Of Things to Come: DIAAS and how the world will measure protein quality

2014 Protein Trends & Technologies Seminar
Arlington Heights, Illinois, USA

9th April, 2014
Why is Protein Quality Assessment Important?

- Adequacy of global food supplies (i.e., amount and quality of protein)
- Informed decision-making (i.e., food and nutrition policy)
- Guidance for labelling, regulation and trade (e.g., CODEX)
- Health/clinical implications

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Overview

- PDCAAS summary
  - 1991 FAO/WHO Report

- Recommended modifications
  - WHO/FAO/UNU 2007 Report

- Issues and concerns
  - Leading into 2011 FAO Expert Consultation

- DIAAS – Overview, applications and implications
  - 2013 FAO Report

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### Examples of Protein Quality Assessment Methods

<table>
<thead>
<tr>
<th>METHOD</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen Balance</td>
<td>Measure of daily N intake minus N excreted</td>
</tr>
<tr>
<td>Protein Efficiency Ratio</td>
<td>Gain in weight of rat per g of protein eaten</td>
</tr>
<tr>
<td>Net Protein Utilisation</td>
<td>Proportion of ingested protein retained</td>
</tr>
<tr>
<td>True Biological Value</td>
<td>Proportion of the absorbed N retained taking into consideration the metabolic N loss</td>
</tr>
</tbody>
</table>

In 1989 the Joint FAO/WHO Expert Consultation on Protein Quality Evaluation recommends use of PDCAAS
Protein Digestibility Corrected Amino Acid Score (PDCAAS)

• To calculate the PDCAAS, the limiting amino acid score* is multiplied by protein digestibility.

(limiting amino acid score* - ratio of first limiting amino acid in a gram of target food to that in a reference protein or requirement)

PDCAAS = f (amino acid score, digestibility)

AAS = \[ \frac{\text{mg of IAA in 1g protein}}{\text{mg of same IAA in 1g of reference pattern}} \]

(Lowest IAA ratio is the amino acid score)

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IAA: Indispensable Amino Acid
Amino Acids

“Indispensable” or “Essential”

• His
• Ile
• Leu
• Lys
• Met
• Phe
• Thr
• Trp
• Val

“Dispensable” or “Nonessential”

• Asp
• Asn
• Glu
• Ala
• Ser
• Cys
• Tyr
• Gly
• Arg
• Gln
• Pro

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Example of reference AA scoring patterns

**Recommended amino acid scoring patterns for infants, children and older children, adolescents and adults**

<table>
<thead>
<tr>
<th>Age Group</th>
<th>His</th>
<th>Ile</th>
<th>Leu</th>
<th>Lys</th>
<th>SAA</th>
<th>AAA</th>
<th>Thr</th>
<th>Trp</th>
<th>Val</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant (birth to 6 months)¹</td>
<td>21</td>
<td>55</td>
<td>96</td>
<td>69</td>
<td>33</td>
<td>94</td>
<td>44</td>
<td>17</td>
<td>55</td>
</tr>
<tr>
<td>Child (6 months to 3 year)²</td>
<td>20</td>
<td>32</td>
<td>66</td>
<td>57</td>
<td>27</td>
<td>52</td>
<td>31</td>
<td>18.5</td>
<td>43</td>
</tr>
<tr>
<td>Older child, adolescent, adult³</td>
<td>16</td>
<td>30</td>
<td>61</td>
<td>48</td>
<td>23</td>
<td>41</td>
<td>25</td>
<td>6.6</td>
<td>40</td>
</tr>
</tbody>
</table>

¹ Infant is based on the gross amino acid content of human milk
² Child group is from the 6 month (0.5 y) values
³ Older child, adolescent, adult group is from the 3-10 y values

Source: FAO Report, 2013
PDCAAS = \( f \) (amino acid score, digestibility)

Digestibility => True protein digestibility (TPD)

(rat balance method)

**TPD** = 100 \times \frac{\text{Protein intake} - (\text{Faecal protein} - \text{metabolic faecal protein})}{\text{Protein intake}}

PDCAAS = f (amino acid score, digestibility)

= mg of *limiting IAA* in 1g protein  x  Digestibility

\[
\frac{\text{mg of same IAA in 1g of reference pattern}}{\text{mg of same IAA in 1g of reference pattern}}
\]

(Units can be expressed as a *decimal* or *percentage*)

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PDCAAS

Scores above 1.00 would be considered as 1.00 or 100%

(i.e., PDCAAS not AAS)

PDCAAS = AAS x TPD

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Other recommendations

a) High moisture foods should be **dried**
(Effect of drying technique on AA?)

b) High fat foods may require **lipid extraction**
prior to analysis
(Effect of technique used on AA?)

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Recommended:

a) **Same protocol** for calculation for **individual protein sources** can be applied to mixture

b) **Weighted average** procedure can be used when data on AAS and TPD is available
### Analytical Data

<table>
<thead>
<tr>
<th></th>
<th>Weight (g)</th>
<th>Protein (g/100g)</th>
<th>Lys</th>
<th>TSAA (mg/g)</th>
<th>Thr</th>
<th>Trp</th>
<th>TPD</th>
<th>Protein (g)</th>
<th>Lys</th>
<th>TSAA</th>
<th>Thr</th>
<th>Trp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>350</td>
<td>13</td>
<td>25</td>
<td>35</td>
<td>30</td>
<td>11</td>
<td>0.85</td>
<td>45.5</td>
<td>1138</td>
<td>1593</td>
<td>1365</td>
<td>501</td>
</tr>
<tr>
<td>Chickpea</td>
<td>150</td>
<td>22</td>
<td>70</td>
<td>25</td>
<td>42</td>
<td>13</td>
<td>0.80</td>
<td>33.0</td>
<td>2310</td>
<td>825</td>
<td>1386</td>
<td>429</td>
</tr>
<tr>
<td>Milk Powder</td>
<td>50</td>
<td>34</td>
<td>80</td>
<td>30</td>
<td>37</td>
<td>12</td>
<td>0.95</td>
<td>17.0</td>
<td>1360</td>
<td>510</td>
<td>629</td>
<td>204</td>
</tr>
</tbody>
</table>

### Quantities in Mixture

\[
\begin{align*}
A \times B &= P \\
\frac{A \times B}{100} &= \frac{P}{100}
\end{align*}
\]

<table>
<thead>
<tr>
<th></th>
<th>A x B</th>
<th>C x D x E x F x G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>95.5</td>
<td>4808 2928 3380 1134</td>
</tr>
<tr>
<td>Chickpea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk Powder</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AA mg/g protein

|          | 50 | 31 | 35 | 12 |

Reference scoring pattern

|          | 58 | 25 | 34 | 11 |

AAS for mixture

|          | 0.86 | 1.24 | 1.03 | 1.09 |

Weighted Average Protein Digestibility

|          | 0.85 |

Score adjusted for digestibility (0.85x0.86)

|          | 0.73 (or 73%) |
Issue: Truncation (1991 Report)

Scores above 1.00 would be considered as 1.00 or 100% (i.e., PDCAAS not AAS)

PDCAAS = AAS x TPD

2007 Report

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Example

Soy protein concentrate

\[
AAS = 1.04
\]

\[
TPD = 95\%
\]

\[
PDCAAS \ (1991 \ report) = 1.04 \times 0.95 = 0.99
\]

\[
PDCAAS \ (2007 \ report) = 1 \times 0.95 = 0.95
\]

**NB:** If AAS is truncated, then the additional benefit of the excess limiting IAA in compensating for any decrease in digestibility is lost.

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PDCAAS \[= f(AAS, \text{digestibility})\]

- To truncate or not to truncate
  (i.e., Value of excess IAA in mixed diets)

- And if yes, which? (PDCAAS or AAS?)

Issue: Amino Acid Score (AAS) (1991 Report)

PDCAAS = f (AAS, digestibility)

- Reference requirement/pattern?
- Analytical method?
- Effect of processing?

Issue: Digestibility (1991 Report)

PDCAAS = \textbf{f} (AAS, digestibility)

- True vs standardised vs apparent vs real?
- Ileal vs feecal?
- \textit{In vivo} vs \textit{in vitro}?
- Protein vs AA digestibility?
- Digestibility vs bioavailability?
- Age and species of animals?
- Food quantity?
- Effect of processing, matrix, ANFs?
Amino Acid Bioavailability

The **bioavailability** of an amino acid is the proportion of ingested dietary AA that is absorbed in a chemical form suitable for it to be utilized for protein synthesis or metabolism.


- Digestibility
- Chemical integrity
- Matrix effects

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Dietary protein quality evaluation in human nutrition

Report of an FAO Expert Consultation
Amino Acids

• Dietary amino acids should be treated as individual nutrients

• Use digestible **amino acids** as opposed to digestible **protein** in calculating protein quality

• For lysine in processed foods, use **available** or **reactive** lysine
2013 FAO Report – Key Recommendations

**Digestibility**

- Use **true ileal** amino acid digestibility (i.e., at terminal ileum at the end of the small intestine as fecal digestibility data is confounded by microflora activity in lower GI tract)
- Preferably determined for each indispensable amino acid, using humans, if not then pigs or rats

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AA reference scoring patterns

- Infants (birth to 6 months), pattern of human milk
- Young children (6 months to 3 y), pattern for the 0.5 y old infant
- Older children, adolescents and adults, pattern for the 3 to 10 y old child

For regulatory purposes two scoring patterns recommended:

- For infant formulas - amino acid composition of human milk
- For all other foods and population groups - pattern for young children (6 months to 3 y)
# AA Reference Scoring Patterns

Recommended amino acid scoring patterns for infants, children and older children, adolescents and adults.

<table>
<thead>
<tr>
<th>Age Group</th>
<th>His</th>
<th>Ile</th>
<th>Leu</th>
<th>Lys</th>
<th>SAA</th>
<th>AAA</th>
<th>Thr</th>
<th>Trp</th>
<th>Val</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant (birth to 6 months)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>21</td>
<td>55</td>
<td>96</td>
<td>69</td>
<td>33</td>
<td>94</td>
<td>44</td>
<td>17</td>
<td>55</td>
</tr>
<tr>
<td>Child (6 months to 3 year)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>20</td>
<td>32</td>
<td>66</td>
<td>57</td>
<td>27</td>
<td>52</td>
<td>31</td>
<td>8.5</td>
<td>43</td>
</tr>
<tr>
<td>Older child, adolescent, adult&lt;sup&gt;3&lt;/sup&gt;</td>
<td>16</td>
<td>30</td>
<td>61</td>
<td>48</td>
<td>23</td>
<td>41</td>
<td>25</td>
<td>6.6</td>
<td>40</td>
</tr>
</tbody>
</table>

<sup>1</sup> Infant is based on the gross amino acid content of human milk.

<sup>2</sup> Child group is from the 6 month (0.5 y) values.

<sup>3</sup> Older child, adolescent, adult group is from the 3-10 y values.
DIAAS - Truncation

- Values above 100% should not be truncated for ingredients
- Values above 100% can be truncated when calculating protein quality for mixed diets and sole source foods
A new method recommended to replace PDCAAS:
Digestible Indispensable Amino Acid Score (DIAAS)

\[
\text{DIAAS} \% = 100 \times \left[ \frac{\text{mg of digestible dietary IAA in 1 g of the dietary protein}}{\text{mg of the same dietary IAA in 1g of the reference protein}} \right]
\]

(Note: value is calculated for each dietary IAA and lowest value is designated as the DIAAS)
Calculation of DIAAS value for whole milk powder (WMP)

<table>
<thead>
<tr>
<th>Weight (g)</th>
<th>Protein (g/100g)</th>
<th>Lys</th>
<th>SAA</th>
<th>Thr</th>
<th>Trp</th>
<th>Lys</th>
<th>SAA</th>
<th>Thr</th>
<th>Trp</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
<td>G</td>
<td>H</td>
<td>I</td>
<td>J</td>
</tr>
<tr>
<td>Milk Powder</td>
<td>100</td>
<td>28</td>
<td>78</td>
<td>35</td>
<td>44</td>
<td>13</td>
<td>0.95</td>
<td>0.94</td>
<td>0.90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age group (y)</th>
<th>IAA Reference pattern: mg/g protein (refer to Table 5 in this report)</th>
<th>Digestible IAA reference ratio</th>
<th>DIAAS for WMP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td>Lys 69  SAA 33  Thr 44  Trp 17</td>
<td>Lys 1.07  SAA 1.00  Thr 0.91  Trp 0.69</td>
<td>69 (Trp)</td>
</tr>
<tr>
<td>Child</td>
<td>Lys 57  SAA 27  Thr 31  Trp 8.5</td>
<td>Lys 1.30  SAA 1.22  Thr 1.29  Trp 1.41</td>
<td>122 (SAA)</td>
</tr>
<tr>
<td>Older child</td>
<td>Lys 48  SAA 23  Thr 25  Trp 6.6</td>
<td>Lys 1.54  SAA 1.43  Thr 1.60  Trp 1.82</td>
<td>143 (SAA)</td>
</tr>
</tbody>
</table>


2 For the sake of example, calculation is shown for four amino acids, where possible all IAA should be included in the calculation.

3 Digestible IAA reference ratio (Digestive IAA in 1 g protein of whole milk powder /mg of the same dietary indispensable amino acid in 1g of the reference protein)

4 DIAAS for whole milk powder (Lowest value of the “digestible IAA reference ratio” expressed as % for each reference pattern; for infants WMP has a calculated DIAAS of 69; for children 122 and for older children, adolescents and adults 143).

5 This is the weighted average of the digestibility coefficients for methionine and cysteine. Lys=lysine, SAA=sulphur amino acids (methionine + cysteine), Thr = threonine, Trp = tryptophan.

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Source: FAO Report, 2013
### DIAAS Calculation – Mixed Diet

#### Calculation of DIAAS value for a mixture of wheat, peas and whole milk powder

<table>
<thead>
<tr>
<th>Composition¹</th>
<th>True ileal IAA Digestibility¹</th>
<th>True ileal digestible IAA content in mixture²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (g)</td>
<td>Protein (g/100g)</td>
<td>Lys (mg/g protein)</td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Wheat</td>
<td>400</td>
<td>11</td>
</tr>
<tr>
<td>Pea</td>
<td>100</td>
<td>21</td>
</tr>
<tr>
<td>Milk powder</td>
<td>35</td>
<td>28</td>
</tr>
<tr>
<td>Totals</td>
<td>535</td>
<td></td>
</tr>
</tbody>
</table>

**Amino acids: mg/g protein (total for each amino acid/total protein)**

<table>
<thead>
<tr>
<th>Age group</th>
<th>Reference pattern: mg/g protein (Refer to Table 5 in this report)</th>
<th>Digestible IAA reference ratio</th>
<th>DIAAS for mixture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant (birth to 6 moths)</td>
<td>Lys 69, SAA 33, Thr 44, Trp 17</td>
<td>Lys 0.56, SAA 0.88, Thr 0.62, Trp 0.56</td>
<td>56 (Lys)</td>
</tr>
<tr>
<td>Child (6 months to 3 yrs)</td>
<td>Lys 57, SAA 27, Thr 31, Trp 8.5</td>
<td>Lys 0.68, SAA 1.08, Thr 0.88, Trp 1.13</td>
<td>68 (Lys)</td>
</tr>
<tr>
<td>Older child, adolescent, adult</td>
<td>Lys 48, SAA 23, Thr 25, Trp 6.6</td>
<td>Lys 0.82, SAA 1.26, Thr 1.10, Trp 1.45</td>
<td>82 (Lys)</td>
</tr>
</tbody>
</table>


² For the sake of example, calculation is shown for four amino acids; where possible all IAA should be included in the calculation.

³ Digestible IAA reference ratio (Digestible IAA in 1 g protein of mixed diet 1 mg of the same dietary indispensable amino acid in 1 g of the reference protein)

⁴ DIAAS for mixed diet (Lowest value of the “digestible IAA reference ratio” expressed as % for each reference pattern; for infants the mixed food has a calculated DIAAS of 56; for children 68 and for older children, adolescents and adults 82; NB: In this case as this is a mixed diet if the calculated DIAAS exceeded 100%, it would be truncated to 100%).

⁵ These are the weighted average of the digestibility coefficients for methionine and cysteine. Lys = lysine, SAA = sulphur amino acids (methionine + cysteine), Thr = threonine, Trp = tryptophan.

Source: FAO Report, 2013
Example of potential application

For CODEX, to qualify for the nutrition claim: “source” for protein, a food must meet the following criteria:

- 10% of NRV* per 100 g (solids)
- 5% of NRV per 100 ml (liquids)
- or 5% of NRV per 100 kcal (12% of NRV per 1 MJ*);
- or 10% of NRV per serving.

To qualify for: “High” for protein, the food must contain two times the values for “source”.

* Nutrient Reference Value (NRV); megajoule (MJ)
When a food meets the criteria for protein quantity, then a quality measure should be applied.

DIAAS cut-off values will be needed to distinguish between excellent/high (e.g. 100 or more), good/source (e.g. 75-99), and no claim.

It is recommended that no nutrition claim be allowed for source or high protein for proteins with DIAAS less than a certain cut-off (e.g. 75).

**NB:** quality cannot be substituted for quantity
Example of potential application contd.

Example of the use of DIAAS for protein quality assessment in the context of making claims.

<table>
<thead>
<tr>
<th>Food</th>
<th>Amount</th>
<th>Protein content (g/100g)</th>
<th>DIAAS&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Judged quality</th>
<th>Eligible for claim based on quantity</th>
<th>Eligible for claim based on quantity and quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>100 g</td>
<td>11</td>
<td>40</td>
<td>Low</td>
<td>Yes, high</td>
<td>No, none</td>
</tr>
<tr>
<td>Peas</td>
<td>100 g</td>
<td>21</td>
<td>64</td>
<td>Low</td>
<td>Yes, high</td>
<td>No, none</td>
</tr>
<tr>
<td>Whole milk powder</td>
<td>100 g</td>
<td>28</td>
<td>122</td>
<td>High</td>
<td>Yes, high</td>
<td>Yes, High</td>
</tr>
</tbody>
</table>

<sup>1</sup> DIAAS calculated using true ileal indispensable amino acid digestibility values and reference amino acid pattern for child (6 months to 3 years).

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Source: FAO Report, 2013
Challenges

• Lack of data on true ileal AA digestibility

• RECOMMENDATION - Until more data becomes available
  – AA digestibility could be considered equivalent to crude protein digestibility
  – DIAAS should be calculated based on true ileal protein digestibility and when not available true faecal crude protein digestibility
  – Use protein digestibility to calculate digestible individual dietary amino acid values

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Approaches to increase PDCAAS and DIAAS

- Develop formulations with ingredients containing complementary IAAs (e.g., legumes and cereals, or protein sources with balanced AA profiles)
- Consider the effect of processing, storage and storage temperature on digestibility and bioavailability of AA
- If possible exploit the use of exogenous proteases in processing
- Consider the use of fermentation, germination, probiotics, etc
- Remove or reduce antinutritional components
- Consider matrix effects on protein digestibility and bioavailability

NOTE: DIAAS more useful when measured on « food » not on grain (e.g., cooked chickpea not raw chickpea)
## Examples of PDCAAS of some plant sources of protein

<table>
<thead>
<tr>
<th>FOOD</th>
<th>PDCAAS* and LAA</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buckwheat</td>
<td>80, Leu</td>
<td>Eggum et al., 1999</td>
</tr>
<tr>
<td>Quinoa (dried, milled)</td>
<td>109, Lys</td>
<td>FAO/WHO/UNU 1985*</td>
</tr>
<tr>
<td>Potato</td>
<td>88, Leu</td>
<td>Jørgensen et al., 2008*</td>
</tr>
<tr>
<td>Pea (soaked, dried)</td>
<td>48, Met + Cys</td>
<td>FAO/WHO 1973*</td>
</tr>
<tr>
<td>Pea (cooked)</td>
<td>91, Met + Cys</td>
<td>FAO/WHO 1973*</td>
</tr>
<tr>
<td>Pea protein (Nutralys®)</td>
<td>82, Met + Cys</td>
<td>Roquette, 2008</td>
</tr>
<tr>
<td>Canola protein (napin-r)</td>
<td>92, Phe + Tyr</td>
<td>FDA GRAS Notice 327*</td>
</tr>
<tr>
<td>Canola protein (cruciferin-r)</td>
<td>77, Phe + Tyr</td>
<td>FDA GRAS Notice 327*</td>
</tr>
<tr>
<td>Whole hempseed</td>
<td>49-53, Lys</td>
<td>House et al., 2010</td>
</tr>
<tr>
<td>Hempseed meal</td>
<td>46-51, Lys</td>
<td>House et al., 2010</td>
</tr>
<tr>
<td>Hempseed (dehulled)</td>
<td>63-66, Lys</td>
<td>House et al., 2010</td>
</tr>
</tbody>
</table>

**Others:** Almond - ~23 – 73%; Peanut - ~ 34-70%

*Calculated using reference pattern for 3-10 yr child; LAA – Limiting amino acid

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## Impact of processing on PDCAAS

<table>
<thead>
<tr>
<th>Product</th>
<th>PDCAAS (rat)</th>
<th>PDCAAS (human)</th>
<th>RPER</th>
<th>RNPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casein + Met</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Casein</td>
<td>85</td>
<td>100</td>
<td>80</td>
<td>84</td>
</tr>
<tr>
<td>Lactalbumin</td>
<td>100</td>
<td>100</td>
<td>89</td>
<td>91</td>
</tr>
<tr>
<td>Lactalbumin, treated</td>
<td>55</td>
<td>67</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Skim milk</td>
<td>74</td>
<td>100</td>
<td>77</td>
<td>82</td>
</tr>
<tr>
<td>Skim milk, heated</td>
<td>29</td>
<td>31</td>
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<tr>
<td>SPI¹</td>
<td>62</td>
<td>100</td>
<td>56</td>
<td>64</td>
</tr>
<tr>
<td>SPI, treated</td>
<td>44</td>
<td>49</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SBM,² raw</td>
<td>58</td>
<td>80</td>
<td>27</td>
<td>44</td>
</tr>
<tr>
<td>SBM, heated</td>
<td>58</td>
<td>83</td>
<td>63</td>
<td>70</td>
</tr>
<tr>
<td>Black beans, raw</td>
<td>45</td>
<td>72</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Black beans, heated</td>
<td>51</td>
<td>84</td>
<td>63</td>
<td>70</td>
</tr>
<tr>
<td>Mustard flour</td>
<td>84</td>
<td>92</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Zein</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Zein + AA³</td>
<td>63</td>
<td>71</td>
<td>3</td>
<td>44</td>
</tr>
</tbody>
</table>

1 Soybean protein isolate.
2 Soybean meal.
3 Lysine + methionine + threonine + tryptophan.
Complementation to improve protein quality

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Amino Acid Score¹</th>
<th>True Protein Digestibility² (%)</th>
<th>PDCAAS³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pea (yellow, split)</td>
<td>0.73</td>
<td>87.9</td>
<td>0.64</td>
</tr>
<tr>
<td>Pea (green, split)</td>
<td>0.59</td>
<td>85.2</td>
<td>0.50</td>
</tr>
<tr>
<td>Lentil (green, whole)</td>
<td>0.71</td>
<td>87.9</td>
<td>0.63</td>
</tr>
<tr>
<td>Lentil (red, split)</td>
<td>0.59</td>
<td>90.6</td>
<td>0.54</td>
</tr>
<tr>
<td>Chickpeas</td>
<td>0.61</td>
<td>85.0</td>
<td>0.52</td>
</tr>
<tr>
<td>Pinto Beans</td>
<td>0.77</td>
<td>76.2</td>
<td>0.59</td>
</tr>
<tr>
<td>Kidney Beans</td>
<td>0.70</td>
<td>78.6</td>
<td>0.55</td>
</tr>
<tr>
<td>Black Beans</td>
<td>0.76</td>
<td>70.0</td>
<td>0.53</td>
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<tr>
<td>Navy Beans</td>
<td>0.83</td>
<td>80.0</td>
<td>0.67</td>
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<tr>
<td>Soy Flour</td>
<td>0.92</td>
<td>83.5</td>
<td>0.77</td>
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<tr>
<td>Wheat Flour</td>
<td>0.47</td>
<td>92.3</td>
<td>0.43</td>
</tr>
<tr>
<td>Rice Flour</td>
<td>0.54</td>
<td>92.0</td>
<td>0.50</td>
</tr>
<tr>
<td>Lentil-Wheat (25:75)</td>
<td>0.78</td>
<td>91.0</td>
<td>0.71</td>
</tr>
<tr>
<td>Lentil-Rice (20:80)</td>
<td>0.82</td>
<td>90.0</td>
<td>0.74</td>
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<tr>
<td>Black Bean-Rice (25:75)</td>
<td>0.81</td>
<td>93.0</td>
<td>0.75</td>
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<tr>
<td>Pea-Wheat (30:70)</td>
<td>0.83</td>
<td>90.0</td>
<td>0.75</td>
</tr>
<tr>
<td>Casein</td>
<td>1.04</td>
<td>96.6</td>
<td>1.00</td>
</tr>
</tbody>
</table>

¹ Amino acid score is limiting the amino acid with the lowest ratio relative to the established amino acid requirement values for humans, aged 2 to 5 years old.

² AOAC Method 991.29 (n=10).

³ PDCAAS = Amino Acid Score x % True Protein Digestibility.

* Calculated data obtained from the 1989 WHO/FAO Report on Protein Quality.
Conclusion: Path Forward

- More data needed on true ileal amino acid digestibility of human foods (i.e., in human and animal models)

- Need for inter-species (human, pig, rat) true ileal amino acid digestibility comparisons

- Need for data on impact of processing, antinutritional factors, matrix effects, etc.

- Clear recommendations on practical applications of DIAAS and implications on food supply (e.g., CODEX applications)

Joyce Boye, 2014 - Presentation
Thank-you!

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