Protein intake adequacy among Nigerian infants, children, adolescents and women and protein quality of commonly consumed foods

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Abstract

Protein is important for growth, maintenance and protection of the body. Both adequacy of protein quantity and protein quality in the diet are important to guarantee obtaining all the essential amino acids. Protein–energy malnutrition is widely present in developing countries such as Nigeria and might result in stunting and wasting. Needs for protein differ depending on age and physiological status and are higher during growth, pregnancy and lactation. The present review assessed protein quantity and quality in diets of Nigerian infants, children, adolescents, and pregnant and lactating women. Literature reviews and calculations were performed to assess adequacy of Nigerian protein intake and to examine the Nigerian diet. The digestible indispensable amino acid score was used to calculate protein quality of nine Nigerian staple foods and of a mixture of foods. The Nigerian population had mostly adequate protein intake when compared with the most recent protein recommendations by the FAO (2013) and WHO/FAO/UNU (2007). An important exception was the protein intake of adolescent girls and pregnant and lactating women. Most of the assessed Nigerian plant-based staple foods were of low protein quality and predominantly lacked the amino acid lysine. The addition of animal-source foods can bridge the protein quality gap created by predominance of plant-based foods in the Nigerian diet. The methodology of this review can be applied to other low- and middle-income countries where diets are often plant-based and lack variety, which might influence protein intake adequacy.

Key words: Nigeria: Protein intake: Essential amino acids: Digestible indispensable amino acid score (DIAAS): Diet

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Introduction

Proteins, made up of amino acids, are essential elements in a diet. They are used for growth (i.e. building tissues and fluids) and replacement of lost amino acids and thus maintenance of approximately 25 000 proteins coded by the human genome(1,2). Furthermore, they have regulatory and catalytic functions, protect against infections and can serve as a source of energy(1,2). Nine essential amino acids cannot be synthesised by the body and should, therefore, be obtained from the diet. The essential amino acids are: histidine (His), isoleucine (Ileu), leucine (Leu), lysine (Lys), methionine (Met), phenylalanine (Phe), threonine (Thr), tryptophan (Tryp) and valine (Val). Conditionally essential amino acids cysteine (Cys) and tyrosine (Tyr) are often combined respectively with Met as sulfur amino acids (SAA) and Phe as aromatic amino acids (AAA) for the purpose of calculating dietary requirements.

Adequate protein intake is especially important for infants, children and adolescents since these life stages are characterised by rapid increases in height, weight, development and function maturation, which require higher protein intake(2). Furthermore, pre-pregnancy underweight has been shown to be associated with low birth weight(2,3). Pregnant and lactating women also have increased protein intake demands for net tissue deposit or milk formation(2). The period from conception until the age of 2 years is especially important for physical, mental and cognitive growth, development and health of the infant(3). However, in the case of developing countries including Nigeria, this period is often characterised by protein–energy malnutrition (PEM), which interferes with optimal growth and development(3). PEM, a form of undernutrition, indicates a lack of supply to the body or underutilisation of protein and energy(4,5). In 2012, PEM was the tenth leading cause of death in the Nigerian population, accounting for 2.5 % of total deaths(6). PEM can also result in wasting, i.e. acute malnutrition, and stunting, i.e. chronic malnutrition, affecting, respectively, 7 % (and 2 % severely wasted) and 37 % (and 19 % severely stunted) of

Abbreviations: AAA, aromatic amino acids; DIAAS, digestible indispensable amino acid score; EAR, estimated average requirement; LOS, level of satisfaction; PDCAAS, protein digestibility-corrected amino acid score; PEM, protein–energy malnutrition; RDA, recommended daily allowance; SAA, sulfur amino acid.

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children in Nigeria under the age of 5 years (3). Although wasting has decreased in the recent years (from 18% in 2013 to 7% in 2018) (7, 8), there has been no improvement in stunting (in 2013 stunting was 37%) (9). Additional protein intake might be beneficial for catch-up growth in children who are stunted and for rapid weight gain in children who are wasted (2).

PEM may be further exacerbated by the fact that many children in Nigeria carry the additional burden of different infections. In Nigeria, acute respiratory infections, diarrhoea, sepsis, HIV and AIDS are among the most prevalent causes of total deaths in children under the age of 5 years, with, respectively, 15, 10, 5 and 3% of deaths (10). For the total population, lower respiratory diseases and HIV/AIDS are the top two leading causes of death accounting for, respectively, 13-9 and 10-4% of deaths (11). Individuals who suffer from infections, such as HIV/AIDS, tuberculosis, acute diarrhoea, acute respiratory infections and sepsis, activate new metabolic pathways that utilise amino acids, and might, therefore, benefit from higher protein intake to replace specific amino acids (2, 9).

In Nigeria, low-cost foods rich in good-quality protein are scarce (12), which makes it difficult to meet protein and amino acid requirements. Studies have been conducted on examining the protein and amino acid composition of certain staple foods and Nigerian diets (13–15), protein and specific amino acid requirements in individuals (2, 5, 9, 14, 15), as well as dietary protein intake among children (16), adolescents (17) and women (18). However, no clear overview of both the adequacy of dietary intake of protein, in terms of quantity, in Nigerian infants, children, adolescents and (pregnant and lactating) women, and the role of the Nigerian diet and specific staple foods in achieving this adequacy exists. Hence, the present review aims at comparing the Nigerian dietary intake of protein with the protein recommendations for these groups. Furthermore, we examined the Nigerian diets regarding the most commonly eaten food groups and staple foods. We also made an effort to examine protein quality, using the most recent protein quality measure, digestible indispensable amino acid score (DIAAS) (19), of some major staple foods that constitute the Nigerian diet. Protein quality was also determined for a mixture of foods since foods are often eaten together with other foods and might complement each other in terms of protein quality (19).

Overall, with this article, we aim to provide a comprehensive overview within the limitations of existing data of protein quality and quantity in the diets of Nigerian infants, children, adolescents, and pregnant and lactating women.

Methodology

The present narrative review has been conducted while applying the methodological rigour of systematic reviews as much as possible. The exact procedures for every step of the writing are described below.

Literature search

A literature search was conducted as described below:

1. The following database search engines were used: Scopus, PubMed, Google Scholar and the online library of the Wageningen University and Research. The following search query was used to select relevant articles about nutrition and diet in Nigerian infants, children, adolescents and women: "(nutrition* OR diet*) AND (intake) AND (Nigeria) AND (children OR women OR infants)". Only articles published after the year 2000 were included to reflect the recent situation. This search yielded 329 articles. All abstracts were reviewed, and relevant complete articles were retrieved.

2. Additional key words and queries such as ‘amino acids’, ‘protein’, ‘requirements’, ‘recommendations’, ‘infants’, ‘children’, ‘women’, ‘adolescents’, ‘Nigeria’, ‘diet’, ‘consumption’, ‘commonly consumed’ and ‘staple foods’, ‘protein quantity’ and ‘protein quality’ were used to categorise articles according to the different research questions, i.e. protein intake adequacy, sources of protein in Nigerian diets and protein quality.

Protein intake adequacy

Studies assessing protein intake in terms of quantity were reviewed based on the study area and population group. The adequacy of this protein intake was calculated using the mean protein intake and the protein requirement, both estimated average requirement (EAR) and recommended daily allowance (RDA) of the participants. The EAR reported by the FAO (19) and the RDA reported by WHO/FAO/UNU (2) were used. The EAR is the amount of a nutrient needed to meet the needs of 50% of the population, whereas the RDA meets the needs of almost everyone (97–98%). These and the mean weight of the participants as reported in the studies were used to calculate the recommended daily protein intake (g/d) per population group. When no mean weight was reported in the article, a reference weight was used. The study of Walpole et al. conducted in 2012 (20) estimated an average body mass of 60.7 kg for African adults, both male and female, which was used in the present review as a reference weight when adult body weight was not reported in the study. The level of satisfaction (LOS), which is a measure of protein intake adequacy, as reported in 2014 by Akerele et al. (4), was calculated by dividing the mean protein intake by the calculated recommended daily protein intake for the participants (both EAR and RDA). A LOS above 100% EAR/RDA means that the protein intake can be considered adequate. The protein intake adequacy of pregnant individuals was calculated in two ways: using an EAR/RDA based on the additional weight (kg) gained during pregnancy or using an EAR/RDA based on normal-weight individuals with an addition of extra protein requirements for pregnancy to the EAR/RDA.

Nigerian diet and its contribution to protein intake adequacy

Major consumed foods and meals across different food groups were examined: cereals, nuts and seeds, legumes, fruits, vegetables, dairy products, meat, poultry, eggs and fish, snacks, roots and tubers, and fats and oils among different age groups. About forty articles were used in compiling an overview of Nigerian consumption patterns mostly based on 24 h recalls and food frequency questionnaires (FFQs).
Table 1. Scoring patterns for calculating the digestible indispensable amino acid score in mg/g protein requirement

| Age                          | Histidine | Isoleucine | Leucine | Lysine | SAA | AAA | Threonine | Tryptophan | Valine |
|------------------------------|-----------|------------|---------|--------|-----|-----|-----------|------------|--------|
| Infant (0–6 months)          | 21        | 55         | 96      | 69     | 33  | 94  | 44        | 17         | 55     |
| Child (6 months–3 years)     | 20        | 32         | 66      | 57     | 27  | 52  | 31        | 8-5        | 43     |
| Older child, adolescent and adult (> 3 years) | 16     | 30         | 61      | 48     | 23  | 41  | 25        | 6-6        | 40     |

SAA, sulfur amino acids (methionine and cysteine); AAA, aromatic amino acids (phenylalanine and tyrosine).
* Based on gross amino acid content in human milk from Table 4 in the FAO report (19).
† Based on 0–5-year values from Table 3 in the FAO report.
‡ Based on 3- to 10-year values from Table 3 in the FAO report.

Protein quality of major staple foods

To assess the dietary protein quality of foods, we used the DIAAS. This measure is based on true ileal digestibility values of individual amino acids rather than the overall (faecal) digestibility of protein which was used in the older method of assessing protein quality: protein digestibility-corrected amino acid score (PDCAAS). Therefore, the DIAAS approach better reflects the number of amino acids absorbed (19). The FAO reported that the digestibility factors should preferably be determined in human subjects, but when this is not possible it can be determined in growing pigs or rats (21).

The FAO (19) reported protein and amino acid intake recommendations for many age groups, but in the end gave the suggestion to use three different age ranges for amino acid scoring patterns to be used in the calculation of protein quality (DIAAS): infants (birth to 6 months), children (6 months to 3 years of age) and older children, adolescents and adults (> 3 years). This age stratification was also used in the present review (Table 1). Nine foods, mostly staples, were chosen from different food groups that were frequently eaten and had a relatively large contribution to (daily) energy or protein intake: cassava, rice, maize, wheat, yam, fish (tilapia), groundnuts, cowpeas and sorghum.

The following equation was used for calculating the DIAAS of these foods:

$$\text{DIAAS} = \left[ \frac{\text{mg of dietary essential amino acid in 1g of the dietary protein} \times \text{digestibility coefficient of amino acid of the food}}{\text{mg of the same dietary essential amino acid in 1g of the reference protein}} \right] \times 100$$

The digestibility is given as a percentage and must be divided by 100 to obtain the digestibility coefficient (for example, digestibility is 88%, the coefficient is 88/100 = 0.88). The reference protein is based on the amino acid scoring patterns as proposed by the FAO (19) (Table 1). The limiting amino acid is the amino acid with the lowest score and this is used to reflect the DIAAS of the entire food. A DIAAS ≥ 75 can be considered as a good source of protein whereas a score ≥ 100 can be considered as an excellent source of protein. The DIAAS of a mixture of foods (rice, beans and fish) was determined to examine the effects of combining multiple foods from different food groups on protein quality. Those foods were selected based on the following: availability of the DIAAS values, the fact that they reflect typical Nigerian meal compositions and aim to optimise the protein quality. The method that was used is adapted from FAO (19) and is based on portion sizes of different foods, protein content, amino acid content, true ileal digestibility factors, and the three scoring patterns. Portion sizes (single servings) for rice and cowpeas were adapted from Sanusi & Olurin (22) and the portion size of tilapia was set at 50 g. The amino acid content in those food portions was calculated as (amino acid content of food (mg/g protein) × true ileal digestibility factors of amino acids in the same food) × (protein content in portion per food). These were compared with references set by the FAO for different age groups to determine the DIAAS (19). (The exact calculations for this mixture are explained in the footnotes of Table 11.)

Results and discussion

Protein intake adequacy

The studies conducted in Nigeria on protein intake cover only a small part of the Nigerian population. Most data available were obtained from the richer southern parts of Nigeria (Table 2 and Fig. 1). Protein-rich foods are usually expensive and not all households have the purchasing power to acquire them (4). Therefore, it can be speculated that protein deficiency is more prevalent in northern Nigeria since there are fewer financial resources available to buy protein-rich foods. Altogether twenty articles were included for examining protein intake adequacy. A total of four studies (19%) focused on school children (aged 2–12 years), seven articles (43%) on adolescents (aged 10–19 years), three studies (14%) concentrated on women including pregnant and lactating women, while six articles (29%) addressed complete households.

It is important to realise the limitations of the present review due to the quality of the reported data. The protein intake values as reported in our review were mean protein intake values. These values are valid to determine average protein intake adequacy; however, they do not take a distribution of intake into account. Furthermore, studies conducted on Nigerian pregnant and lactating individuals were scarce. Due to lack of data (we found only one study; Table 2) on the protein intake among disadvantaged (for example, HIV/AIDS, respiratory diseases, etc.) target populations, we did not analyse this further. Some studies did report a percentage of stunted/wasted children, but most gave no separate protein intake value for this group. Other studies did not provide information on whether the study population included pregnant, lactating or diseased individuals. Also, many studies did not report the actual weights of the participants, making it difficult to calculate a precise EAR/RDA based on their actual body weight.
Table 2. Adequacy of protein intake in different states in Nigeria

| Study | Area in Nigeria | Design/method | Study population (n) | Protein intake (g) (mean ± sd) | Mean weight (kg)* | EAR/RDA (g/d)† | Level of satisfaction (%)‡ | EAR/RDA |
|-------|-----------------|---------------|----------------------|-------------------------------|------------------|----------------|--------------------------|---------|
| (60)  | Enugu State     | Cross-sectional survey | 300 Women, of which 88.5% were aged 25–45 years | Farmers 35.8 ± 8.4 | 53.5 | 35.3/44.4 | 101.4/80.6 | 123.9/98.6 |
|       |                 |               |                      | Traders 43.1 ± 5.0 | 52.7 | 34.8/43.7 | 143.6/114.2 | 62.8/50.0 |
|       |                 |               |                      | Teachers 58.6 ± 13.8 | 61.8 | 40.8/51.3 | 91.3/75.9 | 57.4/45.6 |
|       |                 |               |                      | Females 23.0 ± 14.3 | 60.7 | 40.1/50.4 | 57.4/45.6 | 6.2/5.0 |
|       |                 |               |                      | Males 25.2 ± 19.7 | 60.7 | 40.1/50.4 | 57.4/45.6 | 6.2/5.0 |
|       |                 |               |                      | Children 18.9 ± 10.4 | 27.4 | 20.7/24.9 | 19.3/14.5 | 91.3/75.9 |
| (23)  | Edo State, Kogi State | FFQ, 3-d weighed food records | Households | Normal/pregnancy gain Rural ≤ 17 years: 33.6 ± 2.4 | 56.4/67.4 | (a) Normal (b) > 24.9 pregnancy requirement | (a) Normal, (b) > 24.9 pregnancy requirement | 197/154.5 |
|       |                 |               |                      | Rural > 17 years: 37.0 ± 3.0 | 56.4/67.4 | (a) 64.4/47.2 | (a) 52.2/71.2 | 42.7/59.4 |
|       |                 |               |                      | Urban ≤ 17 years: 33.1 ± 2.2 | 56.4/67.4 | (a) 64.4/47.2 | (a) 52.2/71.2 | 42.7/59.4 |
| (29)  | Ogun State      | Questionnaire, weighed food intake, chemical analysis of foods | 101 Pregnant adolescents 15–19 years (trimester 3) | Normal/pregnancy gain Urban ≤ 17 years: 42.2 ± 3.9 | 56.4/67.4 | (a) 64.4/47.2 | (a) 52.2/71.2 | 42.7/59.4 |
|       |                 |               |                      | Urban > 17 years: 42.2 ± 3.9 | 56.4/67.4 | (a) 64.4/47.2 | (a) 52.2/71.2 | 42.7/59.4 |
|       |                 |               |                      | Urban > 17 years: 42.2 ± 3.9 | 56.4/67.4 | (a) 64.4/47.2 | (a) 52.2/71.2 | 42.7/59.4 |
| (39)  | Edo State       | FFQ           | Normal and protein-deficient children, 3–5 years | Normal 40.3 ± 0.7 | 16.8 | 12.3/15.1 | 327.6/266.9 | 273.2/222.5 |
|       |                 |               | Urban (55 men aged 20–75 years and 77 women aged 20–70 years) and Fulani (rural) subjects (42 men and 79 women) | Protein-deficient 33.6 ± 1.1 | 16.8 | 12.3/15.1 | 327.6/266.9 | 273.2/222.5 |
|       |                 |               | Urban 75 ± 35 | 65.5 | 43.2/54.4 | 173.6/137.9 | 223.1/177.1 | 132.1/105.2 |
| (37)  | Jos and 40 km east of Jos, Plateau State | Urban: subjects: 4 d dietary recall. Rural subjects (data used from Glew et al.85): 7 d dietary recall and FFQ | Urban 63 ± 24 | 72.2 | 47.7/59.9 | 186.2/148.0 | 132.1/105.2 | 186.2/148.0 |
|       |                 |               | Rural 62 ± 14 | 50.5 | 33.3/41.9 | 132.1/105.2 | 186.2/148.0 | 132.1/105.2 |
| (62)  | Akwa Ibom State | Not specified | 418 Female adolescents aged 12–18 years | 31.7 ± 7.8 | 51.3 | 36.7/44.4 | 86.4/71.4 | 86.4/71.4 |
| (24)  | Abia State      | 3 d weighed inventory | 190 Adolescents, boys and girls 15–18 years | Males 54.4 ± 7.9 | 56.5 | 39.6/49.2 | 137.4/110.6 | 137.4/110.6 |
|       |                 |               |                      | Females 51.5 ± 9.6 | 53.5 | 37.5/44.9 | 137.3/114.7 | 137.3/114.7 |
| (63)  | Uyo, Akwa Ibom State | 24hr | 300 Adults living with HIV and/or AIDS (160 female, 140 male) | Males 18–30 years: 34.8 ± 6.4 | 60.7 | 60.1/75.6 | 70.0/55.7 | 57.9/46.0 |
|       |                 |               |                      | 31–43 years: 35.9 ± 8.2 | 60.7 | 60.1/75.6 | 70.0/55.7 | 57.9/46.0 |
|       |                 |               |                      | 44–56 years: 36.5 ± 6.1 | 60.7 | 60.1/75.6 | 70.0/55.7 | 57.9/46.0 |
|       |                 |               |                      | 57–69 years: 38.8 ± 6.2 | 60.7 | 60.1/75.6 | 70.0/55.7 | 57.9/46.0 |
|       |                 |               |                      | Females 18–30 years: 42.1 ± 9.3 | 60.7 | 60.1/75.6 | 70.0/55.7 | 57.9/46.0 |
|       |                 |               |                      | 31–43 years: 43.4 ± 12.5 | 60.7 | 60.1/75.6 | 70.0/55.7 | 57.9/46.0 |
|       |                 |               |                      | 44–56 years: 42.9 ± 4.8 | 60.7 | 60.1/75.6 | 70.0/55.7 | 57.9/46.0 |
|       |                 |               |                      | 57–69 years: 43.9 ± 6.7 | 60.7 | 60.1/75.6 | 70.0/55.7 | 57.9/46.0 |
| (25)  | Abia State      | 3 d weighed food intake | 160 Adolescent girls 10–19 years | Secondary 93.5 | 51.3 | 36.7/44.4 | 254.8/210.6 | 368.9/305.0 |
|       |                 |               |                      | University 135.4 | 51.3 | 36.7/44.4 | 254.8/210.6 | 368.9/305.0 |
Table 2. (Continued)

| Study | Area in Nigeria | Design/method | Study population (n) | Protein intake (g) (mean ± SD) | Mean weight (kg)* | EAR/RDA (g/d)† | Level of satisfaction (%)‡ | EAR/RDA |
|-------|----------------|---------------|----------------------|-------------------------------|------------------|----------------|----------------------------|---------|
| (26)  | Lagos State    | Food intake measurements (not specified) 40 College students (adolescents) 10–19 years | 10–12 years: 38.5   | 54.0                          | 39.4/48.6        | 97.7/79.2     | 126.1/105.4                |
|       |                |               | 13–15 years: 55.0   | 59.7                          | 43.6/52.2        | 169.1/138.5   |                           |
|       |                |               | 16–19 years: 70.5   | 59.6                          | 41.7/50.9        | 135.9/107.3   |                           |
|       |                |               | Total 56.0          | 58.9                          | 41.2/51.5        | 135.9/108.7   |                           |
| (64)  | Lagos State    | Food intake measurements (not specified) 40 College students (adolescents) 11–17 years | 56.0 ± 21.1           | 58.9                          | 41.2/51.5        | 135.9/108.7   |                           |
| (38)  | Orhionmwon and Ikpoba-Okha, Edo State | 48-h recall method 384 Household members | Males | 12.7                          | 11.3/13.7        | 183.2/151.1   |                           |
|       |                |               | Female | 12.0                          | 10.7/13.0        | 213.1/175.4   |                           |
| (13)  | Southeast Nigeria | 24hR       | 656 Cassava-consuming children aged 2–5 years | 2.5 ± 1.2 g/kg: 33 208.7 ± 12.2 | 10.5/12.2 | 314.2/270.5 |                           |
| (16)  | Ogun State     | 3 d weighed measurements and 24hR 116 Preschool children (24–60 months) | 17.0 ± 2.7           | 15.2                          | 12.2/14.2       | 139.3/119.7   |                           |
| (65)  | Kaduna, Kaduna State | Cross-sectional and descriptive (questionnaire and 24hR) 394 School-age children 7–11 years from two schools: conventional primary school and integrated Qur’anic school | Conventional primary school | 28.3                          | 20.7/25.5 | 111.6/90.6 |                           |
|       |                |               | Total: 28.8 ± 10.0  | 32.4                          | 23.7/29.2        | 121.5/98.6    |                           |
|       |                |               | Integrated Qur’anic school | 28.3                          | 20.7/25.5 | 144.9/117.6 |                           |
|       |                |               | Total: 32.2 ± 9.0   | 32.4                          | 23.7/29.2        | 135.9/110.3   |                           |
|       |                |               | Total 7–9 years: 26.4 ± 8.1 | 28.3                          | 20.7/25.5 | 127.5/103.5 |                           |
|       |                |               | 10–11 years: 33.1 ± 9.7 | 36.6                          | 26.7/32.9        | 124.0/100.6   |                           |
|       |                |               | Total: 30.5 ± 9.7   | 32.4                          | 23.7/29.2        | 128.7/104.5   |                           |
| (66)  | Ondo and Osun State | FFQ         | 402 University students from Obafemi Awolowo University (1) and Adekunle Ajasin University (2) aged 15–35 years | Males | 61.0                          | 40.3/51.9       | 208.4/161.8   |                           |
|       |                |               | Female | 59.0                          | 38.9/49.3        | 213.4/168.4   |                           |
|       |                |               | University 1: 83 ± 25 | 61.0                          | 40.3/51.9        | 206.0/159.9   |                           |
|       |                |               | University 2: 88 ± 22 | 58.0                          | 38.3/48.4        | 229.8/181.8   |                           |
Table 2. (Continued)

| Study Area in Nigeria | Design/method | Study population (n) | Protein intake (g) (mean ± sd) | Mean weight (kg)* | EAR/RDA (g/d)† | Level of satisfaction (%)‡ |
|-----------------------|---------------|----------------------|-------------------------------|------------------|----------------|--------------------------|
| (4) Ado Ekiti, in Ekiti State | Questionnaires and 24hR | 321 Household members | Males | | | |
| | | | < 6 years: 23.8 | 12.7 | 11.3/13.7 | 210.6/173.7 |
| | | | 6–10 years: 34.1 | 28.1 | 20.5/25.3 | 166.3/134.8 |
| | | | 11–18 years: 53.8 | 55.8 | 39.9/49.4 | 134.8/108.9 |
| | | | 19–59 years: 65.0 | 60.7 | 40.1/50.1 | 162.1/129.7 |
| | | | Females | | | |
| | | | < 6 years: 23.5 | 12.0 | 10.7/13.0 | 219.6/180.8 |
| | | | 6–10 years: 30.0 | 28.5 | 20.8/25.7 | 148.6/120.2 |
| | | | 11–18 years: 51.1 | 51.3 | 36.7/44.4 | 139.2/115.1 |
| | | | 19–59 years: 63.7 | 60.7 | 40.1/50.4 | 158.9/126.4 |
| (67) Abia State | 24hR and FFQ | Lactating women and adolescents 16–45 years | 50.0 ± 12.2 | 68.4 | 59.1/72.8 | 84.6/68.7 |
| | | | Urban 77.4 | 27.0 | 21.9/26.7 | 353.4/289.9 |
| | | | Rural 78.6 | 27.0 | 21.9/26.7 | 358.9/294.4 |
| (36) Across all states of Nigeria | Data from The Nigeria Living Standard Survey 2003–2004(48). Calculations based on food expenditure (collected weekly for 6 weeks) and edible portion sizes | 13 142 Households | Males | | | |
| | | | < 6 years: 23.8 | 12.0 | 10.7/13.0 | 219.6/180.8 |
| | | | 6–10 years: 30.0 | 28.5 | 20.8/25.7 | 148.6/120.2 |
| | | | 11–18 years: 51.1 | 51.3 | 36.7/44.4 | 139.2/115.1 |
| | | | 19–59 years: 63.7 | 60.7 | 40.1/50.4 | 158.9/126.4 |
| (34) Iwo Local Government area of Osun State | Cross-sectional and descriptive (24hR) | 250 Women, 20–59 years | 56 ± 84 | 56.8 | 37.5/47.1 | 149.3/118.9 |
| (69) Across all states of Nigeria | Data from General Household Survey 2010–2011(70). Food consumption past 7 d. Calculations based on household food expenditure and food prices | 1557 Rural households | Post-harvest season 147.0 | 27.0 | 21.9/26.7 | 671.2/550.6 |
| | | | Post-planting season 117.4 | 27.0 | 21.9/26.7 | 536.1/439.7 |

EAR§ (RDA∥) protein

| Age (years) | g/kg per d |
|------------|------------|
| 0-5 | 1.12 (1.31) |
| 1 | 0.86 (1.14) |
| 2 | 0.86 (0.97) |
| 3–10 | 0.73 (0.90) |
| 11–14 | 0.73 (0.90 male/0.89 female) |
| 15–18 | 0.70 (0.87 male/0.84 female) |
| >18 | 0.66 (0.83) |
Table 2. (Continued)

| Age (years) | Pregnancy || Lactating || Reference weights (when actual weight unknown) |
|-------------|------------|------------|------------|
| Trimester 1 | +0.5 (0.7) g/d | +0.8 | 7.8 7.2 |
| Trimester 2 | +7.7 (9.6) g/d | +4.8 | 10.2 9.5 |
| Trimester 3 | +24.9 (31.2) g/d | +11.0 | 11.5 10.8 |
| HIV         | 50% allowance |          |           |
| ≤6 months   | 15.1 (18.9)  |       | 0.57 0.58 |
| >6 months   | 10.0 (12.5)  |       | 1.15 1.15 |

Reference weights (when actual weight unknown)

| Age (years) | Male (kg) | Female (kg) |
|-------------|-----------|-------------|
| 0–5         | 7.8       | 7.2         |
| 1           | 10.2      | 9.5         |
| 1–5         | 11.5      | 10.8        |
| 2           | 12.3      | 11.8        |
| 3           | 14.6      | 14.1        |
| 4–6         | 19.7      | 18.6        |
| 7–10        | 28.1      | 28.5        |
| 11–14       | 45.0      | 46.1        |
| 15–18       | 66.5      | 56.4        |
| >18         | 60.7      | 60.7        |

EAR, estimated average requirement; FFQ, food frequency questionnaire; RDA, recommended daily allowance; 24hR, 24 h recall.

* Mean weight expressed in kg, weight used as reported in an article if available, if not a reference weight was used. Average reference weights were calculated when a study covered multiple age groups. When only household data were available, a mean weight of 27.0 kg was calculated from all the reference weights for men and (non-pregnant) women for all ages.

† EAR = sum of protein needed for maintenance and growth(19) = 'the intake that meets the estimated nutrient needs of half the individuals in a group'. RDA (safe intake level) = average protein requirement plus twice the standard deviation, meeting the needs of 97–98% of the population(2).

‡ Level of satisfaction (%) calculated as protein in g/d consumed by study population divided by the calculated EAR/RDA in g/d x 100.

§ Adapted from FAO(19).

¶ Adapted from WHO/FAO/UNU(20).

Adapted from Waipole et al.19.
Based on the reviewed literature, protein intake of the Nigerian population of non-pregnant and non-lactating women and children seems to be mostly adequate (LOS > 100%). However, notable exceptions were also reported in the study on overall households’ intakes in Edo and Kogi, where protein intake was reported to be inadequate for all family members, with females’ intakes being the lowest. Based on our calculations, protein intake of female adolescents seems to be mostly inadequate (LOS < 100%). The exceptions of satisfactory intake were reported by Ogechi et al. and Anyika et al., and for adolescents above 13 years by Akinyemi & Ibraheem. Pregnant and lactating women were another group of concern with inadequate protein intake. This could be due to cultural beliefs that exist in certain parts of Nigeria that extra protein cannot be consumed during pregnancy and myths about some forbidden protein-rich foods during pregnancy (for example, eggs, beans, snails and grasscutter meat). Especially, the protein intake of pregnant adolescents was low (LOSEAR < 70%); these females were not even able to meet the requirements for healthy non-pregnant and non-lactating women (LOS EAR < 84-0% and LOS RDA < 69-8%). The adult lactating women could only just meet the EAR (LOSEAR = 104%) but not the RDA (LOSEDA = 86-1%) for healthy non-pregnant and non-lactating women. This is of concern because inadequate protein intake during pregnancy has both short- and long-term consequences for both the infant and mother. Epidemiological studies in human subjects have shown that protein deficiency during pregnancy gives rise to low birth weight, intra-uterine growth restriction and that these offspring are at greater risk for development of the metabolic syndrome in adult life. Nutritional intervention during pregnancy is necessary to ensure that mothers consume appropriate amounts of dietary protein such that there are no negative effects on fetal growth and development. Adequate nutrition is also important during the lactation period, as the nutritional content of breast milk was shown to be dependent on maternal diet, for example, fatty acid content, water-soluble vitamins, etc. There are also some reports indicating that the protein quality of the mother’s diet is reflected in the amino acid composition of the breast milk. Especially lysine, methionine and tryptophan were substantially reduced in women with poor protein intake from the diet (for example, by consumption of mostly cereal grains and legumes).

Interestingly, sufficient protein intakes (LOS > 200) were also reported among children classified as protein deficient based on their anthropomorphic measures. When studies provided their own level of adequacy and reported percentages of individuals with inadequate intakes, a more detailed picture emerged. For example, in the only study with children (2–5 years old) in which such distinction was made, 13% of the participants were reported to have inadequate protein intake. Within studies focused on women, inadequate intakes were reported for 18% of women of childbearing age (15–49 years) in south-east Nigeria, 14-4% of women aged 20–59 years in Osun State, and 22-2% of adolescent females in Osun.

**Nigerian diet and its contribution to protein intake adequacy**

Previous literature concluded that dietary diversity was low in six states in Nigeria and should be increased. The search into the Nigerian consumption pattern shows that all examined food
groups in the Nigerian diet were consumed frequently by at least 25% of the population, with ‘fats and oils’, ‘cereals’ and ‘snacks’ being consumed the most (> 65-0%). Snack consumption was most often reported in studies assessing adolescents and could be an explanation for the low protein intake of adolescent girls since snacks are often fat- and carbohydrate-rich, but protein-poor. Wheat and rice were the most frequent consumed cereals. Cassava and yam were the most eaten roots and tubers; beans and groundnuts the most frequently consumed legumes. Beef, chicken and fish were frequently eaten animal foods, while dairy products were less frequently consumed.

The percentage of the Nigerian population that frequently consumed roots and tubers is 49-5%. Cereals and grains were on average consumed daily by 81-3% of the population. Several studies showed a contribution of cereals to the protein intake of approximately 20-40% [36-38]. Legumes were eaten by 45-5% of the population on average.

Meat, poultry and fish intakes varied widely depending on the study and geographical location, but on average the consumption percentage was 48-5% for meat and poultry and 49-1% for fish and shellfish. According to a study conducted in the south-east of Nigeria, animal-source products contributed only 3% to the total daily energy intake [33]. Dairy products were found to account for barely 0-9% of protein intake [30]. In general, dairy products were only consumed by 38-4% of the population, with milk being consumed by only 31-9% (Table 3).

**Protein quality of staple foods**

Even though most Nigerian population groups seem to have adequate protein intakes in terms of quantity, it does not guarantee high-enough protein quality. The drastic effects of a poor protein quality cassava-based diet were demonstrated in a study among children displaying signs of protein malnutrition despite their overall protein intakes being very high with LOS > 200 [39]. However, since almost complete protein intake was based on cassava, which has very low protein quality, with leucine being the first limiting amino acid (DIAAS 11–18), it did not cover the children’s nutritional needs, resulting in malnutrition. Overall, the nine major staple foods eaten by Nigerians appear not to deliver protein of good quality (Tables 4–9). For the foods from the cereal group (rice, wheat, maize and sorghum), lysine was the first limiting amino acid for all age groups, resulting in DIAAS being inadequate (< 75). Wheat and rice were shown to be of good protein quality for children and adults when looking at the second limiting amino acids (DIAAS > 75), but not for infants. The digestibility factor we used for calculating DIAAS of yam was the overall crude protein digestibility for cassava since no factor for yam could be found in the literature. Protein quality of yam depended on the way of its processing. Processed yam compared with the two unprocessed species had lower protein quality in terms of limiting amino acids (DIAAS < 75). The unprocessed (and thus unetable) yam was shown to be of (marginally) better protein quality for the first SAA and second (lysine) limiting amino acids (DIAAS > 75 for population > 3 years of age). For both groundnuts and cowpeas, the first limiting amino acid was also lysine (DIAAS 27–38), the second SAA (groundnut DIAAS 40–58; cowpea DIAAS 33–49). The DIAAS of rice, maize, wheat and sorghum were, respectively, 42–69, 37–53, 30–43 and 18–26. All sources of cereals/grains did not have good-quality proteins based on their amino acid score and digestibility, and the most deficient amino acid appears to be lysine, followed by SAA. The only source of good-quality protein, which is commonly consumed, was fish. Tilapia, which is also frequently eaten in Nigeria, was the only fish for which information was available to calculate DIAAS: DIAAS > 94 for children 6 months–3 years of age, and excellent DIAAS > 100 for individuals above 3 years.

Overall, all DIAAS for the scoring pattern for infants were inadequate. However, infants are supposed to be exclusively breastfed, and the protein of human milk meets all the amino acid requirements. Therefore the FAO [40] based the scoring pattern for infants on breast milk and consequently no foods from either plant- or animal-based foods can satisfy infant amino acid requirements like human breast milk. However, given the worrying possibility that maternal amino acid deficiencies may be reflected in the composition of breast milk protein, we believe that impact of maternal diet on the amino acid pattern in breast milk requires further research to assure the optimal nutrition for breastfed infants [33,32].

Foods with high protein quality (DIAAS ≥ 100) are important to bridge the nutritional gaps created by consumption of the low-quality plant-based staple foods. Animal protein sources such as dairy products, beef, chicken and eggs were animal-source foods shown to be such excellent protein sources (DIAAS ≥ 100; Table 10) [41–43]. These foods could be of importance in bridging the gap between the lack of lysine from cereals and legumes. Our results showed that about 40% of the Nigerian population eats beef frequently. Eggs and chicken are eaten frequently by one-quarter of the Nigerian population. Milk was frequently consumed by one-third of the population. It was shown that plant-based foods had an average DIAAS of 61, whereas animal-source foods had an average DIAAS of 114 [41]. If these animal-source foods are consumed daily, they could replenish the amino acids that are consumed in inadequate amounts due to the daily consumption of mainly cereals. A relatively high-quality plant-based food is soya beans which was shown to be an excellent source of protein and could, therefore, be a valuable (plant food) addition to the Nigerian diet (Table 10) [41].

**Dietary diversity and protein quality of a food mixture**

As a rule, it applies that eating from multiple food groups, being both plant and animal foods, increases the chance of meeting the nutrient requirements [34,44]. Dietary diversity is widely recognised as a key component of high-quality diets, as consuming a variety of foods across and within different food groups helps ensure adequate intake levels of essential nutrients [45]. However, previous literature concluded that dietary diversity was low in all six examined states in Nigeria and should be increased [35]. Resource-poor settings are generally characterised by consumption of monotonous diets [46].

Consumption from animal-source food groups was found to be significantly related to nutrient adequacy in Nigeria [25]. Animal-source foods are still regarded as the best source of.
Table 3. Commonly consumed foods and meals from different food groups and their contribution to meeting the protein requirements

| Commonly eaten foods/dishes | Population group | States in Nigeria | % of consumption |
|-----------------------------|------------------|------------------|-----------------|
| Roots and tubers            |                  |                  |                 |
| Whole group                 | Households, adolescents, women, children, lactating and pregnant women, and adolescents | Nationwide, Osun, Borno, Kaduna, Taraba, Kwara, Akwa Ibom, Abia | 78.3(70), 45.5(66), 17.6(33), 74.4(34), 59.8(35), 34.5(87), 36.2(76) |
| Yam                         | Adolescents, households, infants, women, pregnant adolescents | Kwara, nationwide, Osun, Federal Capital Territory Abuja, Enugu, Ogun | 11.3(74), 50.0(46), 9.0(46), 30.2(44), 7.6(33), 34.8(79), 9.1(79), 25.0(79), 5.5(79) |
| Cocoyam                     | Households       | Nationwide       | 20.3(20)        |
| Cassava                     | Households, adolescents, children | Nationwide, Kwara, Enugu, South-East | 20.0(46), 50.0(46), 11.3(74) |
| Potatoes                    | Adolescents, households, infants, children | Kwara, nationwide, Osun, Enugu | 11.3(74), 6.0(48), 14.0(46), 0.9(44), 3.0(79) |
| Meals/dishes                |                  |                  |                 |
| Amala (made with yam flour) | Infants, women, children | Osun, Federal Capital Territory Abuja | Average 22.1(44,53) 5.05(79) |
| Pigeon pea pottage + cassava| Children, adolescents | Enugu | Average 15.5(44,53,79) |
| Fufu                        | Infants, women, children, adolescents | Osun, Federal Capital Territory Abuja, Enugu | Average 21.0(44,53) |
| Eba (made from garri)       | Women, children, adolescents | Federal Capital Territory Abuja, Enugu | Average 10.0(53,79) |
| Akpu (cassava-based porridge)| Children, adolescents | Enugu | 8.0(79) |
| Garri (cassava flower)      |                  |                  |                 |
| Legumes, nuts and seeds     | Adolescents, infants, women, children, women, pregnant and lactating women, and adolescents | Osun, nationwide, Plateau, Borno, Kaduna, Taraba, Kwara, Akwa Ibom, Ondo, Abia, Ondo Abia, Cross River | 52.2(17), 23.0(25), 70.4(34), 77.6(37), 63.5(53), 47.5(77), 21.4(87), 35.7(87), 18.6(87) |
| Nuts and seeds              |                  |                  | Average 45.5 |
| Beans                       | Households, infants, children, adolescents | Nationwide, Osun, Borno, Kaduna, Taraba, Kwara, Akwa Ibom, Ondo, Abia | 77.2(26), 26.8(43), 23.0(39), 63.5(35), 36.7(78), 18.6(81) |
| Peas                        | Households, children, adolescents | Nationwide, Enugu | Average 38.4 |
| Palm kernel                 | Children, adolescents | Enugu | Average 9.3 |
| Groundnuts                  | Households, children, adolescents, women, infants | Nationwide, Enugu, Kwara, Oyo, Enugu | 33.0(46), 8.1(79), 11.3(74), 35.3(82) |
| Meals/dishes                |                  |                  | Average 21.9 |
| Akara (made with cowpeas)   | Infants, adolescents, children | Osun, Enugu | 23.1(44), 3.0(79) |
| Bean porridge               | Children, adolescents | Enugu | Average 13.1 |
| Ayaraya oka (cowpeas and maize) | Children, adolescents | Enugu | 6.5(79) |
| Moin-moin (made with peas)  | Infants, children, adolescents | Osun, Enugu | 11.0(79) |
| Okpa (steamed bambara groundnut paste pudding) | Children, adolescents | Enugu | 28.4(44), 2.0(79) |
| Dairy products              |                  |                  | Average 15.2 |
| Whole group                 | Children, households, adolescents, infants, women, pregnant and lactating adolescents, and women | South-East, nationwide, Osun, Kwara, Borno, Kaduna, Taraba, Akwa Ibom, Cross River | 41.0(13), 90.8(70), 38.0(70), 38.7(17), 14.6(33), 10.8(34), 27.0(35), 17.4(78), 67.6(81) |
| Milk (all sorts)            | Women, adolescents, infants, children, pregnant and lactating women and adolescents, households | Osun, Ondo, Nationwide, Kwara, Plateau, Oyo | Average 38.4 |
|                            |                  |                  | 20.5(86), 13.5(53), 2.7(74), 87.0(37), 26.9(78), 47.6(44), 47.6(80), 50.5(80), 11.0(46), 22.0(46), 21.8(44) |
|                            |                  |                  | Average 31.9 |
| Commonly eaten foods/dishes | Population group | States in Nigeria | % of consumption |
|----------------------------|------------------|-------------------|-----------------|
| Cheese                     | Adolescents, infants, children | Kwara, Osun | 16.1 (74), 4.0 (44) |
|                            |                  |                   | Average 10.1 |
| Ice cream/(frozen) yoghurt | Adolescents, children | Kwara, Oyo, Enugu | 7.2 (74), 48.5 (80), 2.0 (79), 24.1 (80) |
|                            |                  |                   | Average 20.5 |
| Meat, poultry, eggs and fish | Women, adolescents, infants, children, lactating women and adolescents, households | Osun, Ondo, nationwide, Kwara, Plateau, Borno, Kaduna, Taraba, Osun, Akwa Ibom, Abia, Cross River, South-East | 40.0 (76), 48.6 (17), 31.4 (7), 9.9 (74), 33.0 (78), 41.2 (34), 100.0 (0), 92.0 (37), 40.0 (0), 34.4 (35), 47.5 (77), 34.3 (67), 44.1 (81), 41.0 (13), 79, 90.8 (70) |
|                            |                  |                   | Average 48.5 |
|                            |                  |                   | 47.0 (75), 55.0 (46), 29.9 (80), 31.0 (80) |
|                            |                  |                   | Average 40.7 |
|                            |                  |                   | 1.0 (46), 17.3 (80), 6.4 (74) |
|                            |                  |                   | Average 8.2 |
|                            |                  |                   | 20.0 (72), 15.0 (46) |
|                            |                  |                   | Average 17.5 |
|                            |                  |                   | 14.0 (75), 5.0 (46), 33.7 (80), 41.2 (80), 31.7 (90), 27.2 (34) |
|                            |                  |                   | Average 25.5 |
|                            |                  |                   | 4.2 (77), 12.2 (78) |
| Meat pies                  | Adolescents      | Oyo               | 9.0 (72) |
|                            |                  |                   | Average 8.2 |
|                            |                  |                   | 19.0–31.0 (70) |
|                            |                  |                   | 23.0 (46) |
| Burgers/hotdogs            | Adolescents      | Kwara             | 37.8 (80) |
|                            |                  |                   | 14.8 (74) |
| Cereals/grains             | Households, women, adolescents, infants, children, pregnant and lactating women, and adolescents | Nationwide, Osun, Ondo, Borno, Kaduna, Taraba, Osun, Akwa Ibom, Abia, Cross River | 96.7 (70), 63.5 (66), 76.5 (17), 61.0 (3), 98.0 (34), 100.0 (0), 92.1 (35), 75.0 (77), 67.6 (87), 72.8 (89), 91.0 (81) |
|                            |                  |                   | Average 81.3 |
|                            |                  |                   | 76.0 (69), 48.9 (64), 31.5 (53), 15.0 (74), 87.8 (79), 28.9 (80), 71.3 (80) |
|                            |                  |                   | Average 51.3 |
|                            |                  |                   | 58.0 (66) |
| Pasta (for example, spaghetti, noodles) | Adolescents, households, women, children, infants | Kwara, nationwide, Federal Capital Territory Abuja, Enugu, Oyo, Nasaraawa | 4.7 (74), 46.0 (48), 4.4 (53), 2.0 (79), 36.9 (80) |
|                            |                  |                   | Average 18.8 |
|                            |                  |                   | 6.0 (74), 12.0 (48), 15.6 (44), 1.5 (79), 3.0 (79), 51.8 (80) |
|                            |                  |                   | Average 14.9 |
|                            |                  |                   | 40.9 (4), 26.8 (53), 2.5 (79), 7.0 (79), 58.1 (80) |
|                            |                  |                   | Average 27.1 |
|                            |                  |                   | 8.0 (44), 6.6 (44), 6.6 (44), 5.5 (78), 31.4 (80), 27.8 (80) |
|                            |                  |                   | Average 14.3 |
|                            |                  |                   | 44.0 (46) |
|                            |                  |                   | 34.0 (66) |
|                            |                  |                   | 5.0 (74), 11.2 (80) |
|                            |                  |                   | Average 8.5 |
| Breakfast cereal (for example, cornflakes, Golden Mom) | Infants, children, pregnant and lactating adolescents and women, adolescents | Nationwide, Federal Capital Territory Abuja, Enugu, Oyo | 46.7 (70), 63.5 (66), 76.5 (17), 61.0 (3), 98.0 (34), 100.0 (0), 92.1 (35), 75.0 (77), 67.6 (87), 72.8 (89), 91.0 (81) |
|                            |                  |                   | Average 81.3 |
|                            |                  |                   | 76.0 (69), 48.9 (64), 31.5 (53), 15.0 (74), 87.8 (79), 28.9 (80), 71.3 (80) |
|                            |                  |                   | Average 51.3 |
|                            |                  |                   | 58.0 (66) |
| Sorghum                    | Households       | Kwara, Oyo        | 37.8 (80) |
|                            |                  |                   | 14.8 (74) |
| Millet                     | Households       | Kwara             | 37.8 (80) |
|                            |                  |                   | 14.8 (74) |
| Oat bran (meal)            | Adolescents      | Kwara             | 37.8 (80) |
|                            |                  |                   | 14.8 (74) |
good-quality protein, since plant proteins, with the exception of soya, are lacking one or more essential amino acids(41,47). Plant foods can make a valuable contribution to overall protein intake, with cereals such as rice and wheat providing adequate amounts of all essential amino acids apart from lysine. The addition of small amounts of animal-based proteins such as milk, cheese, eggs and meat to the diet can possibly bridge the lysine gap that legumes (apart from soya beans) and cereals leave behind.

To demonstrate this in the present review we examined an example of a mixture of commonly eaten plant- and animal-based foods: rice, cowpeas and tilapia (Table 11). The combination of rice, beans and fish is frequently eaten in Nigeria. Portion sizes for rice (51·9 g) and beans (cowpeas) (54·9 g) were obtained from a study in southwestern Nigeria(22). A portion size of 50 g was assumed for tilapia. The same true ileal digestibility factors and amino acid contents of the foods as for the individual food calculations (Tables 4, 7 and 8) were used. The first limiting amino acids were tryptophan and valine. However, the tryptophan content of cowpeas was not determined. Therefore, the DIAAS based on the second limiting amino acids (isoleucine, lysine and tryptophan) was also determined. If we exclude tryptophan, the DIAAS for infants, children and others were, respectively, 51, 76 and 84 %. For young children and individuals older than 3 years the protein quality for this mixture was good (> 75 %). Where rice and cowpeas individually had lysine as the first limiting amino acid for individuals older than 3 years, this mixture of foods is of good protein quality in terms of lysine (reference ratio = 0·90) for this age group and tilapia bridged the lysine gap that rice and cowpeas left behind. It should still be examined whether the addition of such foods is feasible in terms of availability, affordability and sustainability.

Importantly, when a similar exercise was performed by Suri et al. in 2014(48), without the addition of an animal protein source, it was shown that both the addition of groundnuts and cowpeas to cereals like maize, millet and sorghum did not yield good protein quality blends (PDCAAS = 42–67 %). The addition of milk (DIAAS > 116) to the diet might be also valuable for increasing linear growth in stunted children(49) and could be easily achieved by adding milk to pap given to young children.

**Strengths**

Nigeria is one of the major countries in the West African region and has a complex and diverse food culture; therefore the results of the present review on Nigeria may be also applicable to other countries in West Africa(11). The methodology of this review can be applied to other low- and middle-income countries since the diets are often, just like the Nigerian diet, mostly plant-based (for example, due to costs) and lack variety, which might influence protein intake adequacy. Diet pattern and protein intake as assessed in the present review reflect recent estimates from the year 2000 and onwards. This review considered both the quantity of protein intake and the protein quality of some major staple foods of the Nigerian diet and a mixture of these foods. Moreover, our review used DIAAS, which is the most recent measure for protein quality and can be considered superior to the old measure (PDCAAS). This was, to our knowledge, the first review that calculated DIAAS of foods such as yam and cassava.
### Table 4. Digestible indispensable amino acid score (DIAAS) of cassava and rice*

| Essential amino acids | Cassava | Rice |
|-----------------------|---------|------|
|                       | AA (mg/g protein) | True ileal digestibility † | Reference ratio infants ‡ | Reference ratio children | Reference ratio other | AA (mg/g protein) | True ileal digestibility † | Reference ratio infants ‡ | Reference ratio children | Reference ratio other |
| Histidine             | 38.5    | 1.58  | 1.66  | 2.07  | 23    | 0.99  | 1.08  | 1.14  | 1.42  |
| Isoleucine            | 93.0    | 0.15  | 0.25  | 0.27  | 35    | 0.75  | 0.48  | 0.82  | 0.88  |
| Leucine               | 12.8    | 0.11  | 0.17  | 0.18  | 77    | 0.81  | 0.65  | 0.95  | 1.02  |
| Lysine                | 17.6    | 0.22  | 0.27  | 0.32  | 36    | 0.92  | 0.48  | 0.58  | 0.89  |
| SAA                   | 25.7    | 0.67  | 0.82  | 0.96  | 53    | 0.92  | 1.47  | 1.80  | 2.11  |
| AAA                   | 19.6    | 0.18  | 0.32  | 0.41  | 91    | 0.83  | 0.80  | 1.44  | 1.83  |
| Threonine             | 15.9    | 0.31  | 0.44  | 0.55  | 34    | 0.82  | 0.63  | 0.90  | 1.12  |
| Tryptophan            | 8       | 0.89  | 0.42  | 0.84  | 57    | 0.88  | 0.91  | 1.17  | 1.25  |
| Crude protein         |         |       |       |       |       | 0.9   |       |       |       |
| Source                | (83)    | (84)  |       |       |       | (71)  | (85)  |       |       |

|                        | (Pig)   | (Human) |
| DIAAS (%) first limiting AA § | 11 | 17 | 18 | 42 | 58 | 69 |
| DIAAS (%) second limiting AA | 15 | 25 | 27 | 48 | 82 | 88 |
| DIAAS (%) third limiting AA | 18 | 27 | 32 | 63 | 84 | 102 |

* Adapted from FAO(19).
† True ileal digestibility = the disappearance of a nutrient between the mouth and the end of the small intestine (terminal ileum)(19).
‡ Reference ratio calculated as (amino acid content × digestibility)/scoring pattern.
§ Limiting AA calculated as the amino acid(s) with the lowest (red) reference ratio score × 100% . Also done for the second (orange) and third (yellow) amino acids.

### Table 5. Digestible indispensable amino acid score (DIAAS) of maize and wheat*

| Essential amino acids | Maize | Wheat |
|-----------------------|-------|-------|
|                       | AA (mg/g protein) | True ileal digestibility † | Reference ratio infants ‡ | Reference ratio children | Reference ratio other | AA (mg/g protein) | True ileal digestibility † | Reference ratio infants ‡ | Reference ratio children | Reference ratio other |
| Histidine             | 30.7   | 0.81  | 1.18  | 1.24  | 1.55  | 22    | 0.88  | 0.92  | 0.97  | 1.21  |
| Isoleucine            | 37.6   | 0.84  | 0.57  | 0.99  | 1.05  | 29    | 0.88  | 0.46  | 0.80  | 0.85  |
| Leucine               | 125.2  | 0.68  | 1.15  | 1.67  | 1.81  | 65    | 0.68  | 0.60  | 0.87  | 0.94  |
| Lysine                | 34.7   | 0.75  | 0.87  | 1.16  | 1.45  | 26    | 0.80  | 1.09  | 1.34  | 1.57  |
| SAA                   | 17.3   | 0.90  | 0.47  | 0.58  | 0.68  | 41    | 0.88  | 1.09  | 1.34  | 1.57  |
| AAA                   | 51.8   | 0.83  | 0.46  | 0.82  | 1.04  | 70    | 0.88  | 0.66  | 1.18  | 1.50  |
| Threonine             | 38.4   | 0.78  | 0.68  | 0.97  | 1.20  | 28    | 0.83  | 0.53  | 0.75  | 0.93  |
| Tryptophan            | 5.9    | 0.80  |       |       |       | 43    | 0.85  | 0.66  | 0.85  | 0.91  |
| Valine                | 50.5   | 0.85  | 0.78  | 1.00  | 1.07  | (80)  |       |       |       |       |
| Crude protein         | (86)   |       |       |       |       | (87)  |       |       |       |       |

|                        | (Pig)   | (Human) |
| DIAAS (%) first limiting AA § | 37 | 45 | 53 | 30 | 36 | 43 |
| DIAAS (%) second limiting AA | 46 | 58 | 68 | 46 | 75 | 85 |
| DIAAS (%) third limiting AA | 47 | 82 | 104 | 53 | 80 | 91 |

* Adapted from FAO(19).
† True ileal digestibility = the disappearance of a nutrient between the mouth and the end of the small intestine (terminal ileum)(19).
‡ Reference ratio calculated as (amino acid content × digestibility)/scoring pattern.
§ Limiting AA calculated as the amino acid(s) with the lowest (red) reference ratio score × 100% . Also done for the second (orange) and third (yellow) amino acids.
Table 6. Digestible indispensable amino acid score (DIAAS) of yam

| Essential amino acids | AA (mg/g protein) | Reference ratio infants‡ | Reference ratio children | Reference ratio other |
|-----------------------|-------------------|--------------------------|-------------------------|----------------------|
|                      | D. rotundata (1)  | 1                        | 2                       | 3                    |
| Histidine             | 23.9              | 0.98                     | 1.06                    | 1.00                 |
| Isoleucine            | 41                | 0.59                     | 0.59                    | 0.49                 |
| Leucine               | 89.6              | 0.80                     | 0.75                    | 0.86                 |
| Lysine                | 46.3              | 0.58                     | 0.59                    | 0.54                 |
| SAA                   | 19.7              | 0.51                     | 0.53                    | 1.10                 |
| AAA                   | 119.1             | 1.09                     | 1.07                    | 0.45                 |
| Threonine             | 51.5              | 1.01                     | 0.92                    | 0.45                 |
| Tryptophan            | 10                | 1.01                     | 0.91                    | 1.17                 |
| Valine                | 48.9              | 0.73                     | 0.65                    | 0.43                 |
| Crude protein Source  | (88)              | Same as cassava used (pig) |

DIAAS (%) first limiting AA§

|                      | 51 (SAA + Tryp) | 46 (Leu) | 36 (SAA) | 63 (SAA) | 53 (Leu) | 74 (SAA) | 57 (Leu) |
|----------------------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|

DIAAS (%) second limiting AA

|                      | 58 (SAA) | 53 (Val) | 43 (SAA) | 70 (SAA) | 56 (Val) | 83 (SAA) | 60 (Val) |

DIAAS (%) third limiting AA

|                      | 64 (Ileu) | 59 (Ileu) | 45 (AAA + Thr) | 94 (Val) | 84 (Val) | 101 (Val) | 90 (Val) |

Table 7. Digestible indispensable amino acid score (DIAAS) of fish (tilapia) and groundnuts

| Essential amino acids | AA (mg/g protein) | True ileal digestibility† | Reference ratio infants‡ | Reference ratio children | Reference ratio other |
|-----------------------|-------------------|---------------------------|--------------------------|-------------------------|----------------------|
|                      | (Chinese fish)    | (Detoxified groundnut meal) (pig) |
| Histidine             | 23                | 0.85                      | 0.93                     | 0.98                    | 1.22                 |
|                      | (human)           |                           |                          |                         |                      |
| Isoleucine            | 37                | 0.93                      | 0.93                     | 1.08                    | 1.15                 |
| Leucine               | 72                | 0.91                      | 0.99                     | 0.99                    | 1.07                 |
| Lysine                | 77                | 0.93                      | 1.04                     | 1.26                    | 1.49                 |
| SAA                   | 40                | 0.91                      | 1.10                     | 1.35                    | 1.58                 |
| AAA                   | 69                | 0.83                      | 0.61                     | 1.10                    | 1.40                 |
| Threonine             | 43                | 0.96                      | 0.93                     | 1.32                    | 1.63                 |
| Tryptophan            | 14                | 0.91                      | 0.75                     | 1.50                    | 1.93                 |
| Valine                | 45                | 0.9                       | 0.74                     | 0.94                    | 1.01                 |
| Crude protein Source  | (71)              | (86)                      |                           |                         |                      |

DIAAS (%) first limiting AA§

|                      | 61 (AAA) | 94 (Val) | 101 (Val) |
|----------------------|----------|----------|-----------|

DIAAS (%) second limiting AA

|                      | 63 (Leu) | 98 (His) | 107 (Leu) |
|----------------------|----------|----------|-----------|

DIAAS (%) third limiting AA

|                      | 68 (Leu) | 99 (Leu) | 115 (lieu) |
|----------------------|----------|----------|------------|

AA, amino acid; SAA, sulfur amino acids (methionine and cysteine); AAA, aromatic amino acids (phenylalanine and tyrosine).

† True ileal digestibility = the disappearance of a nutrient between the mouth and the end of the small intestine (terminal ileum).‡ Reference ratio calculated as (amino acid content × digestibility)/scoring pattern.

§ Limiting amino acid calculated as the amino acid(s) with the lowest (red) reference ratio score × 100 %. Also done for the second (orange) and third (yellow) amino acids.

(19) Essential amino acids: histidine (His), isoleucine (Ileu), leucine (Leu), lysine (Lys), methionine (Met), cysteine (Cys), phenylalanine (Phe), tyrosine (Tyr), threonine (Thr), tryptophan (Tryp) and valine (Val).

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Table 8. Digestible indispensable amino acid score (DIAAS) of cowpeas*

| Essential amino acids | AA (mg/g protein) | True ileal digestibility | Reference ratio infants | Reference ratio children | Reference ratio other |
|-----------------------|-------------------|--------------------------|-------------------------|--------------------------|-----------------------|
|                       | cream coat moderate | (mg/g protein)          |                         |                          |                       |
|                        | cowpea (1)         | while coat small         | 1                       | 2                       | 1                     |
| HiS                   | 20-0               | 20-6                     | 0.81                    | 0.77                     | 0.79                  |
| Ileu                  | 30-8               | 30-2                     | 0.77                    | 0.43                     | 0.42                  |
| Leu                   | 59-3               | 57-2                     | 0.77                    | 0.48                     | 0.46                  |
| Lys                   | 28-0               | 29-1                     | 0.81                    | 0.53                     | 0.51                  |
| SAA                   | 21-1               | 20-6                     | 0.74                    | 0.47                     | 0.46                  |
| AAA                   | 63-3               | 69-0                     | 0.77                    | 0.52                     | 0.57                  |
| Thr                   | 22-9               | 22-9                     | 0.74                    | 0.39                     | 0.39                  |
| Tryp                  | 0.69               | 0.74                     | 0.42                    | 0.42                     | 0.54                  |
| Val                   | 31-2               | 31-2                     | 0.74                    | 0.39                     | 0.55                  |
| Crude protein         | 0.78               |                          |                         |                          |                       |
| Source                | (91)               |                          |                         |                          |                       |

DIAAS (%) first limiting AA§ 33 (Lys) 34 (Lys) 40 (Lys) 41 (Lys) 47 (Lys) 49 (Lys)
DIAAS (%) second limiting AA 39 (Thr) 39 (Thr) 54 (Val) 54 (Val) 58 (Val) 58 (Val)
DIAAS (%) third limiting AA 42 (Val + lleu) 42 (Thr) 55 (Thr) 55 (Thr) 68 (SAA) 66 (SAA)

AA, amino acid; SAA, sulfur amino acids (methionine and cysteine); AAA, aromatic amino acids (phenylalanine and tyrosine).

* Adapted from FAO(18).
† True ileal digestibility = the disappearance of a nutrient between the mouth and the end of the small intestine (terminal ileum)(19).
‡ Reference ratio calculated as (amino acid content × digestibility)/scoring pattern.
§ Limiting amino acid calculated as the amino acid(s) with the lowest (red) reference ratio score × 100 %.
Source (91) (91) (85)

Table 9. Digestible indispensable amino acid score (DIAAS) of sorghum*

| Essential amino acids | AA (mg/g protein) | True ileal digestibility | Reference ratio infants | Reference ratio children | Reference ratio other |
|-----------------------|-------------------|--------------------------|-------------------------|--------------------------|-----------------------|
|                       | (mg/g protein)    | (mg/g protein)           | 1                       | 2                       | 1                     |
| HiS                   | 17                | 0.81                     | 0.66                    | 0.69                     | 0.86                  |
| Ileu                  | 34                | 0.87                     | 0.54                    | 0.92                     | 0.99                  |
| Leu                   | 124               | 0.88                     | 1.14                    | 1.65                     | 1.79                  |
| Lys                   | 16                | 0.79                     | 0.18                    | 0.22                     | 0.26                  |
| SAA                   | 15                | 0.83                     | 0.28                    | 0.46                     | 0.64                  |
| AAA                   | 80                | 0.87                     | 0.74                    | 1.34                     | 1.70                  |
| Thr                   | 31                | 0.84                     | 0.59                    | 0.84                     | 1.04                  |
| Tryp                  | 8                 | 0.87                     | 0.41                    | 0.82                     | 1.05                  |
| Val                   | 43                | 0.86                     | 0.67                    | 0.86                     | 0.92                  |
| Crude protein         | 0.83              |                          |                         |                          |                       |
| Source                | (92)              |                          |                         |                          |                       |

DIAAS (%) first limiting AA§ 18 (Lys) 22 (Lys) 26 (Lys)
DIAAS (%) second limiting AA 38 (SAA) 46 (SAA) 54 (SAA)
DIAAS (%) third limiting AA 41 (Tryp) 69 (His) 86 (His)

AA, amino acid; SAA, sulfur amino acids (methionine and cysteine); AAA, aromatic amino acids (phenylalanine and tyrosine).

* Adapted from FAO(18).
† True ileal digestibility = the disappearance of a nutrient between the mouth and the end of the small intestine (terminal ileum)(19).
‡ Reference ratio calculated as (amino acid content × digestibility)/scoring pattern.
§ Limiting amino acid calculated as the amino acid(s) with the lowest (red) reference ratio score × 100 %. Also done for the second (orange) and third (yellow) amino acids.

Source (92)

Table 10. Digestible indispensable amino acid score (DIAAS) of high-quality protein foods (adapted from Ertl et al.(41))

| Food          | DIAAS (limiting amino acid)* |
|---------------|------------------------------|
| Beef          | 112                          |
| Milk          | 116                          |
| Chicken       | 108                          |
| Eggs          | 116                          |
| Soya beans    | 100                          |
| Beef          | 112                          |
| Milk          | 116                          |
| Chicken       | 108                          |
| Eggs          | 116                          |
| Soya beans    | 100                          |

AA, amino acid; SAA, sulfur amino acids (methionine and cysteine).

* Based on the scoring pattern of 6 months–3 years using pig true ileal digestibility factors.
† Adapted from Rutherfurd et al.(42) based on the scoring pattern of 6 months–3 years using rat true ileal digestibility factors.
‡ Adapted from Mathai et al.(43) based on the scoring pattern of >3 years of age using pig true ileal digestibility factors.
§ Adapted from Mathai et al.(44) based on a scoring pattern of >3 years of age using pig true ileal digestibility factors.

**Limitations**

The lack of information in the literature on amino acid contents of foods and on true ileal digestibility factors for calculating DIAAS was a major limitation for the present review. Many true ileal digestibility factors are determined in animals, such as pigs, and it is still unsure if these results and methods are also applicable to humans(21). Many studies did not measure the tryptophan content of foods and we could therefore not calculate a score for this essential amino acid. Given the above, DIAAS was calculated only for nine Nigerian foods, which does not
### Table 11. Digestible indispensable amino acid score (DIAAS) of a mixture of rice, cowpeas and tilapia (mixed meal) using the method of the FAO\(^{(19)}\)

| Amino acids       | Rice     | Cowpeas  | Tilapia | Total     | True ileal digestive AA content (%) | Mixture mg of each AA in a total protein | Reference ratio (Isoleucine) | Reference ratio (Tryptophan) | Reference ratio (Valine) |
|-------------------|----------|----------|---------|-----------|-------------------------------------|------------------------------------------|-------------------------------|-----------------------------|---------------------------|
| Histidine         | 18.7     | 17.0     | 17.1    | 17.1      | 0.80                                | 0.80                                      | 0.80                          | 0.80                        | 0.80                      |
| Isoleucine        | 27.9     | 27.9     | 28.1    | 27.9      | 0.51                                | 0.51                                      | 0.51                          | 0.51                        | 0.51                      |
| Leucine           | 54.9     | 57.0     | 58.0    | 57.0      | 0.57                                | 0.57                                      | 0.57                          | 0.57                        | 0.57                      |
| Lysine            | 43.2     | 43.2     | 43.0    | 43.1      | 0.63                                | 0.63                                      | 0.63                          | 0.63                        | 0.63                      |
| SAA               | 28.1     | 28.0     | 28.1    | 28.1      | 0.85                                | 0.85                                      | 0.85                          | 0.85                        | 0.85                      |
| AAA               | 57.9     | 62.5     | 61.6    | 59.9      | 0.62                                | 0.62                                      | 0.62                          | 0.62                        | 0.62                      |
| Threonine         | 27.6     | 27.8     | 27.6    | 27.6      | 0.63                                | 0.63                                      | 0.63                          | 0.63                        | 0.63                      |
| Tryptophan        | 5.9      | 5.9      | 5.9     | 5.9       | 0.89                                | 0.89                                      | 0.89                          | 0.89                        | 0.89                      |
| Valine            | 33.6     | 33.8     | 33.6    | 33.6      | 0.78                                | 0.78                                      | 0.78                          | 0.78                        | 0.78                      |

| DIAAS for the mixture (%) | (Tryptophan) | (Tryptophan) | (Valine) |
|---------------------------|--------------|--------------|----------|
| First limiting amino acid  | 51           | 76           | 89       |
| Second limiting amino acid| 51           | 76           | 89       |

AA, amino acid; SAA, sulfur amino acids (methionine and cysteine); AAA, aromatic amino acids (phenylalanine and tyrosine); n.d., not determined.

* Portion sizes (single serving) for rice and cowpeas were adapted from Sanusi & Olurin\(^{(22)}\) and the portion size of tilapia was set at 50 g.
† Protein content of raw foods adapted from Stadlmayr\(^{(49)}\).
‡ Calculated as portion (g) × protein (g/100 g)/100.
§ Calculated as (amino acid content of foods (mg/g protein) × true ileal digestibility factors of amino acids in the same food) × (protein content in portion per food). The amino acid contents of rice and fish were adapted from Shaheen\(^{(67)}\) and for cowpeas from Oluleke et al\(^{(69)}\). The true ileal digestibility factors were adapted from Gilani et al\(^{(68)}\).
¶ Calculated as the sum of each amino acid content per food/total protein content in the mixture (24.7 g).
‖ Calculated as total in mixture mg of each amino acid in total protein/scoring patterns. Scoring patterns for infants (birth–6 months), children aged 6 months to 3 years and other individuals older than 3 years were adapted from FAO\(^{(19)}\).
** Digestible indispensable amino acid score (DIAAS) determined by multiplying the reference ratio of the first (marked red) and second (marked yellow) limiting amino acid by 100%.

Reflect the total diet. The measure for protein quality, DIAAS, does not take quantity into account since it calculates protein quality based on the amounts of amino acid (mg) per 1 g of food protein\(^{(19)}\). Furthermore, our review did not take anti-nutritional factors, such as trypsin inhibitors (legumes), tannins (legumes and cereals) and phytates (cereals), both present naturally in the food or formed during processing, into account that may possibly interfere with the absorption of nutrients from the diet. The FAO\(^{(19)}\) reported that the methods for determining true ileal digestibility factors might not always fully account for anti-nutritional factors.

**Recommendations and future research**

We calculated protein quality for a mixture of foods, but information on protein quality of more foods should be determined to calculate DIAAS for complete meals (for example, soups, stews with vegetables, etc.), which play an important role in the Nigerian diet. Also, it is advised to determine the protein quality for more mixtures of foods to examine the role of animal-source proteins in bridging the essential amino acid gaps that plant-based foods leave. To do this, more research should be conducted on amino acid contents of such foods and true ileal digestibility factors to broaden the DIAAS calculations. Also, research should examine whether animal-source proteins can increase the dietary diversity score of Nigerian individuals. Related to this, future research should aim at studying the effects of dietary diversity on protein and amino acid adequacy. The distinction between protein quality (v. quantity) should be made clearer. This might help in determining portion sizes of (mixtures) of foods for meeting the essential amino acid requirements.

Another attention point for future research might be the development of specific products that address the protein and amino acid needs for those individuals that currently do not consume enough protein. For example, for adolescent girls, it may be beneficial to enrich often consumed snacks with good-quality proteins from, for example, soybean flour\(^{(50)}\) or dairy products. Also, possibilities of enriching complementary foods for children, like pap, with good-quality proteins such as soya beans, fish or milk could be explored further\(^{(51,52)}\). Providing children with a good-quality protein-rich lunch that will account for about one-third of the protein recommendations in the context of a school feeding programme, for example, might help in eradicating PEM\(^{(53,54)}\).

Previous Nigerian studies have suggested affordable and available protein-rich foods such as rabbit meat\(^{(55)}\), insects\(^{(56)}\), wild plant species\(^{(57)}\), indigenous leafy vegetables\(^{(12)}\) and goat milk\(^{(58)}\). Some studies have already been conducted on determinants (for example, socio-economic factors, education, infections) of protein intake and PEM, and it is advised to extend

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**Note:**
- Portion sizes (single serving) for rice and cowpeas were adapted from Sanusi & Olurin\(^{(22)}\) and the portion size of tilapia was set at 50 g.
- Protein content of raw foods adapted from Stadlmayr\(^{(49)}\).
- Calculated as portion (g) × protein (g/100 g)/100.
- Calculated as (amino acid content of foods (mg/g protein) × true ileal digestibility factors of amino acids in the same food) × (protein content in portion per food).
- The amino acid contents of rice and fish were adapted from Shaheen\(^{(67)}\) and for cowpeas from Oluleke et al\(^{(69)}\). The true ileal digestibility factors were adapted from Gilani et al\(^{(68)}\).
- Calculated as the sum of each amino acid content per food/total protein content in the mixture (24.7 g).
- Calculated as total in mixture mg of each amino acid in total protein/scoring patterns. Scoring patterns for infants (birth–6 months), children aged 6 months to 3 years and other individuals older than 3 years were adapted from FAO\(^{(19)}\).
- Digestible indispensable amino acid score (DIAAS) determined by multiplying the reference ratio of the first (marked red) and second (marked yellow) limiting amino acid by 100%.
this knowledge to better understand the context of protein malnutrition. Also, we believe further research into the effects of maternal diets deficient in essential amino acids on the breast milk amino acid composition is warranted. Finally, we suggest applying the methodology of this review to other developing countries to examine if there is a trend in protein intake adequacy across these countries.

Conclusions

Overall, it was shown that Nigerian population groups had adequate protein intake. The troubling exceptions are adolescent girls and pregnant and lactating women. Furthermore, the Nigerian diet consists mainly of cereals and other plant-based foods, with animal-source foods being consumed to a lesser extent. These results might also be expected in other developing countries since animal-source foods are often more expensive. The protein quality of all plant-based foods as assessed in the present review was shown to be poor when looking at the first limiting amino acids. Rice and wheat were shown to be good sources of protein when looking at the second limiting amino acids. The most limiting amino acids were lysine, leucine, valine, SAA and isoleucine. Tilapia was shown to be an excellent source of protein for individuals above 3 years of age. A mixture of foods from different food groups (rice, cowpeas and tilapia) was shown to be of good protein quality (DIAAS > 75). The addition of animal-source foods bridged the protein quality gap that was created by a predominance of plant-based foods in the Nigerian diet. For example, milk, with its excellent protein quality, could be a valuable addition to the Nigerian diet, especially for malnourished children. Future steps include determination of protein quality of more foods and mixtures and developing and promoting good-quality protein-rich products or meals, which are cost-effective.

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