Protein quality of vegan and vegetarian university canteen dishes

of the Studentenwerk Schleswig-Holstein using the example of the University of Kiel

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Abstract

The demand for plant-based nutrition is increasing in public catering and is particularly high in campus catering and gastronomy. Based on recipes from the *Studentenwerk* Schleswig-Holstein's (student services organization) lunch menu, the protein quality was calculated using the Digestible Indispensable Amino Acid Score (DIAAS) for 46 vegan, 11 vegetarian and 9 meat-containing dishes, taking into account ileal digestibility coefficients from the literature. About half of the vegan dishes were of low protein quality (DIAAS < 75). This was due to a lack of intake of lysine from grain products or of sulfur-containing amino acids from legumes when these were the first protein-providing ingredient and were not adequately complemented. For this reason, when planning vegan dishes it is recommended to focus on ingredients with a high lysine content and also a high ileal digestibility of the lysine.

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Introduction

Particularly among young adults, the proportion is high of those who eat a plant-based diet low in animal foods [1, 2] and the demand for vegan lunch menus in campus catering is therefore correspondingly high [3]. In addition to potential health benefits, the orientation of the food offering towards a more plant-based and, in particular, low-meat food in public catering has a benefit in terms of climate and resource protection [4]. However, animal protein sources usually have a higher protein quality than plant sources [5, 6]. These also contain all 9 indispensable Amino Acids (AA) (Indispensable Amino Acids, IAA), but often not in a comparably balanced amount with regard to human requirements. In cereals, for example, the IAA lysine is limiting, and in legumes it is often the sulfur-containing AA methionine and cysteine (Sulphur Amino Acids, SAA) [7, 8]. In addition, the bioavailability of AA can be reduced by antinutritive factors such as phytic acid, protease and trypsin inhibitors, lectins or tannins [9, 10]. Therefore, for most plant proteins, it is necessary to complement the limiting IAA with a suitable combination of plant protein sources to achieve a protein quality comparable to animal sources [11, 12].

The Digestible Indispensable Amino Acid Score (DIAAS) is the recommended method by the Food and Agriculture Organization of the United Nations (FAO) to assess the quality of dietary proteins since 2013 [13]. The IAA content of the dietary protein as well as the ileal digestibility of the AA are included in the calculation of the DIAAS and are compared with the AA pattern of a reference protein, which reflects the respective requirement of an age group.

The bioavailability of proteins or AA is traditionally estimated based on their digestibility [14]. In brief, the intake of AA from food is compared

with the AA contained in the digesta and therefore not absorbed, in order to determine the amount of AA absorbed by the body [15]. There are different approaches of measuring protein digestibility [16]. For the predecessor of the DIAAS, the Protein Digestibility Corrected Amino Acid Score (PDCAAS), the so-called True Protein Digestibility (TPD) was used [17]. It is also known as faecal digestibility, and refers to the entire digestive tract [18, 19]. However, one disadvantage of the TPD is that microbial degradation in the large intestine is not taken into account and protein digestibility is therefore overestimated [9, 20].

The DIAAS now measures the True Ileal Digestibility (TID), which represents an important improvement [13]. For this purpose, ileal digesta are collected *in vivo* from the final section of the small intestine, the terminal ileum. This more accurately reflects the actual absorption of AA in the human organism [21–23]. The measurement of the TID should ideally be carried out directly in humans. If this is not possible, the pig is preferred over the rat as a model animal [13]. Currently, the majority of data on ileal digestibility of dietary proteins comes from measurements on (growing) pigs [11, 12, 24, 25].

Amino Acid Digestibility (DIAAS)

- the protein supplied with food is digested and amino acids are released
- digestibility is used to estimate the absorption (bioavailability) of the amino acids
- here, a digestibility coefficient (0–100%) is determined for each amino acid in balance tests
- the term digestibility does not refer to the material breakdown of the amino acids

The objective of the study was to calculate the DIAAS for dishes from the *Studentenwerk* Schleswig-Holstein's (SH) lunch menu based on recipes. The research questions were: What is the protein quality (DIAAS) of vegetarian and vegan dishes served at the Kiel campus canteen? Which factors or IAA contribute to the limitation of the protein quality of the dishes? What side dish additions could improve the meals' protein quality?

Methods

The *Studentenwerk* SH Kiel campus canteen offers an extensive vegetarian lunch menu, with approximately two-thirds of the entire lunch menu comprising vegan dishes. The database for the present study was a sample of 9 meat-containing, 11 vegetarian and 46 vegan recipes from the *Studentenwerk* SH. The 46 vegan recipes were representative of a 6-week lunch menu cycle at the canteen. Two dishes with complex meat analogues (vegetarian schnitzel, burger patty) and one with a convenience product (*Börekstange*) were excluded from the calculations. The recipes were evaluated using the DIAAS mixed diet calculations according to the equations of the FAO (2013), ◆ Figure 1 [13]. The digestible IAA reference ratio was calculated for each of the nine IAA of the ingredients considered in the meal: histidine (His), isoleucine (Ile), leucine (Leu), lysine (Lys), methionine and cysteine (SAA), phenylalanine (Phe) and tyrosine (Tyr) summarized as aromatic AA (Aromatic Amino Acids, AAA), threonine (Thr), tryptophan (Trp), and valine (Val) [13]. For this purpose, the reference protein AA pattern (AA scoring pattern) for children over 3 years old, adolescents and adults was used (◆ Table 1). The final result of the DIAAS in percent refers to the lowest of all nine calculated IAA reference ratios and corresponds to the limiting IAA (IAA_{lim}) of the entire dish, including the planned side dishes. A DIAAS of < 75 classifies protein quality as low, while a score of 75–99 is indicative of good protein quality and a DIAAS > 100 is indicative of excellent protein quality [13]. DIAAS results above 100% were not truncated to 100% [cf. 26].

$$DIAAS_{mixed\ diet}\ (\%) = 100 * \text{lowest value}\ (Digestible\ IAA\ reference\ ratio)$$

$$= 100 * \text{lowest value}\left(\frac{mg\ of\ digestible\ IAA\ in\ 1g\ protein\ of\ a\ mixed\ diet}{mg\ of\ the\ same\ IAA\ in\ 1g\ of\ the\ referece\ protein}\right)$$

$$= 100 * \text{lowest value}\left(\frac{TID * mg\ IAA\ in\ 1g\ protein\ of\ a\ mixed\ diet}{mg\ of\ the\ same\ IAA\ in\ 1g\ of\ the\ reference\ protein}\right)$$

Fig. 1: **Equation for calculating the DIAAS for a mixed diet** [according to 13]
DIAAS: Digestible Indispensable Amino Acid Score

Scoring pattern (mg/g protein requirement)								
His	Ile	Leu	Lys	SAA	AAA	Thr	Trp	Val
16	30	61	48	23	41	25	6.6	40

Tab. 1: **FAO reference protein AA pattern (AA scoring pattern) for children aged 3 and over, adolescents and adults** [according to 13]
AA: amino acid; AAA: aromatic amino acids (Phe + Tyr); SAA: sulfur amino acids (Cys + Met)

Procedure

The ingredients of the campus canteen recipes were converted to portion size and dry quantities were translated into cooked quantities [cf. 27]. The side dishes and sauces/dips provided for the lunch menus were taken from the weekly menus from November 2022. The assumptions for the portion sizes of the side dishes were based on the *Monica Mengenliste* [28] and information in the recipes from the campus canteen. In the absence of recipes or manufacturer information for individual menu components, e.g. dips, sauces or desserts, common recipes were adopted. Additionally, random samples were collected on-site, i.e. dishes were weighed to record the actual portion sizes and the proportions of the components from one dish to another.

The protein and IAA contents of the ingredi-

ents were determined using PRODI® based on the *Bundeslebensmittelschlüssel* (BLS, version 3.02). If IAA contents were not available, the nutritional value database of the United States Department of Agriculture (USDA) was used as an alternative [29]. The individual ingredients of the dish were included in the DIAAS calculation, with a minimum protein content of 1 g in the mixed diet. Accordingly, ingredients with a very low protein content or a small proportion in the dish, such as herbs and spices, were excluded from the calculation. Of the protein-delivering ingredients included in the DIAAS calculation with the corresponding protein, IAA concentrations and AA digestibility coefficients, the respective degree of processing and preparation was taken into account [cf. 27]. The TID coefficients of the IAA for each ingredient were taken from published data [e.g. 20, 21, 24, 30, 31]. If no TID coefficients were available for certain ingredients or degrees of processing, existing TPD coefficients were used in accordance with the FAO approach [13] [e.g. 9, 32]. The TID values were recorded individually for each single IAA [13], whereas for the TPD, one factor was estimated equally for all 9 IAA [9, 17].

Exemplary additional calculations

The dishes that achieved a DIAAS of < 100 in the initial calculations were subsequently combined or supplemented with different side dishes or desserts and recalculated: lentils, French fries, basmati rice, millet, buckwheat, quinoa, cornbread, polenta, oats, soy dessert, soy yogurt Vanilla (representing the vegan fruit yoghurt offered in the canteen), vanilla pudding, curd pudding, and quark dessert (all 150 g each) or 100 g tofu (natural, firm). Initially, side dishes and desserts from the standard range were taken into account (e.g. quark dessert). In addition, other suitable supplements (e.g. pseudograins and a vegan "high protein" pudding enriched with soy protein isolate) were calculated that were not yet part of the campus canteen supply.

Results

In accordance with the established cut-off for the minimum protein content of an ingredient (1 g, as detailed in the methods section), each of the 66 selected recipes included at least one protein-providing ingredient, thus meeting the criterion for a DIAAS. The DIAAS calculation was applicable to 92% of the protein content of the ingredients. 22 of the 46 vegan dishes were of low protein quality (DIAAS < 75), 23 demonstrated a moderate protein quality (DIAAS 75–99), and one vegan dish had a high protein quality (DIAAS > 100) (◆ Figure 2). Of the 11 vegetarian dishes, 6 were of excellent quality, 4 were of good quality, and 1 was of low protein quality. Of the 9 meat dishes analysed, all were found to have excellent protein quality.

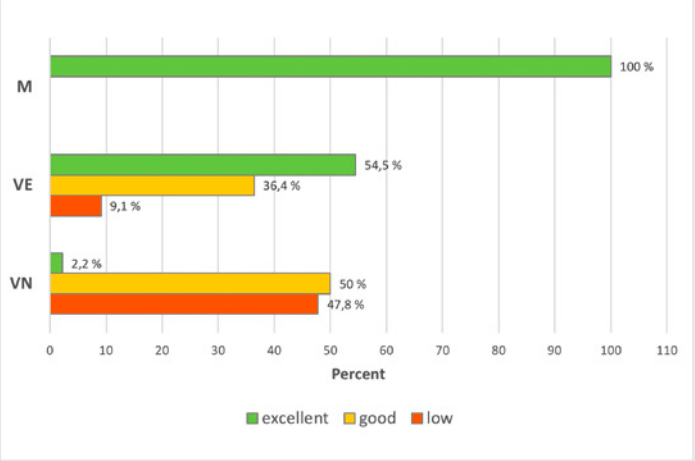


Fig. 2: **Protein quality (DIAAS) of the 46 vegan (VN), 11 vegetarian (VE) and 9 meat-containing (M) dishes according to FAO DIAAS categorization [13]**
low: DIAAS < 75; good: DIAAS 75–99; excellent: DIAAS > 100
DIAAS: Digestible Indispensable Amino Acid Score; FAO: Food and Agriculture Organization

Limiting IAA

Of the 23 dishes (22 vegan and one vegetarian) with low protein quality (DIAAS < 75), lysine was the most prevalent IAA_{lim} (69.9%), followed by SAA (13%) and leucine and histidine with 8.7% each (◆ Figure 3). The limitation of lysine was largely attributable to grains, which were frequently used as a quantitatively relevant first protein-providing ingredient in the dishes. These were mainly wheat noodles, wheat baguette, or rice, whithout complementary ingredients. In dishes with legumes as the main source of protein, the SAA were often the limiting factor. An example of dishes in which the DIAAS was low due to limitation of lysine are vegan pasta dishes with nut pesto, as both grains and some types of nuts and seeds have lysine as IAA_{lim}. Potato and vegetable stews with a side dish of wheat baguette were also of lower protein quality (DIAAS < 75). In principle, potato protein has a high protein quality [11]; however, this is not relevant in vegan dishes with cooked potato, given the low protein content of potatoes (2%). These vegan stews were served with a side dish of wheat baguette which turned out to be the primary protein-providing ingredient. However, a suitable ingredient with complementary protein composition, such as legumes, was not provided in sufficient quantity.

DIAAS of an example vegan dish

◆ Figure 4 illustrates the DIAAS result of the vegan dish "African vegetable stew". In terms of protein-providing ingredients, the wheat baguette was the primary ingredient, followed by peanut butter, kidney beans, and sweet corn, which constituted the

first, second, and third protein sources in the DIAAS, respectively. In this lunch dish, the IAA_{lim} lysine was found to be 72% of the lysine content of the FAO reference protein. Therefore, the DIAAS of the stew at just below 75% did not reach the range of good protein quality (DIAAS 75–99). In comparison to the legume ingredients, i.e. kidney beans and peanut butter, the wheat baguette provides a lesser quantity of lysine, but a greater quantity of SAA. Assuming compensation of the IAA_{lim} lysine, the DIAAS would increase to 105 for the next-limiting IAA valine and thus already achieve a very good protein quality (DIAAS > 100).

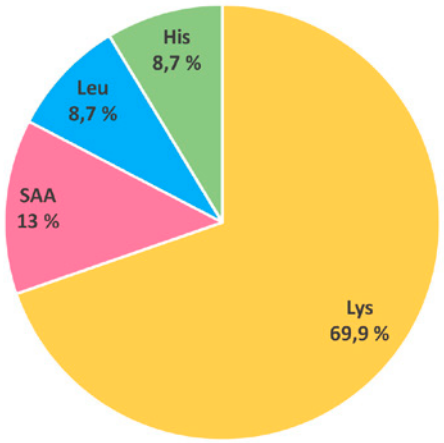


Fig. 3: **Frequency of the limiting indispensable amino acid (IAA_{lim}) in vegan and vegetarian dishes with low protein quality**
DIAAS < 75, n = 23 dishes
DIAAS: Digestible Indispensable Amino Acid Score; IAA: Indispensable Amino Acid

Optimising the meals' protein quality through addition of side dishes and desserts

Complementation with milk protein

For all 50 dishes with an initial DIAAS value < 100, variants with different side dishes and desserts to complement the protein were calculated. The quark dish achieved the most substantial DIAAS increase with an average of 31%. As shown in ◆ Figure 5, this resulted in an improvement of protein quality to a rating of "good" (DIAAS 75–99) or even "very good" (DIAAS > 100). The vegetarian dishes which initially showed good or very good protein quality also usually contained dairy products.

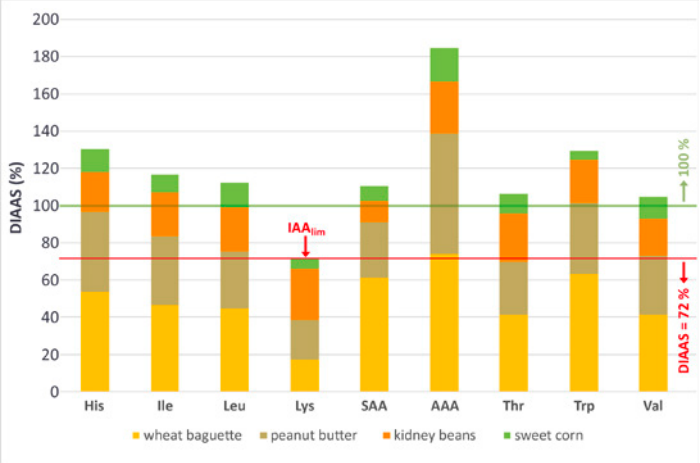


Fig. 4: **DIAAS example of the vegan dish "African vegetable stew" with the limiting Indispensable Amino Acid (IAA_{lim}) lysine and a DIAAS of 72%**
low: DIAAS < 75; good: DIAAS 75–99; excellent: DIAAS > 100
DIAAS: Digestible Indispensable Amino Acid Score

Complementation with legumes

In comparison to the vegetarian complementation with milk protein, a vegan option, which included an additional portion of tofu, achieved an average increase in DIAAS of 20.8% in the same 50 dishes. With the exception of 3 dishes with the lowest initial DIAAS, all dishes were at least improved to good protein quality. In 29 out of 31 dishes with the IAA_{lim} lysine and DIAAS < 100, the addition of lentils improved the DIAAS by an average of 22.6%. The addition of the vegan desserts soy dessert, soy yoghurt or silken tofu dessert did not significantly increase the DIAAS. Consequently, a "vegan high protein" pudding enriched with 15 g soy protein isolate (based on a commercial product with 10 g protein per 100 g pudding) was evaluated to improve the protein quality. This enriched vegan dessert increased the DIAAS by an average of 21.6% across 42 of the 50 vegan dishes (◆ Figure 6). In 8 of the dishes that were limited in SAA and already had a good DIAAS, the addition of the "vegan high protein" pudding did not improve protein quality further.

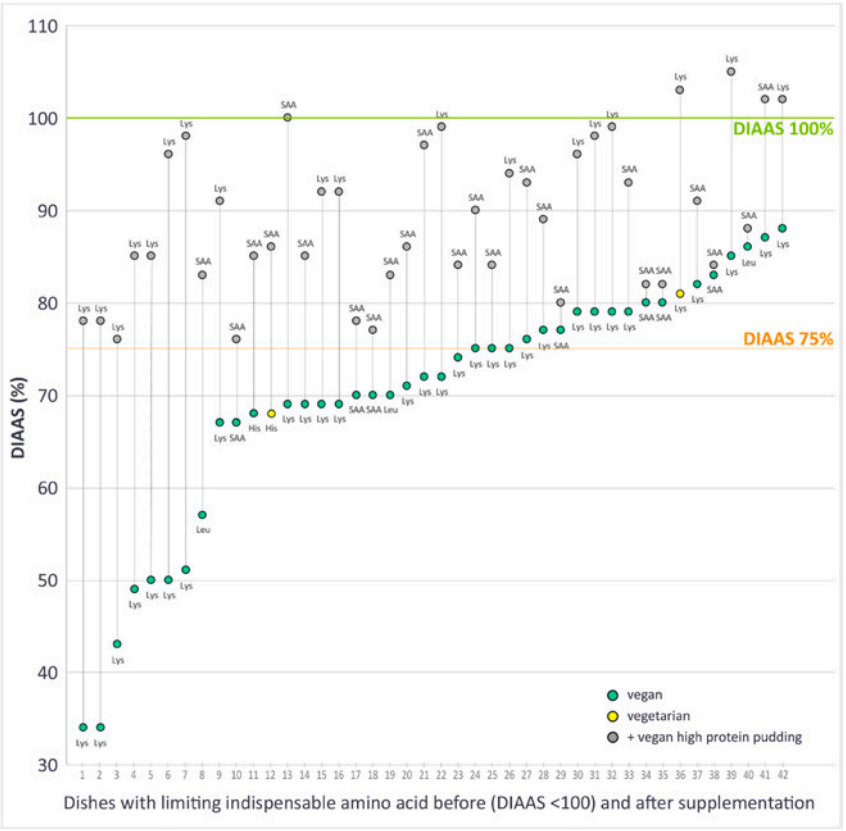
Complementation with pseudograins

In the 50 dishes with DIAAS < 100, an additional portion of quinoa led to an average DIAAS increase of 15.1% in all cases. In the subgroup of dishes limited in SAA with DIAAS < 100 (n = 13), buckwheat resulted in a greater improvement in DIAAS than quinoa, with an average increase of 13%.

Examples of replacing side dishes to optimise protein quality

◆ Figure 7 illustrates the impact of replacing the initial side dish, a wheat baguette, with different alternative options, including polenta, quinoa, buckwheat, and oats, in dishes with the IAA_{lim} lysine. It is evident that the individual dishes are differently improved through the incorporation of specific side dishes. The highest average increase in DIAAS was observed for quinoa (26.9%), followed by buckwheat (23.9%), corn (polenta; 23.5%), and oats (17.9%).

Fig. 5: **Protein quality (DIAAS) of vegan and vegetarian dishes (n = 50) with DIAAS < 100 before and after supplementation with 150 g of quark dish**
DIAAS: Digestible Indispensable Amino Acid Score



Discussion

The analysis of the lunch menu in the Kiel campus canteen revealed that approximately half of the 46 vegan dishes exhibited a low protein quality, whereas 6 of the 11 vegetarian dishes demonstrated a notably high protein quality. Given the high proportion of grain products, the IAA_{lim} of the plant-based dishes was typically lysine. The first protein-providing ingredients in these vegan dishes with a lysine deficiency were often the inexpensive and popular wheat pasta, the quick and easy-to-bake wheat baguette and rice. However, other protein-providing ingredients present in these dishes did not contribute significantly to lysine content. Conversely, an improvement in protein quality can be accomplished through the incorporation of legumes and pseudograins in an appropriate manner. One relatively inexpensive and simple method is to incorporate pulses (e.g. tinned) into the salad buffet. It would be beneficial to provide recommendations (e.g. information signs) regarding the optimal protein sources, side dishes, or desserts for improving the nutritional profile of the respective dishes on the daily menu. For instance, low protein potato and vegetable stews accompanied by a side dish of wheat baguette can be improved by the addition of (smoked) tofu. In vegetarian dishes, the protein quality can be optimised by integrating dairy products. The high potential of lysine-rich milk protein to assure adequate protein intake, particularly when combined with cereals deficient in lysine, is well-documented [12].

Optimizing protein quality at the meal level would generally be desirable, as a balanced intake of IAA per meal enables optimal muscle protein synthesis and thus anabolic utilization of the protein ingested with food [12, 33]. For young adults, 20–30 g of protein per meal is considered sufficient for maximum muscle protein synthesis, and high-quality plant protein sources can be just as suitable as animal sources, especially in this age group [34]. Currently, the number of studies assessing protein quality at the meal level is very limited. Most studies investigating the protein

Fig. 6: **Protein quality (DIAAS) of vegan and vegetarian dishes (n = 42) with DIAAS < 100 before and after supplementation with soy-based "vegan high protein" pudding**
DIAAS: Digestible Indispensable Amino Acid Score

quality using the DIAAS exist at the level of single ingredients fed, often including protein concentrates and isolates [11, 12]. To date, there have been few studies that determine the protein quality of a mixed diet using protein digestibility values published in the literature, as in the present study. Tas et al. (2019) analysed recipes for vegetarian and meat dishes from 93 restaurants in Turkey using the DIAAS. As expected, the analysis revealed a higher protein quality in the meat dishes, while 31.2% of the vegetarian dishes were of low protein quality (DIAAS < 75) [26]. Tas et al. attributed this to a lack of SAA in legume menu components and to a lack of lysine in grain components. Indeed, 16% of the vegetarian dishes (n = 15 of 93) contained no protein-providing ingredient at all and therefore had a DIAAS of 0. However, only ingredients with a protein content of at least 2.5% were considered in the calculations [26]. In contrast to Tas et al., ingredients with a lower protein content (e.g. potato with 2% protein) were also considered in the present evaluation, provided that they were relevant in terms of quantity in the recipe and reached a minimum value of 1 g of protein in the entire meal. It is recommended that the IAA content of lower-protein ingredients, such as fruits and vegetables, be considered, as they can contribute to a significant proportion of the total protein intake, particularly in a plant-based diet [7, 8, 27]. Had we applied their threshold of > 2.5%, vegan potato and vegetable dishes from the *Studentenwerk* Schleswig-Holstein's menu would have been assigned a DIAAS of 0, as the potato would not have been included in the calculations as a sufficient protein-containing ingredient. The majority of vegetable ingredients would also have been excluded from the calculations, which would have had a detrimental impact on the DIAAS of vegan (and vegetarian) dishes in particular.

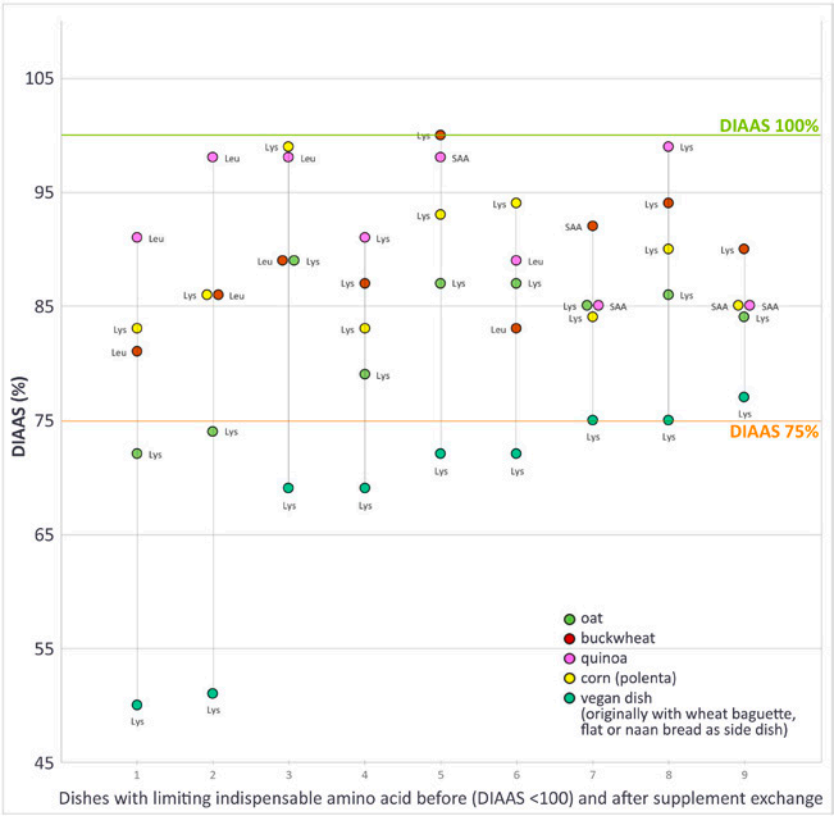


Fig. 7: **Protein quality (DIAAS) optimized by replacing side dishes of lysine-limited vegan dishes (n = 9) (polenta, quinoa, buckwheat or oats instead of wheat)**
DIAAS: Digestible Indispensable Amino Acid Score

Limitations

The number of meals containing meat was relatively low in this sample. However, an evaluation of the protein quality of these meals was not the objective of the study, as dishes containing meat are generally known to have a high protein quality [12, 26]. The DIAAS approach is merely an approximation of the actual protein quality, i.e. the protein and IAA contents of the ingredients were not measured directly, but estimated on the basis of the BLS data. These are average values derived from analyses or calculated using algorithms, and therefore may be prone to error (for further details, please refer to the BLS discrepancy list [36]). Furthermore, the missing IAA contents were obtained from the USDA database. The ileal digestibility coefficients for the ingredients were derived from experimental studies that analysed individual test proteins. It should be noted that depending on the methodology employed, these values are subject to additional uncertainty factors [11, 24]. A major limitation of this study was the availability of TID coefficients for specific ingredients of the dishes, particularly in relation to the extent of processing and preparation. In accordance with the recommendations by the FAO (2013), TPD coefficients were used as an equivalent to TID coefficients [13]. This was particularly the case with vegetables, for which no TID coefficients were available [cf. 27]. The same factor was assumed for a number of ingredients within this food group, for example, carrot and tomato, for which a TPD coefficient of 81% was applied [27, 32]. As the TPD coefficients are based on measurements of faecal protein digestibility, they tend to be higher than the AA-specific TID coefficients. Thus, an overestimation of the contribution of the IAA of certain ingredients, and consequently a partial overestimation of the DIAAS results, cannot be ruled out.

Conclusion and Outlook

It was found that approximately 50% of the vegan dishes had an inadequate protein quality, particularly due to a low content of the IAA lysine. Therefore, it is recommended that attention be paid to ingredients with a high lysine content in relation to the protein content, with a simultaneous high ileal digestibility of the lysine, in the vegan meal planning of public catering. Within the food groups, there are discernible gradations in terms of protein quality complementation potential. In our study, for example, the vegetarian quark dish or tofu stood out as lysine-rich options for complementation. The development of further appropriate menu components for protein quality improvement (possibly taking into account potentially critical micronutrients for vegans, such as calcium, iron, zinc and selenium [37]) increases the feasibility, attractiveness and variety of a plant-based diet and should therefore be the subject of future studies to improve public catering.

As a consequence of demographic shifts and social change in Germany, including an increase in single-person households and greater mobility, the role of public catering is becoming increasingly important [38]. At the same time, it may be assumed that the relevance of plant-based dishes in public catering will continue to grow. The proportion of students who adhere to a vegan or vegetarian diet is high, and campus catering in particular is therefore experiencing considerable demand for plant-based dishes [1, 38]. By switching to sustainable concepts, campus catering can serve as a role model for change and thus make an important contribution to the nutritional transformation [39]. If the consumption of foods containing milk, eggs, or meat is eliminated or significantly reduced when modifying the menu, it is imperative to skillfully combine and complement plant-based protein sources at the meal level. It is recommended that, in the future, the optimal protein composition and corresponding ingredient ratios be estimated using DIAAS mixed diet calculations. Nevertheless, there is currently a paucity of data regarding the nutritional value of complex meat analogues and convenience foods, as well as certain substitute products, such as vegan cheese or egg substitutes. It would be beneficial to incorporate these products into the protein quality assessment, given their growing prevalence in public catering settings. Further studies in public catering facilities at the meal level, e.g. in daycare centres and schools or facilities for senior citizens, are desirable. Furthermore, protein quality results should also be linked to climate-related data to ensure that environmental impacts are also taken into account when selecting ingredients.

Disclosures on Conflicts of Interest and the use of AI
The authors declare that there is no conflict of interest and that no AI applications were used in the preparation of the manuscript.

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