Novel approaches to improve nutrient bioavailability in food aid products

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Michael Joseph, PhD
Food Matrix

- The nutrient & non-nutrient components of foods and their molecular relationships (chemical bonds) to each other

- Major food components
  - Carbohydrates
  - Protein
  - Fat

- Other Food Components
  - Micronutrients (vitamins & minerals)
  - Phytonutrients (polyphenols, carotenoids, flavanoids etc.)
  - Anti-oxidants
  - Anti nutritional factors
  - Probiotics
Bioavailability

- The proportion of a nutrient that is absorbed from the diet and used for normal body functions\(^1,2\)

- **Major bioavailability pathways\(^3\)**
  - Nutrient release from the physicochemical dietary matrix
  - Effects of digestive enzymes in the intestine
  - Binding and uptake by the intestinal mucosa
  - Transfer across the gut wall
  - Systemic distribution & storage
  - Metabolic and functional use

- The bioavailability of macronutrients is usually very high, more than 90% of the amount ingested\(^4\)

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Goals of exploring food matrices

- Incorporate advances in food science & technology that have been excluded from food aid formulas
- Understand the ‘real’ effect that consuming food aid products has on recipients
- Create better food products that can carry energy and nutrition more effectively
- Design more ‘cost-effective’ products: optimized ingredients can lend higher nutritional value at similar costs
Food matrices in food aid

- **Unprocessed**
  Wheat, corn, soybeans, lentils, milled rice, dry peas

- **Processed**
  Fortified vegetable oil, textured soy protein, iodized salt, corn soy blend (roasted, extruded), RUTF (roasted, ground), high energy biscuits (baked)
Literature Review Search Strategy (2000-2018)

**Food and Nutrient Bioavailability**
- Web of Science (WS): 4506
- Scopus: 3253

**Fortified foods**
- WS: 512
- Scopus: 280

**Food Aid**
- WS: 8 (5)
- Scopus: 12 (4)

**Nutrient Interactions**
- WS: 59 (9)
- Scopus: 123 (14)

**Processing & Nutrition**
- WS: 161 (30)
- Scopus: 117 (21)

**Food matrices**
- WS: 33 (6)
- Scopus: 60 (11)

**ANF**
- WS: 10 (5)
- Scopus: 9 (2)

**Food matrices & nutrient bioavailability**
- WS: 259 (15)
- Scopus: 60 (7)

Total articles reviewed = 129

*Bold & Italicized* words are the keywords used for literature search

Numbers in parentheses are the actual articles that are relevant to this review; ANF – Anti-nutritional factors
High-potential areas for improvement

- Enhance energy density of porridges
- Improve protein quality and digestibility
- Improve shelf-life of food aid products
- Lower $\omega_6 : \omega_3$ ratio in oils selected for food aid
- Reduce phytate content of food aid ingredients
- Reduce/eliminate mycotoxin contamination
- Address gut health issues of beneficiaries of food aid
### Suggestions to improve bioavailability of food aid products

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Potential Uptake</th>
<th>Category</th>
<th>Potential Uses</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diastatic Malt (0.25%)</td>
<td>Certain</td>
<td>Food additive</td>
<td>FBFs</td>
<td>Improve energy density of FBFs Improve protein digestibility Reduce phytates</td>
</tr>
<tr>
<td>Defatted wheat germ (15-20%)</td>
<td>Likely</td>
<td>Macronutrient</td>
<td>FBFs, plant based RUTF and RUSF, HEB</td>
<td>Source of high quality protein with branched chain amino acids higher than corn</td>
</tr>
<tr>
<td>Compaction of FBFs</td>
<td>Exploratory</td>
<td>Processing</td>
<td>FBFs</td>
<td>Improve shelf life</td>
</tr>
<tr>
<td>Canola Oil or blend of vegetable oils</td>
<td>Likely</td>
<td>Macronutrient</td>
<td>FBFs, RUTFs, HEB</td>
<td>Provide ω6:ω3 ratio as close to 1 Neurocognitive and immune development</td>
</tr>
<tr>
<td>Synthetic amino acids</td>
<td>Likely</td>
<td>Food additive</td>
<td>FBFs, plant based RUTF and RUSF, HEB</td>
<td>Provide highly bioavailable form of lacking/limiting amino acids</td>
</tr>
<tr>
<td>Yeast cell wall (0.1-0.25%)</td>
<td>Likely</td>
<td>Food additive</td>
<td>FBFs, plant based RUTF and RUSF, HEB</td>
<td>Mycotoxin binding</td>
</tr>
<tr>
<td>Oligosaccharides for gut health at 1.8%-6% of dry matter</td>
<td>Probably</td>
<td>Food additive</td>
<td>FBFs, plant based RUTF and RUSF, HEB</td>
<td>Need more information on use of fibers for undernourished population.</td>
</tr>
</tbody>
</table>
Diastatic Malt to Enhance Energy Density

Need
- Energy density of FBF porridge is 0.4-0.7 kcal/g
- Protein digestibility can be improved
- Phytates in cereals and legumes reduce mineral bioavailability

Proposed Solution
- Add diastatic malt (malted barley flour with Diastatic Power of 160-200°Lintner)

Role in Food Aid products
- Increase energy density of FBFs without increase in volume
- Improve protein digestibility
- Reduce phytates from plant based ingredients

Cost of malt flour: ~US$ 0.85/lb; Addition Rate: 0.25%

In 1 MT, 5.5 lbs of DM is needed x 0.85 = $4.68 additional cost/ton
FBFs – Bostwick values after 30s @ 45°C

*(55) USDA standards for CSB+; CSB+ = Corn Soy Blend Plus
FBFs = Fortified Blended Foods; DM = Diastatic Malt; CSWB = Corn Soy Whey Blend.
<table>
<thead>
<tr>
<th>Study</th>
<th>Study Group</th>
<th>Products</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy and nutrient intake increased by 47–67% when amylase was added to fortified blended foods—a study among 12- to 35- month-old Burkinabe children (Kampstra et al., 2016)</td>
<td>Children between 12-35 months, Burkina Faso</td>
<td>SC+ and SC (CSB, WSB, and RSB) with and without amylase CSB = extruded and drum dried</td>
<td>Addition of amylase significantly increased energy intake and consequently nutrient intake per serving; by 67% for SC+ (1.16 kcal/g) porridges in children aged 12–23 months and 47% for SC (1.03 kcal/g) porridges in children aged 24–35 months.</td>
</tr>
<tr>
<td>Does the consumption of amylase-containing gruels impact on the energy intake and growth of Congolese infants? (Moursi et al., 2003)</td>
<td>Infants between 18-24 weeks, Congo</td>
<td>Maize/soy flour with and without amylase</td>
<td>Consumption of amylase treated gruels allows an increase in energy intake from these gruels without affecting breast milk consumption</td>
</tr>
<tr>
<td>Effects of dietary viscosity and energy density on total daily energy consumption by young Peruvian children(Bennett et al., 1999)</td>
<td>Children between 8-17 months, Peru</td>
<td>Wheat flour, pea flour, full fat milk powder, and oil with and without amylase rich flour</td>
<td>Amylase liquefaction of High Density-High Viscosity porridges resulted in increased energy consumption by young children.</td>
</tr>
<tr>
<td>Power Flour (High Diastatic Milled Barley Malt) Its Important and Critical Role in the Care of Weanling Infants and the Severely Malnourished (Herlache, J.L., 2007)</td>
<td>----------</td>
<td>Malted Barley Flour</td>
<td>Milled high diastatic barley malt is a natural, inexpensive, food grade flour that contains naturally generated digestive enzymes. – Amylase, Protease, and Phytase</td>
</tr>
<tr>
<td>Development of weaning food formulations based on malting and roller drying of sorghum and cowpea (Malleshi et al., 1989)</td>
<td>----------</td>
<td>Malted sorghum and malted cowpea in the ratio of 70:30 and pearled sorghum and roasted cowpea in the same ratio</td>
<td>The malted food had lower cooked paste viscosity, and higher protein content and protein efficiency ratio as compared to unmalted counterpart.</td>
</tr>
</tbody>
</table>
Wheat Germ to Improve Protein Content

**Need**
- Improve the protein quality of food aid products

**Proposed Solution**
+ Addition of toasted wheat germ

**Role in Food Aid products**
- Improve the protein quality

**Cost:** ~ US$ 0.52/lb; **Addition rate:** ~ up to 20%

**Special consideration:** Wheat Germ potentially reduces shelf-life; needs to be assessed by accelerated storage studies
# Toasted wheat germ cost-effectiveness

<table>
<thead>
<tr>
<th></th>
<th>Corn</th>
<th>TWG</th>
<th>Full fat soy</th>
<th>Protein (g/100g)</th>
<th>Energy (kcal/100g)</th>
<th>Cost/ton (USD)</th>
<th>Cost savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSB+</td>
<td>79%</td>
<td>----</td>
<td>20%</td>
<td>13</td>
<td>380</td>
<td>$1,140</td>
<td>0%</td>
</tr>
<tr>
<td>CSB+ &amp; 5% TWG*</td>
<td>75%</td>
<td>4%</td>
<td>20%</td>
<td>14</td>
<td>380</td>
<td>$1,150</td>
<td>-1%</td>
</tr>
<tr>
<td>CSB+ &amp; 10% TWG</td>
<td>71%</td>
<td>8%</td>
<td>17%</td>
<td>14</td>
<td>370</td>
<td>$1,090</td>
<td>5%</td>
</tr>
<tr>
<td>CSB+ &amp; 15% TWG</td>
<td>67%</td>
<td>12%</td>
<td>15%</td>
<td>14</td>
<td>350</td>
<td>$1,020</td>
<td>10%</td>
</tr>
<tr>
<td>CSB+ &amp; 20% TWG</td>
<td>63%</td>
<td>16%</td>
<td>12%</td>
<td>14</td>
<td>340</td>
<td>$960</td>
<td>16%</td>
</tr>
</tbody>
</table>

*Figures are based on the macro-ingredients, vitamin and mineral premixes amount to 1-5%, Costs are for indicative purposes:
Degermed yellow corn-0.55/kg, Full fat Soy-US$ 3.53/kg; TWG: $ 1.14/kg
CSB+ - Corn Soy Blend Plus; TWG- Toasted wheat germ
### Toasted Wheat germ based studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Product</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>To study classification of defatted wheat germ proteins by amino acid composition, predicted nutritional quality, molecular weight distribution of subunits, and thermal properties (Zhu et al., 2016a)</td>
<td>Defatted wheat germ flour</td>
<td>Defatted Wheat germ has a well-balanced amino acid profile, which can make it a good vegetable protein supplement for cereal-based diets</td>
</tr>
<tr>
<td>Some Nutritional and Functional Properties of Defatted Wheat Germ Protein (Yiqiang et al., 2000)</td>
<td>Defatted wheat germ</td>
<td>Defatted wheat germ is abundantly nutritious, with high contents and equilibrium pattern of amino acids.</td>
</tr>
<tr>
<td>Nutritional assessment of cookies supplemented with defatted wheat germ (Arshad et al., 2007)</td>
<td>Defatted wheat germ enriched wheat flour cookies</td>
<td>The cookies containing 15% DFWG, were best regarding protein bioavailability in rats.</td>
</tr>
<tr>
<td>Defatted Wheat germ extract analyzed for antioxidant activity (Mahmoud et al. 2015)</td>
<td>Whole wheat germ and defatted wheat germ</td>
<td>Defatted wheat germ extract has anti-oxidant properties and oxidative stability. It is a potential source of antibacterial agents that act mainly on Gram-positive and Gram-negative bacteria.</td>
</tr>
<tr>
<td>To estimate and compare apparent and standardized ileal digestibility of amino acid and nitrogen in wheat germs as non-traditional feed fed to growing pigs (Brestensky et al., 2013)</td>
<td>Wheat germ (only source of nitrogen) based experimental diet</td>
<td>The digestibility of amino acids and nitrogen of wheat germs is comparable with soybean meal which is the main protein source in diets for pigs. Therefore, it is possible to recommend the use of wheat germs as an alternative protein source,</td>
</tr>
</tbody>
</table>
Compaction to Extend Shelf Life

Need
- Improve shelf life of FBFs by reducing moisture and oxygen migration inside packaging
- Reduction in insect infestations

Proposed Solution
- Compaction of FBFs

Role in Food Aid products
- Improved shelf life of FBFs
- Reduced shipping volumes
Compaction – Proof of Concept

Equipment
- Manually operated hydraulic press

Compaction Pressure
- 160 Bar (2320 psi)

Volume reduction due to compaction
- 70%

Friability
- Can be disintegrated with some force
## Compaction based studies

<table>
<thead>
<tr>
<th>Study (Authors, year)</th>
<th>Publication</th>
<th>Product</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical compaction of flour: The effect of storage temperature on dough rheological properties (Cenkowski et al., 2000)</td>
<td>Canadian Agricultural Engineering</td>
<td>Wheat flour with low extraction (75%) and high extraction (83%)</td>
<td>Compaction offers advantages for long term storage. It would reduce storage volume, slow down diffusion of oxygen into the flour during storage and, therefore, reduce oxidative processes and improve storage stability. Also, compacted flour would have more resistance to possible infestation by mites or other micro-organisms.</td>
</tr>
<tr>
<td>Sorption Isotherms of flour and flow behaviour of dough as influenced by flour compaction (Ramanathan &amp; Cenkowski, 1995)</td>
<td>Canadian Agricultural Engineering</td>
<td>All purpose flour</td>
<td>The compaction of flour to 60% of its original volume can lead to a significant decrease in the storage volume and transportation cost.</td>
</tr>
<tr>
<td>Theory of granulation (Augsburger and Vuppala, 1997)</td>
<td>Handbook of Pharmaceutical Granulation Technology</td>
<td></td>
<td>The suitable way to compact dry powders is through pressure agglomeration which would not require other liquids or binders and subsequent drying. This process has less operating costs and requires simpler equipment</td>
</tr>
<tr>
<td>Size reduction and size enlargement (Snow et al., 1999)</td>
<td>Perry's Chemical Engineering Handbook</td>
<td></td>
<td>The overall effect of geometry of the confined space, nature of applied force, physical properties of the particulate material and of the confining walls control the ability of the material to form and maintain inter-particle bond during compaction</td>
</tr>
<tr>
<td>Caloric densification of rations (Barrett and Cardello)</td>
<td>Military Food Engineering and Ration Technology</td>
<td>First Strike Ration (FSR) vs. Meals Ready to Eat (MRE)</td>
<td>The FSR, on a daily or meal basis, represents a 50% reduction in volume when compared to MRE.</td>
</tr>
</tbody>
</table>
Novel Food Matrices Approaches

Technologies
1. Diastatic malt to improve energy density
2. Wheat germ to improve protein quality
3. Compaction to extend shelf-life

Benefits
✓ Improved nutrient bioavailability
✓ No major changes in the existing production set-up
✓ “Cost-effective”

Challenges
- Regulatory hurdles with some of the recommendations
- Industry cooperation with formula/processing changes?
- Funding to research/implement the recommendations
- For compaction: Additional manufacturing steps & costs of capital equipment
Thank You