choices emphasized in the Dietary Guidelines for Americans.[14] This example is not intended to represent complete daily nutritional recommendations only to highlight protein-rich foods. For the purposes of this example, protein foods include the USDA protein food groups plus dairy and grains.
b. In the center column, animal-based protein foods from the original MyPlate Kitchen Recipes are substituted with plant-based protein foods using USDA protein food ounce-equivalents as directed in the “Ounce-Equivalent of Protein Foods Table.”[4]
c. In the third column, animal-based protein foods from the original MyPlate recipes are substituted with servings of plant-based protein foods which were determined by scaling the serving to achieve equivalent EAA-9 scores to the original MyPlate Recipe protein foods.
d. Values shown in the "Total Nutrient Metrics of Protein Foods" panel, represent the sum of nutrients provided by protein foods only, they do not represent the entire recipe. In total, non-protein foods accounted for less than 5 grams of protein. Food composition data obtained from SR Legacy[11] and FoodData Central Foundation Foods.[19] Complete nutrient composition and mappings of protein foods in MyPlate Kitchen Recipes are provided on Mendeley Data (https://doi.org/10.17632/xwwsmncckr.4). [25]

Figure 4: Complementary plant-based protein food substitutions applied to a MyPlate Kitchen Recipe

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a. The original protein foods in the Chicken Waldorf Salad MyPlate Kitchen Recipe (as depicted in Figure 2), along with their associated calories, EAA-9 score, and total protein, are shown in black and white. EAA-9 score was calculated cumulatively, meaning amino acid content of the protein foods were combined before score calculation.
b. The first row (shown in red) displays USDA protein food ounce-equivalents for (a) the original substitution of chicken with kidney beans (as depicted in Figure 2) and (b) a complementary plant-based substitution of chicken with a 50/50 rice and bean combination. The rice and bean pairing was selected based on complementary limiting amino acids, with the intent of creating a balanced plant-based protein exchange.
c. The second row (shown in green) displays the EAA-9 Equivalence servings for (a) the original chicken to kidney bean substitution (as shown in Figure 2) and (b) the complementary plant-based substitution of rice and beans. The EAA-9 Equivalence serving for the rice-and-beans combination was calculated by scaling the serving to match the EAA-9 score of the original protein foods in the Chicken Waldorf Salad recipe (EAA-9 = 95%).

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Step 1: Calculate the EAA-9 scores [a]

The EAA-9 scoring method defines the amount of each EAA in a serving of food as the percentage of its RDA and then expresses the food score as the single percentage for the most limiting EAA.

$$\text{EAA-9 Score} = \text{\% of limiting EAA}\left(\frac{\text{His (mg/svg)}}{\text{His RDA}}, \frac{\text{Ile (mg/svg)}}{\text{Ile RDA}}, \frac{\text{Leu (mg/svg)}}{\text{Leu RDA}}, \frac{\text{Lys (mg/svg)}}{\text{Lys RDA}}, \frac{\text{Met + Cys (mg/svg)}}{\text{Met+ Cys RDA}}, \frac{\text{Phe + Tyr (mg/svg)}}{\text{Phe + Tyr RDA}}, \frac{\text{Thr (mg/svg)}}{\text{Thr RDA}}, \frac{\text{Trp (mg/svg)}}{\text{Trp RDA}}, \frac{\text{Val (mg/svg)}}{\text{Val RDA}}\right)$$

RDAs (mg/70kg/d):
Histidine (His) 980; Isoleucine (Ile) 1330; Leucine (Leu) 2940; Lysine (Lys) 2660; Methionine + Cystine (Met + Cys) 1330; Phenylalanine + Tyrosine (Phe + Tyr) 3210; Threonine (Thr) 1400; Tryptophan (Trp) 350; Valine (Val) 1680

EAA-9 Score of 1 egg

$$\begin{aligned} &= \text{\% of limiting EAA}\left(\underset{His}{\frac{154.50}{980}}, \underset{Ile}{\frac{355.50}{1330}}, \underset{Leu}{\frac{545.00}{2940}}, \underset{Lys}{\frac{456.00}{2660}}, \underset{Met+Cys}{\frac{326.00}{1330}}, \underset{Phe+Tyr}{\frac{589.50}{2310}}, \underset{Thr}{\frac{287.00}{1400}}, \underset{Trp}{\frac{83.50}{350}}, \underset{Val}{\frac{429.00}{1680}}\right) \\ &= \text{\% of limiting EAA}(15.77\%, 26.73\%, 18.54\%, 17.14\%, 24.51\%, 25.25\%, 20.50\%, 23.86\%, 25.54\%) \\ &= 15.77\% \end{aligned}$$

EAA-9 Score of 1 tbsp peanut butter

$$\begin{aligned} &= \text{\% of limiting EAA}\left(\underset{His}{\frac{88}{980}}, \underset{Ile}{\frac{97.28}{1330}}, \underset{Leu}{\frac{244.80}{2940}}, \underset{Lys}{\frac{107.52}{2660}}, \underset{Met+Cys}{\frac{78.08}{1330}}, \underset{Phe+Tyr}{\frac{321.44}{2310}}, \underset{Thr}{\frac{82.88}{1400}}, \underset{Trp}{\frac{36.48}{350}}, \underset{Val}{\frac{123.68}{1680}}\right) \\ &= \text{\% of limiting EAA}(8.98\%, 7.31\%, 8.33\%, 4.04\%, 5.87\%, 13.92\%, 5.92\%, 10.42\%, 7.36\%) \\ &= 4.04\% \end{aligned}$$

Step 2: Calculate the EAA-9 Equivalence serving size [b]

EAA-9 Equivalence offers an approach to assess foods and serving sizes while ensuring they meet amino acid targets.

Target Food	Protein Food Standard
Peanut Butter	*Egg*
Serving size = 1 tbsp (16 g)	Serving size = 1 Egg (50 g)
EAA-9 Score = 4.04%	EAA-9 Score = 15.77%

$$\text{EAA-9 Equivalence serving size} = \text{serving size of target food} \times \left(\frac{\text{EAA-9 Score of standard}}{\text{EAA-9 Score of target food}}\right)$$

$$= 1 \text{ tbsp (16 g)} \times \left(\frac{15.77\%}{4.04\%}\right)$$

= 3.90 tbsp (62.46 g)
or ~4 tbsp

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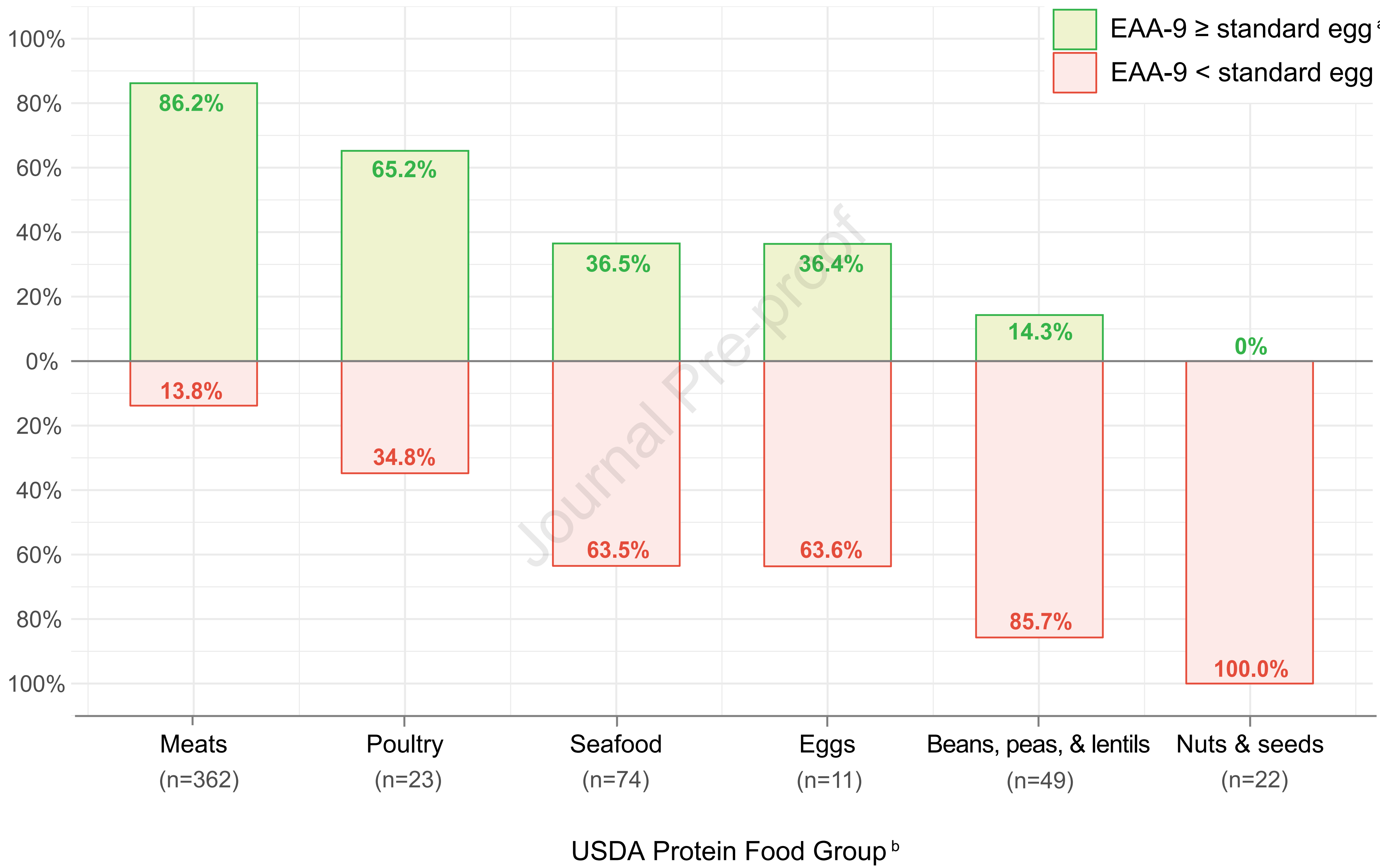

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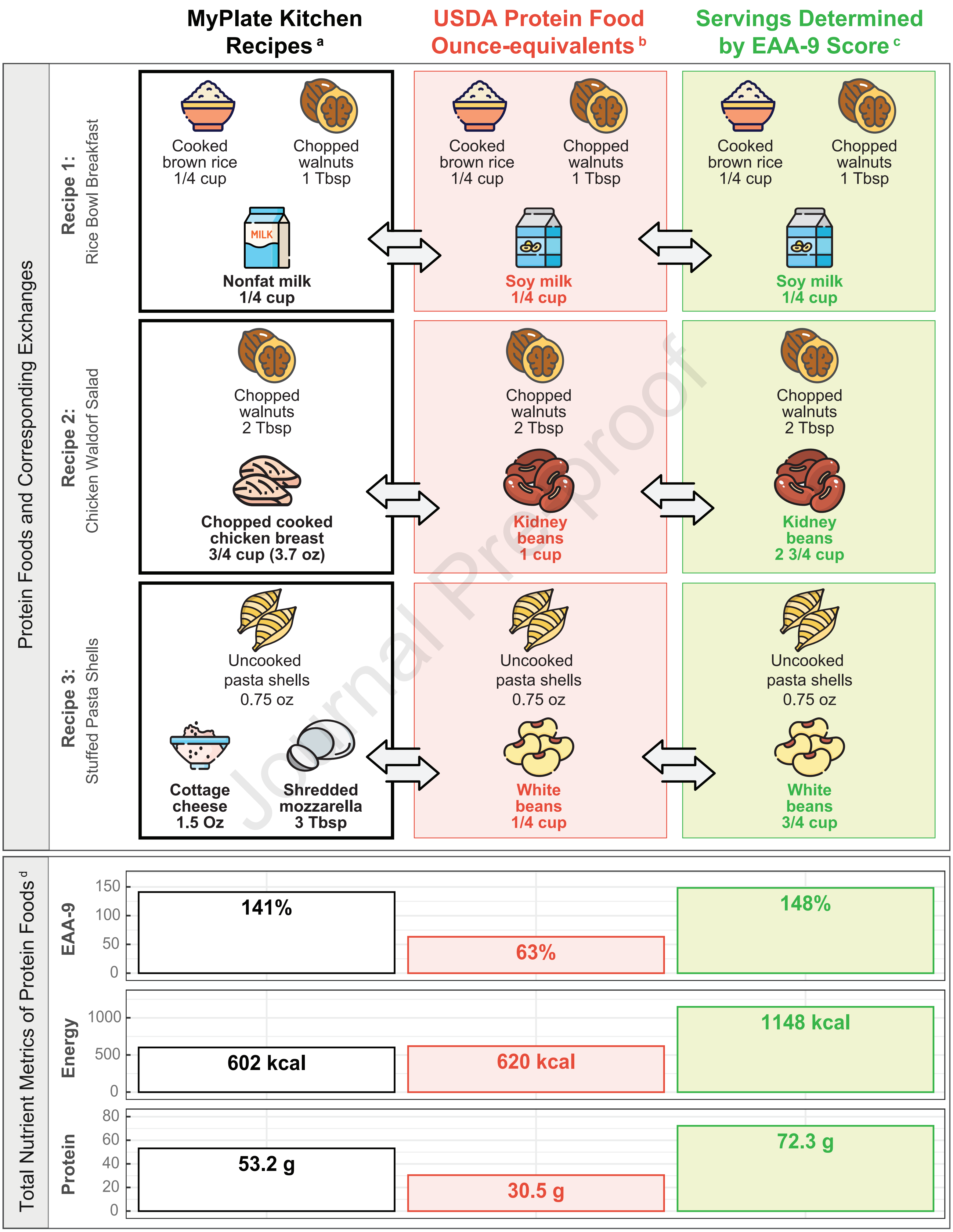

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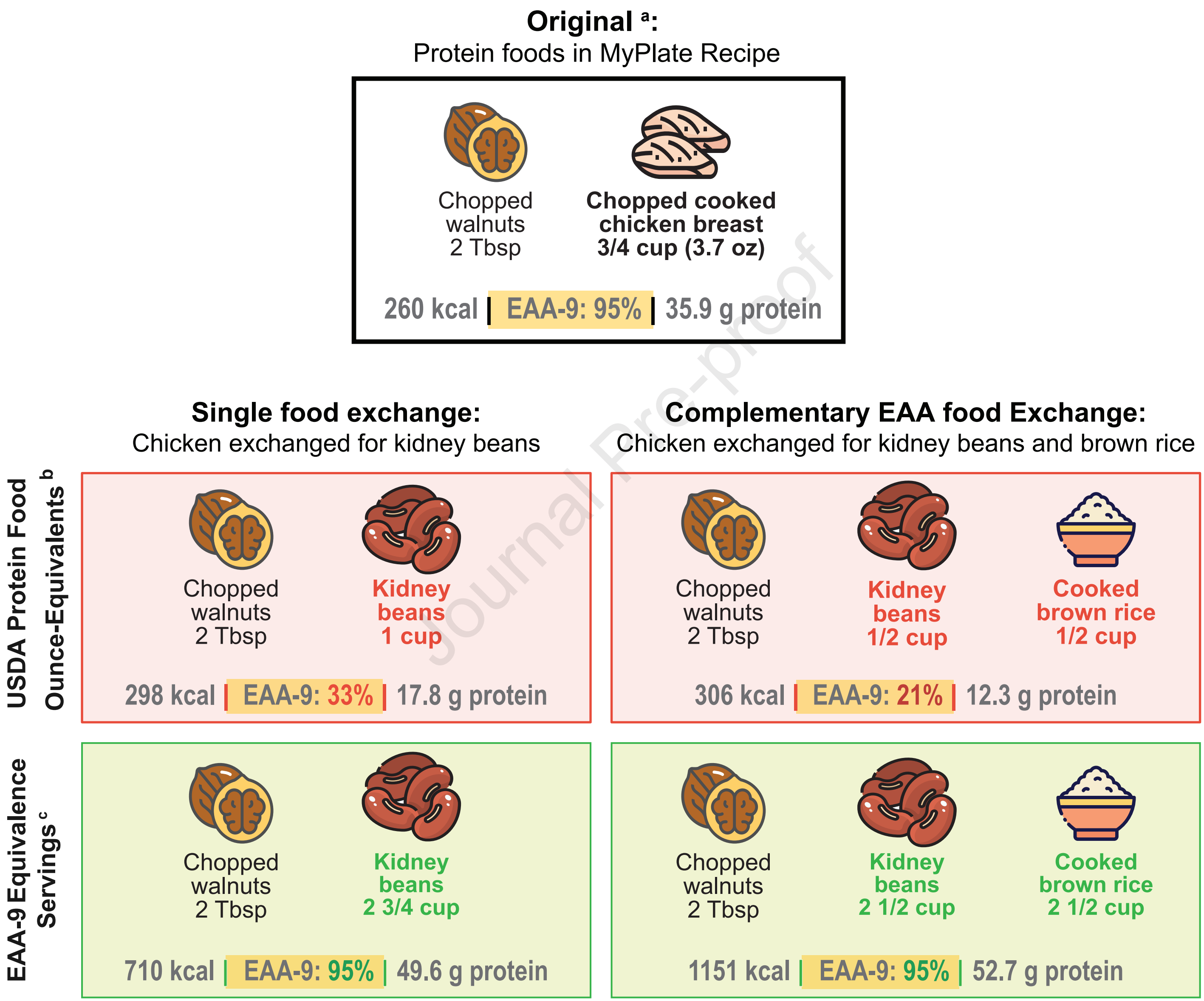

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Table 1. Calories, macronutrients, and EAA[a] in USDA ounce-equivalent protein foods[b]

	One USDA ounce-equivalent	Calories	Protein	Carbohydrates	Fat	Total EAA	EAA/Protein
		kcal	g				%
Chicken Breast	1 ounce (28.3g)	44	9.1	0.0	0.9	4.0	44.0
Beef Sirloin	1 ounce (28.3g)	52	8.7	0.0	1.6	3.5	40.3
Salmon	1 ounce (28.3g)	43	7.0	0.0	1.5	2.9	42.0
Egg	1 egg (50g)	72	6.3	0.4	4.8	2.8	44.6
Tofu	2 ounces (56.7g)	43	4.6	1.1	2.7	1.9	41.2
Kidney Beans	¼ cup (44.3g)	56	3.8	10.1	0.2	1.5	39.6
Lentils	¼ cup (49.5g)	57	4.5	10.0	0.2	1.6	35.6
Split Peas	¼ cup (49g)	58	4.1	10.4	0.2	1.5	36.6
Peanut Butter	1 tbsp (16g)	94	3.9	3.5	8.0	1.0	26.2
Almonds	½ ounce (14.2g)	82	3.0	3.1	7.1	0.9	29.6
Sunflower Seeds	½ ounce (14.2g)	88	2.4	2.9	8.1	0.9	37.9

[a] EAA, essential amino acids

[b] Food composition data from SR Legacy[11]; fdc_ids: chicken breast - 171140, beef sirloin - 168634, salmon - 172001, egg- 171287, tofu - 172476, kidney beans - 175194, lentils - 172421, split peas -172429, peanut butter - 174294, almonds - 170567, sunflower seeds - 170154.

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Table 2. USDA ounce-equivalents compared to EAA-9 Equivalences [a]

	USDA ounce-equivalents			EAA-9 Equivalences	
	Serving Size	**Kcal**	**EAA-9 Score (limiting EAA)**	**Serving Size**	**Kcal**
Chicken Breast	1 ounce	44	24.90% (Met + Cys)	0.63 ounce	28
Beef Sirloin	1 ounce	52	16.25% (Trp)	0.97 ounce	50
Salmon	1 ounce	43	18.00% (Leu)	0.88 ounce	38
Egg	1 Egg	72	15.77% (Met + Cys)	1 egg	72
Tofu	¼ cup (2 ounces)	43	5.84% (Met + Cys)	0.68 cup (5.40 ounces)	116
Kidney Beans	¼ cup	56	7.45% (Met + Cys)	0.53 cup	119
Lentils	¼ cup	57	7.26% (Met + Cys)	0.54 cup	125
Split Peas	¼ cup	58	7.81% (Met + Cys)	0.50 cup	117
Peanut Butter	1 tbsp	94	4.04% (Met + Cys)	3.91 tbsp	368
Almonds	½ ounce	82	3.03% (Met + Cys)	2.60 ounce	427
Sunflower Seeds	½ ounce	88	3.77% (Lys)	1.90 ounce	332

[a] Nutrient composition from SR Legacy data[11]; fdc_ids: chicken breast - 171140, beef sirloin - 168634, salmon - 172001, egg- 171287, tofu - 172476, kidney beans - 175194, lentils - 172421, split peas -172429, peanut butter - 174294, almonds - 170567, sunflower seeds - 170154. A full list of foods and amino acid composition is available on on Mendeley Data (https://doi.org/10.17632/xwwsmncckr.3) [25]

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Table 3. Practical EAA-9 Equivalences [a]

	USDA ounce-equivalent Serving Size	**EAA-9 Equivalence Serving Size**
Chicken Breast	1 ounce	1 ounce
Beef Sirloin	1 ounce	1 ounce
Salmon	1 ounce	1 ounce
Egg	1 Egg	1 Egg
Tofu	¼ cup (2 ounces)	¾ cup (5 ½ ounces)
Kidney Beans	¼ cup	¾ cup (3 ½ ounces)
Lentils	¼ cup	(¾ cup) 4 ounces
Split Peas	¼ cup	¾ cup (3 ½ ounces)
Peanut Butter	1 tbsp	4 tbsp
Almonds	½ ounce	3 ounces
Sunflower Seeds	½ ounce	2 ½ ounces

[a] EAA-9 Equivalences rounded up to the nearest practical serving. Nutrient composition from SR Legacy data[11]; fdc_ids: chicken breast - 171140, beef sirloin - 168634, salmon - 172001, egg- 171287, tofu - 172476, kidney beans - 175194, lentils - 172421, split peas -172429, peanut butter - 174294, almonds - 170567, sunflower seeds - 170154. A full list of foods and amino acid composition is available on on Mendeley Data (https://doi.org/10.17632/xwwsmncckr.3) [25]

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