Quest for novel feed resources

Harinder Makkar
Livestock Production Systems Branch
Animal Production and Health Division,
FAO, Rome
Outline of presentation

1. The quest for novel feed resources: why?
2. Co-products from bioethanol and biodiesel production
3. Unconventional feed resources
4. Future areas of research
5. Concluding remarks
## Trends in use of feed concentrates & production

### (Million tonnes)

<table>
<thead>
<tr>
<th></th>
<th>1980</th>
<th>2005</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use of concentrates</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developed</td>
<td>669</td>
<td>457</td>
<td>647</td>
</tr>
<tr>
<td>Developing</td>
<td>240</td>
<td>172</td>
<td>603</td>
</tr>
<tr>
<td><strong>Production of meat, milk &amp; eggs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developed</td>
<td>457</td>
<td>647</td>
<td>487</td>
</tr>
<tr>
<td>Developing</td>
<td>172</td>
<td>603</td>
<td>537</td>
</tr>
</tbody>
</table>

From SOFA 2009 Livestock in the balance
<table>
<thead>
<tr>
<th>Region/Country</th>
<th>1960</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td></td>
<td>35%</td>
</tr>
<tr>
<td>EU</td>
<td></td>
<td>53%</td>
</tr>
<tr>
<td>Brazil</td>
<td></td>
<td>44%</td>
</tr>
<tr>
<td>Oceania</td>
<td></td>
<td>28%</td>
</tr>
<tr>
<td>N America</td>
<td></td>
<td>22%</td>
</tr>
<tr>
<td>India</td>
<td></td>
<td>4%</td>
</tr>
<tr>
<td>China</td>
<td>7%</td>
<td>22%</td>
</tr>
<tr>
<td>Brazil</td>
<td>30%</td>
<td>44%</td>
</tr>
</tbody>
</table>
Additional grain required by 2050

1305 million tonnes of which:

- 553 million tonnes for livestock
- 752 million tonnes for humans

IAASTD 2009 using IFPRI economic models to generate predictions
The dilemma

From where we will get feed?

- Growth in pig and poultry meat production putting great pressure on demand for grain
- Food-feed-fuel competition
- Decrease in arable land
- On-going global warming
- Increase in water shortage
- Challenge of feeding 9 billion people by 2050
Biofuels: first, second and third generation

- **1st generation**
  - Cereals, oilseeds and sugar crops

- **2nd generation**
  - Lignocellulosic feedstocks

- **3rd generation**
  - Algae, other hydrocarbons, cellulosic biomass, pyrolysis, etc.
Bioethanol production: 5-fold increase
From what bioethanol is being produced?

<table>
<thead>
<tr>
<th></th>
<th>Maize</th>
<th>Wheat</th>
<th>Other Grain</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>186</td>
<td>0</td>
<td>9</td>
<td>195</td>
</tr>
<tr>
<td>EU</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>26</td>
</tr>
<tr>
<td>CANADA</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>16</td>
</tr>
</tbody>
</table>
Approximately 1/3 of grain used for fuel ethanol is protein-rich co-products.

Source: F.O. Licht, 2011
Ethanol and co-product formation from grains

- Grain
  - Ethanol
  - Residue (protein, fibre, fat, minerals, remnants of fermentation yeast)
    - Centrifuge
      - Wet Distillers Grain
      - Thin Stillage (TS) (liquid)
        - Condensed Distillers Solubles (CDS)
          - Wet Distillers Grain plus Solubles (WDGS)
            - Distillers Dried Grain plus Solubles (DDGS)
Wet-milling processes and co-products

SOURCE: Erickson et al., 2005
Historical production of ethanol co-products

**U.S. ETHANOL CO-PRODUCTS OUTPUT**

<table>
<thead>
<tr>
<th>Year</th>
<th>Distillers Grains (000 MT)</th>
<th>Corn Gluten Feed (000 MT)</th>
<th>Corn Gluten Meal (000 MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90-91</td>
<td>1.2</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>91-92</td>
<td>1.4</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>92-93</td>
<td>1.6</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>93-94</td>
<td>1.8</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>94-95</td>
<td>2.0</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td>95-96</td>
<td>2.2</td>
<td>2.0</td>
<td>2.2</td>
</tr>
<tr>
<td>96-97</td>
<td>2.4</td>
<td>2.2</td>
<td>2.4</td>
</tr>
<tr>
<td>97-98</td>
<td>2.6</td>
<td>2.4</td>
<td>2.6</td>
</tr>
<tr>
<td>98-99</td>
<td>2.8</td>
<td>2.6</td>
<td>2.8</td>
</tr>
<tr>
<td>99-00</td>
<td>3.0</td>
<td>2.8</td>
<td>3.0</td>
</tr>
<tr>
<td>00-01</td>
<td>3.2</td>
<td>3.0</td>
<td>3.2</td>
</tr>
<tr>
<td>01-02</td>
<td>3.4</td>
<td>3.2</td>
<td>3.4</td>
</tr>
<tr>
<td>02-03</td>
<td>3.6</td>
<td>3.4</td>
<td>3.6</td>
</tr>
<tr>
<td>03-04</td>
<td>3.8</td>
<td>3.6</td>
<td>3.8</td>
</tr>
<tr>
<td>04-05</td>
<td>4.0</td>
<td>3.8</td>
<td>4.0</td>
</tr>
<tr>
<td>05-06</td>
<td>4.2</td>
<td>4.0</td>
<td>4.2</td>
</tr>
<tr>
<td>06-07</td>
<td>4.4</td>
<td>4.2</td>
<td>4.4</td>
</tr>
<tr>
<td>07-08</td>
<td>4.6</td>
<td>4.4</td>
<td>4.6</td>
</tr>
<tr>
<td>08-09</td>
<td>4.8</td>
<td>4.6</td>
<td>4.8</td>
</tr>
<tr>
<td>09-10</td>
<td>5.0</td>
<td>4.8</td>
<td>5.0</td>
</tr>
<tr>
<td>10-11E</td>
<td>5.2</td>
<td>5.0</td>
<td>5.2</td>
</tr>
</tbody>
</table>

**Source:** RFA, 2011
### Properties of corn ethanol co-products

<table>
<thead>
<tr>
<th>Animal feed/other co-products</th>
<th>Crude protein (%)</th>
<th>Fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>8.3</td>
<td>3.9</td>
</tr>
<tr>
<td>Soy bean meal</td>
<td>45-50</td>
<td>1.4</td>
</tr>
<tr>
<td>DDGS</td>
<td>30.8</td>
<td>11.2</td>
</tr>
<tr>
<td>WDGS</td>
<td>36.0</td>
<td>15.0</td>
</tr>
<tr>
<td>d-DGS(^1)</td>
<td>34.0</td>
<td>2.7</td>
</tr>
<tr>
<td>HP-DDG(^2)</td>
<td>48.6</td>
<td>3.4</td>
</tr>
<tr>
<td>Corn gluten feed</td>
<td>23.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Corn germ</td>
<td>17.2</td>
<td>19.1</td>
</tr>
</tbody>
</table>

\(^1\) De-oiled DGS  
\(^2\) High-protein dry distillers’ grains

For normal inclusion levels of DDGS in animal diets, the limiting EAAs are lysine and tryptophan for maize DDGS, and lysine and threonine for wheat DDGS.
Exports of US DDGS

U.S. Distillers grains exports

Shurson et al. 2012
Distillers grain use in the US

- Co-products: 26 million tonnes
  - Beef: 66%
  - Dairy: 14%
  - Pigs: 12%
  - Poultry: 8%

USA annual production
Composition changes (on a % DM basis) in typical beef feedlot diets before and after 2000 (USA)

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Before 2000</th>
<th>Current with moderate maize price</th>
<th>Current with high maize price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracked and/or high moisture maize</td>
<td>75.0</td>
<td>52.0</td>
<td>44</td>
</tr>
<tr>
<td>Maize silage</td>
<td>15.0</td>
<td>15.0</td>
<td>-</td>
</tr>
<tr>
<td>Distillers Grain</td>
<td>-</td>
<td>25.0</td>
<td>45.0</td>
</tr>
<tr>
<td>Alfalfa hay</td>
<td>5.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grass hay</td>
<td>-</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Maize stalks</td>
<td>-</td>
<td>-</td>
<td>3.0</td>
</tr>
<tr>
<td>Soybean meal, 44%</td>
<td>3.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Urea</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Vitamin-mineral mix</td>
<td>1.5</td>
<td>3.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Shurson et al. 2012
## Ingredient composition changes (% as-fed basis) in typical growing swine diets in the decades before and after 2000 (US)

**Shurson et al. 2012**

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Before 2000</th>
<th>At current maize, soybean meal and DDGS prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>70</td>
<td>53</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>25</td>
<td>11</td>
</tr>
<tr>
<td>Canola meal</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DDGS</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>Choice white grease</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Other ingredients, vitamins, minerals, amino acids</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

**Shurson et al. 2012**
Distillers grains in ruminant diets

- Corn co-products:
  - primarily as a source of dietary protein in feedlot diets
  - at high levels of grain replacement, fat & fibre contribute meaningful amounts of energy).

- WDGS has a feeding value 30–40% > maize at 10–40% of diet DM.

- Distillers grains are an excellent supplement for cattle on high-forage diets (because: high energy, protein and P contents).

- Reduced rumen degradability of crude protein and increased un-degraded protein increase.

- Maximum recommended levels of DG with solubles (on DM Basis):
  - pre-weaned calves 25%
  - growing heifers 30%
  - dry cows 15%
  - lactating dairy cows 20%
Distillers grains in pigs and poultry diets

- Growing pigs (2-3 wks after weaning): 30% of corn DDGS
- Gestating sows: 50% of DDGS.
- Lactating sows: 30% DDGS
- With finishers: Necessary to withdraw DDGS 3 to 4 wks before slaughter (because high amount of PUFA in the corn oil -- reduce pork fat quality)
- Laying hens: DDGS (~15%) 
- Broilers: >10% wheat DDGS reduce performance -- NSP degrading enzymes needed to overcome adverse effects
### Current, revised recommendations for maximum dietary inclusion rates of DDGS for various species of fish

<table>
<thead>
<tr>
<th>Species</th>
<th>% DDGS</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catfish</td>
<td>Up to 30%</td>
<td>-</td>
</tr>
<tr>
<td>Trout</td>
<td>Up to 15%</td>
<td>Without synthetic lysine and methionine supplementation</td>
</tr>
<tr>
<td>Trout</td>
<td>Up to 22.5%</td>
<td>With synthetic lysine and methionine supplementation</td>
</tr>
<tr>
<td>Salmon</td>
<td>Up to 10%</td>
<td>-</td>
</tr>
<tr>
<td><strong>Freshwater prawns</strong></td>
<td>Up to 40%</td>
<td>Can replace some or all of the fishmeal in the diet</td>
</tr>
<tr>
<td>Shrimp</td>
<td>Up to 10%</td>
<td>Can replace an equivalent amount of fishmeal</td>
</tr>
<tr>
<td>Tilapia</td>
<td>Up to 20%</td>
<td>Without synthetic lysine and supplementation in high protein diets (40% CP)</td>
</tr>
</tbody>
</table>

**HP-DDGS has also been tested**
Safety issues

- **Contamination resulting from the process**: excess mycotoxins, antibiotics, pesticides, harmful bacteria (shedding of *E. coli* 0157:H7 in beeflot cattle).

- **Oil present in DDGS** (maize oil has high PUFA) -- if oxidised, produce toxic aldehydes -- affecting pig health and performance, and meat quality.

- At high levels of S (0.47%) it inhibits oxidative processes in nervous tissue -- leading to Polioencephalomalacia. (Distillers grains may be high in S (0.5–1.7 percent, DM basis)

- **High S may decrease bio-availability** of selenium and vitamin E
Bioethanol co-products – Vinasses

• *Vinasse* is produced from cassava, sugar cane, sweet potato, and sweet sorghum.

• *Vinasse:* preparation of multi-nutrient blocks – increase nutrient utilization & productivity of animals on low quality roughage diets
Growth and anticipated world expansion of biodiesel production

2010 world feedstock usage for biodiesel (thousand tonne)

- Rapeseed oil: 5,750
- Soybean oil: 2,440
- Palm oil: 2,230
- Sunflower oil: 211
- Animal fats & yellow grease: 161
- Other: 5,700

Source: F.O. Licht, 2011
Basic Technology

Vegetable oils

Recycled Greases

Dilute Acid Esterification

Sulfuric acid + methanol

Crude Glycerin

Crude biodiesel

Methanol + KOH

Methanol recovery

Glycerin refining

Glycerine

Refining

Biodiesel

Fatty acid distillate
Biodiesel co-products – Fatty acid distillate

- **Fatty acid distillate**: good source of energy.

- Fatty acids distillate reacted with calcium oxide to develop a **rumen-protected fat** --- an effective way to protect fatty acids against ruminal biohydrogenation.

- **Augment** the oleic, linoleic, α-linolenic and stearic acid content in the milk of dairy cows and reduce that of palmitic acid.
Biodiesel co-products – Glycerol in ruminant diets

- **Glycerol: 15% of the diet** (recommended inclusion)
  - In dairy cow diets as an energy source (often shortly after calving)
  - Or as a preventative for ketosis.

- In beef cattle, feed value of glycerine is greatest at ≤ 10%.

⚠️ Glycerine (similar to starch) **has a deleterious effect on fibre digestion on high-grain diets.**
Biodiesel co-products – Glycerol in pig & fish diets

• Glycerine contains energy similar to that of corn for pigs.

• If affordable, diet can contain glycerine up to:
  • Sow diets  9%
  • Weaners  6%
  • Finishers  15%

• Use of glycerin in fish diet is less clear, and further research needed
Oil palm co-products

Palm oil and palm kernel oil = ~30% of the total global production of oils & fats

<table>
<thead>
<tr>
<th>Co-products</th>
<th>CP</th>
<th>ME (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palm kernel cake (PKC)</td>
<td>17.2</td>
<td>11.13</td>
</tr>
</tbody>
</table>

- a good energy and protein sources - ruminant

- Recommended levels of PKC feeding
  - Growing beef cattle: 30–80%
  - Goats: 20–50%
  - Lactating dairy cattle: 20–50%
  - Poultry and freshwater fish: < 10%

Limiting AA: Lys, met, try
Jatropha curcas kernel meal

Kernel meal (58% protein of 90% digestibility & excellent amino acid composition)
Antinutritional and toxic factors in Jatropha meal

Antinutrients /Toxic components in Jatropha kernel meal

- Trypsin inhibitor: 18 – 27 TIU/g
- Lectin: 50 – 102 U*
- Phytase enzyme
- Phytate: 8.2 – 10.1%
- Phorbol esters: 1-3 mg/g
- Moist heating
- New detoxification method

*U*: 1 mg of meal that produced haemagglutination per ml assay medium. (Source: Makkar and Becker, 2009)
Histopathological & biochemical studies

Biochemical parameters: Normal range

Fig. 3
Common carp (Cyprinus carpio L.) diet:
Crude protein - 38% and lipid - 10%

Rainbow trout (Oncorhynchus mykiss) diet:
Crude protein - 45% and lipid - 24%

Nile tilapia (Orechromis niloticus):
Crude protein - 36% and lipid - 8%

White leg shrimp (Pennaeus vannamei):
Crude protein - 35% and lipid - 9%

50% replacement of fishmeal on protein basis

Jatropha kernel meal in fish, pig and turkey diets

50% replacement of soymeal on protein basis
Non-toxic Jatropha

Jatropha platyphylla (non-toxic)  
Jatropha curcas (non-toxic)
Biodiesel co-products – Camelina sativa meal

Camelina sativa or false flax - the Brassica (Cruciferae) family

- Crude protein: 36-40% (rich in EAA including lys & meth)
- Poultry (layer and broiler) diet: 10%
- When compared to control birds fed a corn-soy diet:
  - 8-10 fold increase in total omega-3 fatty acids and ±-linolenic acid
  - Omega-6: omega-3 fatty acid ratio in eggs -- Decreased
- Two large eggs from hens fed Camelina meal: provides over 300 mg omega-3 fatty acids to the human diet.
### Co-products (meal/cake) of non-edible oil-based biodiesel industry

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Crude Protein</th>
<th>Toxic Compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ricinus communis</strong></td>
<td>27.1 - 40</td>
<td>Ricin, ricinine (alkaloid), CB-1A (stable allergen)</td>
</tr>
<tr>
<td><strong>Hevea brasiliensis</strong></td>
<td>21.9</td>
<td>Cyanogenic glycosides (linamarin and lotaustralin), phytohaemagglutinin (antifertility factor)</td>
</tr>
<tr>
<td><strong>Crambe abyssinica</strong></td>
<td>46 – 58</td>
<td>Epi-progoitrin (thioglucoside)</td>
</tr>
<tr>
<td><strong>Thevetia peruviana</strong></td>
<td>42.8 – 47.5</td>
<td>Cardiac glycosides (thevetin A, thevebioside, gluco-peruvoside and acetylated monoside)</td>
</tr>
<tr>
<td><strong>Azadirachta indica</strong></td>
<td>45.0 – 49.4</td>
<td>Azadirachtin (tetra-nortriterpenoid antifeedant), isoprenoids and nimbidin (sulphurous compound)</td>
</tr>
<tr>
<td><strong>Pongamia pinnata</strong></td>
<td>24.2</td>
<td>Karanjinin (furano-flavonoid), antinutritional factors (phytates, tannins and protease inhibitors &amp; glabrin)</td>
</tr>
</tbody>
</table>
Co-products of non-edible oil-based biodiesel industry

**Azadirachta indica meal**
Water washed, methanol extraction, urea and alkali treatments of **Azadirachta indica meal** -- promising results in farm animals (up to 45% of concentrate for calves).

**Pongamia pinnata meal**
Water-washed, alkali treated **Pongamia pinnata meal**: up to 13.5% of the concentrate in lamb diet.
## Chemical composition of micro-algae

<table>
<thead>
<tr>
<th>Species</th>
<th>Protein</th>
<th>Carbohydrate</th>
<th>Lipids</th>
<th>Nucleic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anabaena cylindrical</strong></td>
<td>43–56</td>
<td>25–30</td>
<td>4–7</td>
<td>Na</td>
</tr>
<tr>
<td><strong>Aphanizomenon flos-aquae</strong></td>
<td>62</td>
<td>23</td>
<td>3</td>
<td>Na</td>
</tr>
<tr>
<td><strong>Scenedesmus obliquus</strong></td>
<td>50–56</td>
<td>10–21</td>
<td>12–14</td>
<td>3–6</td>
</tr>
<tr>
<td><strong>Scenedesmus quadricauda</strong></td>
<td>47</td>
<td>na</td>
<td>1.9</td>
<td>na</td>
</tr>
<tr>
<td><strong>Chlamydomonas rheihardii</strong></td>
<td>48</td>
<td>17</td>
<td>21</td>
<td>na</td>
</tr>
<tr>
<td><strong>Chlorella vulgaris</strong></td>
<td>51–58</td>
<td>12–17</td>
<td>14–22</td>
<td>4–5</td>
</tr>
<tr>
<td><strong>Chlorella pyrenoidosa</strong></td>
<td>57</td>
<td>26</td>
<td>2</td>
<td>na</td>
</tr>
<tr>
<td><strong>Spirogyra sp.</strong></td>
<td>6–20</td>
<td>33–64</td>
<td>11–21</td>
<td>na</td>
</tr>
<tr>
<td><strong>Dunaliella salina</strong></td>
<td>57</td>
<td>32</td>
<td>6</td>
<td>na</td>
</tr>
<tr>
<td><strong>Euglena gracilis</strong></td>
<td>39–61</td>
<td>14–18</td>
<td>14–20</td>
<td>na</td>
</tr>
<tr>
<td><strong>Prymnesium parvum</strong></td>
<td>28–45</td>
<td>25–33</td>
<td>22–38</td>
<td>1–2</td>
</tr>
<tr>
<td><strong>Tetraselmis maculate</strong></td>
<td>52</td>
<td>15</td>
<td>3</td>
<td>na</td>
</tr>
<tr>
<td><strong>Porphyridium cruentum</strong></td>
<td>28–39</td>
<td>40–57</td>
<td>9–14</td>
<td>na</td>
</tr>
<tr>
<td><strong>Spirulina platensis</strong></td>
<td>46–63</td>
<td>8–14</td>
<td>4–9</td>
<td>2–5</td>
</tr>
<tr>
<td><strong>Euglena gracilis</strong></td>
<td>39–61</td>
<td>14–18</td>
<td>14–20</td>
<td>na</td>
</tr>
</tbody>
</table>
## Amino acid profile of a few algae (g/100 g protein)

<table>
<thead>
<tr>
<th>Source</th>
<th>Ile</th>
<th>Leu</th>
<th>Val</th>
<th>Lys</th>
<th>Phe</th>
<th>Tyr</th>
<th>Met</th>
<th>Cys</th>
<th>Try</th>
<th>Trp</th>
<th>Ala</th>
<th>Arg</th>
<th>Asp</th>
<th>Glu</th>
<th>Gly</th>
<th>His</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Egg</strong></td>
<td>6.6</td>
<td>8.8</td>
<td>7.2</td>
<td>5.3</td>
<td>5.8</td>
<td>4.2</td>
<td>3.2</td>
<td>2.3</td>
<td>1.7</td>
<td>5.0</td>
<td>Na</td>
<td>6.2</td>
<td>11.0</td>
<td>12.6</td>
<td>4.2</td>
<td>2.4</td>
</tr>
<tr>
<td><strong>Soybean</strong></td>
<td>5.3</td>
<td>7.7</td>
<td>5.3</td>
<td>6.4</td>
<td>5.0</td>
<td>3.7</td>
<td>1.3</td>
<td>0.7</td>
<td>0.7</td>
<td>5.3</td>
<td>9.4</td>
<td>6.9</td>
<td>9.3</td>
<td>13.7</td>
<td>6.3</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>Chlorella vulgaris</strong></td>
<td>3.2</td>
<td>9.5</td>
<td>7.0</td>
<td>6.4</td>
<td>5.5</td>
<td>2.8</td>
<td>1.3</td>
<td>na</td>
<td>Na</td>
<td>5.3</td>
<td>9.4</td>
<td>6.9</td>
<td>9.3</td>
<td>13.7</td>
<td>6.3</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>Dunaliella bardawil</strong></td>
<td>4.2</td>
<td>11.0</td>
<td>5.8</td>
<td>7.0</td>
<td>5.8</td>
<td>3.2</td>
<td>2.3</td>
<td>1.2</td>
<td>0.7</td>
<td>5.4</td>
<td>7.3</td>
<td>7.3</td>
<td>10.4</td>
<td>12.7</td>
<td>5.5</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Spirulina platensis</strong></td>
<td>6.7</td>
<td>9.8</td>
<td>7.1</td>
<td>4.8</td>
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<td>5.3</td>
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<td>9.5</td>
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<td>11.8</td>
<td>10.3</td>
<td>5.7</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Aphanizomenon flos-aquae</strong></td>
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<td>5.2</td>
<td>3.2</td>
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<td>2.5</td>
<td>na</td>
<td>0.7</td>
<td>0.2</td>
<td>0.7</td>
<td>3.3</td>
<td>4.7</td>
<td>3.8</td>
<td>4.7</td>
<td>7.8</td>
<td>2.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Notes: Compared with soymeal EAA reasonably good
Other Novel Feed Resources

- **Moringa oleifera**: Feed for dry areas
- **Thornless cactus**: Feed for dry areas
- **Winter barley**: Feed for winter
- **Azola**: Grow Moringa as fodder and not as a tree
- **Moringa oleifera**: Grow Moringa as fodder and not as a tree
### Decreasing food-feed competition using Moringa?

**Intensive cultivation of Moringa oleifera**

<table>
<thead>
<tr>
<th>Yield</th>
<th>Yield (tons/ha/yr)</th>
<th>Concentration (% DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM yield</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>Protein</td>
<td>21.4</td>
<td>17.0</td>
</tr>
<tr>
<td>Sugar</td>
<td>12.6</td>
<td>10.0</td>
</tr>
<tr>
<td>Starch</td>
<td>10.0</td>
<td>7.9</td>
</tr>
</tbody>
</table>

6% leaf meal i.e. 7.56 tons = 25% protein
Total protein yield/ha = 1.9 tons

Soybean = 2 tons/ha & has 35% protein
Total protein yield/ha = 0.7 tons
Other Novel Feed Resources

Insect as feed for poultry, pigs and fish

Black Soldier Fly or Hermetia illucens

Maggots: larvae of the housefly Musca domestica

- Protein quality is generally high, similar to other animal meat sources.
- Protein content: ca 50%
- Fat content is variable, but in general a good source of essential polyunsaturated fatty acids.
- A significant source of iron, zinc and vitamin A.

Challenges: Mass production at an industrial scale, safety issue and regulatory aspects
Major knowledge gaps and future research needs

- Need for standardisation of products from within a plant and between plants (distillers grains)
- Mass rearing of insects
- Evaluation of feeding value of biofuel co-products, insects and moringa – especially aquaculture
- Safety standards for use of co-products and insects

FAO document: Biofuel co-products as livestock feed - Opportunities and challenges

An array of co-products of the bio-fuel industry, unconventional resources such as Moringa, Aquatic plants and Insect are good source of protein and energy and can replace soymeal and cereals such as maize in animal diets -- easing food-feed competition"