9. References


Cassani, J.R. 1981. Feeding behaviour of underyearling hybrids of the grass carp, Ctenopharyngodon idella (female) and the bighead carp, Hypophthalmichthys nobilis (male), on selected species of aquatic plants. Journal of Fish Biology, 18: 127-133.


References


Juliano, R.O. 1985. The biology of milk fish (Chanos chanos, Forsskal) and ecology and dynamics of brackishwater ponds in Philippines. University of Tokyo, Japan. (Dissertation)


References


Annex 1

Essential amino acid (EAA) composition of aquatic macrophytes

The EAA of some aquatic macrophytes is provided in Table 1. Further information on the EAA composition of *Azolla* and on duckweed is contained in Table 2 and Table 3 respectively.
### TABLE 1
Essential amino acid composition of some aquatic macrophytes

<table>
<thead>
<tr>
<th>Aquatic macrophytes</th>
<th>CP (percent)</th>
<th>Arg</th>
<th>Hist</th>
<th>Iso</th>
<th>Leu</th>
<th>Lys</th>
<th>Met</th>
<th>Phen</th>
<th>Thr</th>
<th>Tryp</th>
<th>Val</th>
<th>Tyr</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alligator weed (Alternanthera philoxeroides)</td>
<td>15.1</td>
<td>2.10*</td>
<td>1.10*</td>
<td>1.50*</td>
<td>1.90*</td>
<td>0.60*</td>
<td>Trace*</td>
<td>1.00*</td>
<td>-</td>
<td>1.00*</td>
<td>-</td>
<td>-</td>
<td>Tacon (1987)</td>
</tr>
<tr>
<td>Arrowhead (Sagittaria spp.)</td>
<td>18.2</td>
<td>1.10*</td>
<td>0.60*</td>
<td>0.90*</td>
<td>1.70*</td>
<td>1.60*</td>
<td>0.20*</td>
<td>Trace*</td>
<td>1.00*</td>
<td>-</td>
<td>1.40*</td>
<td>-</td>
<td>Tacon (1987)</td>
</tr>
<tr>
<td>Azolla (Azolla filiculoides)</td>
<td>n.s.</td>
<td>6.62</td>
<td>2.31</td>
<td>5.38</td>
<td>9.05</td>
<td>6.45</td>
<td>1.88</td>
<td>5.64</td>
<td>4.70</td>
<td>2.01</td>
<td>6.75</td>
<td>4.10</td>
<td>Buckingham et al. (1978)</td>
</tr>
<tr>
<td>Azolla (Azolla pinnata) Bangkok strain</td>
<td>n.s.</td>
<td>11.14</td>
<td>2.19</td>
<td>3.64</td>
<td>7.10</td>
<td>5.77</td>
<td>1.27</td>
<td>4.61</td>
<td>2.82</td>
<td>0.23</td>
<td>4.62</td>
<td>-</td>
<td>Almazan et al. (1986)</td>
</tr>
<tr>
<td>Canadian pondweed (Elodea canadensis), Canada</td>
<td>14.1</td>
<td>6.95</td>
<td>1.35</td>
<td>4.26</td>
<td>7.45</td>
<td>5.68</td>
<td>1.63</td>
<td>4.47</td>
<td>3.76</td>
<td>1.70</td>
<td>5.32</td>
<td>3.48</td>
<td>Muztar, Slinger &amp; Burton (1978)</td>
</tr>
<tr>
<td>Curlyleaf pondweed (Potamogeton crispus), Canada</td>
<td>12.9</td>
<td>6.36</td>
<td>1.40</td>
<td>4.89</td>
<td>8.14</td>
<td>5.12</td>
<td>2.72</td>
<td>4.81</td>
<td>3.72</td>
<td>0.31</td>
<td>5.74</td>
<td>3.14</td>
<td>Muztar, Slinger &amp; Burton (1978)</td>
</tr>
<tr>
<td>Chara sp., Canada</td>
<td>6.1</td>
<td>3.94</td>
<td>0.82</td>
<td>3.28</td>
<td>5.57</td>
<td>3.77</td>
<td>0.82</td>
<td>3.44</td>
<td>3.61</td>
<td>1.48</td>
<td>4.43</td>
<td>2.13</td>
<td>Muztar, Slinger &amp; Burton (1978)</td>
</tr>
<tr>
<td>Duck weed (Lemna minor), Canada</td>
<td>20.0</td>
<td>5.30</td>
<td>1.60</td>
<td>4.75</td>
<td>8.50</td>
<td>5.65</td>
<td>1.50</td>
<td>4.40</td>
<td>4.40</td>
<td>1.15</td>
<td>5.80</td>
<td>2.85</td>
<td>Muztar, Slinger &amp; Burton (1978)</td>
</tr>
<tr>
<td>Eelgrass (Vallisneria americana), Canada</td>
<td>18.3</td>
<td>4.26</td>
<td>0.99</td>
<td>4.10</td>
<td>7.16</td>
<td>2.19</td>
<td>1.26</td>
<td>4.92</td>
<td>3.33</td>
<td>1.15</td>
<td>4.70</td>
<td>3.17</td>
<td>Muztar, Slinger &amp; Burton (1978)</td>
</tr>
<tr>
<td>Eurasian water milfoil (Myriophyllum spicatum), Canada</td>
<td>12.8</td>
<td>7.04</td>
<td>1.87</td>
<td>5.76</td>
<td>9.92</td>
<td>7.37</td>
<td>2.12</td>
<td>7.54</td>
<td>4.75</td>
<td>0.60</td>
<td>7.37</td>
<td>3.90</td>
<td>Muztar, Slinger &amp; Burton (1978)</td>
</tr>
<tr>
<td>Oxygen weed (Hydrilla verticillata)</td>
<td>n.s.</td>
<td>4.18</td>
<td>1.43</td>
<td>3.89</td>
<td>7.16</td>
<td>4.12</td>
<td>1.63</td>
<td>4.61</td>
<td>3.78</td>
<td>-</td>
<td>4.69</td>
<td>3.55</td>
<td>Boyd (1969)</td>
</tr>
<tr>
<td>Sago pondweed (Potamogeton pectinatus), Canada</td>
<td>19.7</td>
<td>4.32</td>
<td>1.12</td>
<td>3.55</td>
<td>5.99</td>
<td>6.45</td>
<td>1.02</td>
<td>4.57</td>
<td>3.15</td>
<td>0.92</td>
<td>4.42</td>
<td>2.54</td>
<td>Muztar, Slinger &amp; Burton (1978)</td>
</tr>
<tr>
<td>Water hyacinth (Eichhornia crassipes)</td>
<td>n.s.</td>
<td>4.55</td>
<td>1.62</td>
<td>3.86</td>
<td>6.78</td>
<td>4.68</td>
<td>1.37</td>
<td>4.09</td>
<td>3.78</td>
<td>-</td>
<td>4.49</td>
<td>2.93</td>
<td>Boyd (1968)</td>
</tr>
<tr>
<td>Water lettuce (Pistia stratiotes)</td>
<td>n.s.</td>
<td>3.63</td>
<td>1.69</td>
<td>3.99</td>
<td>7.06</td>
<td>5.27</td>
<td>1.35</td>
<td>4.45</td>
<td>3.84</td>
<td>-</td>
<td>4.82</td>
<td>3.19</td>
<td>Boyd (1968)</td>
</tr>
<tr>
<td>Water spinach (Ipomoea aquatica)</td>
<td>n.s.</td>
<td>3.31</td>
<td>2.66</td>
<td>3.42</td>
<td>6.55</td>
<td>4.56</td>
<td>1.53</td>
<td>5.67</td>
<td>3.92</td>
<td>-</td>
<td>5.27</td>
<td>4.14</td>
<td>Peñaflorida (1989)</td>
</tr>
<tr>
<td>Water willow (Justicia americana)</td>
<td>17.6</td>
<td>3.00*</td>
<td>1.10*</td>
<td>2.50*</td>
<td>4.30*</td>
<td>2.80*</td>
<td>0.90*</td>
<td>2.80*</td>
<td>2.30*</td>
<td>-</td>
<td>2.90*</td>
<td>-</td>
<td>Tacon (1987)</td>
</tr>
</tbody>
</table>

Arg = Arginine; Hist = Histidine; Iso = Isoleucine; Leu = Leucine; Lys = Lysine; Met = Methionine; Phen = Phenylalanine; Thr = Threonine; Tryp = Tryptophan; Val = Valine; Tyr = Tyrosine

n.s. = not stated.

*Values expressed as percent DM basis.
Annex 1. Essential amino acid (EAA) composition of aquatic macrophytes

TABLE 2
Essential amino acid composition of Azolla species

<table>
<thead>
<tr>
<th>Amino acids (percent DM)</th>
<th>A. microphylla</th>
<th>A. caroliniana</th>
<th>A. filiculoides</th>
<th>A. nilotica</th>
<th>A. pinnata var. imbricata</th>
<th>A. mexicana</th>
<th>A. pinnata var. pinnata</th>
<th>A. pinnata</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arg</td>
<td>1.90</td>
<td>1.58</td>
<td>1.04</td>
<td>1.56</td>
<td>1.43</td>
<td>1.33</td>
<td>1.32</td>
<td>1.15</td>
</tr>
<tr>
<td>Hist</td>
<td>0.47</td>
<td>0.40</td>
<td>0.28</td>
<td>0.37</td>
<td>0.33</td>
<td>0.32</td>
<td>0.32</td>
<td>n.s.</td>
</tr>
<tr>
<td>Iso</td>
<td>1.07</td>
<td>0.85</td>
<td>0.57</td>
<td>0.84</td>
<td>0.76</td>
<td>0.75</td>
<td>0.81</td>
<td>0.93</td>
</tr>
<tr>
<td>Leu</td>
<td>2.29</td>
<td>1.96</td>
<td>1.42</td>
<td>1.71</td>
<td>1.79</td>
<td>1.66</td>
<td>1.71</td>
<td>1.65</td>
</tr>
<tr>
<td>Lys</td>
<td>1.62</td>
<td>1.34</td>
<td>1.04</td>
<td>1.27</td>
<td>1.15</td>
<td>1.06</td>
<td>1.06</td>
<td>0.98</td>
</tr>
<tr>
<td>Met + Cys</td>
<td>0.43</td>
<td>0.46</td>
<td>0.47</td>
<td>0.52</td>
<td>0.21</td>
<td>0.51</td>
<td>0.23</td>
<td>0.52</td>
</tr>
<tr>
<td>Phen + Tyr</td>
<td>2.17</td>
<td>1.93</td>
<td>1.29</td>
<td>1.51</td>
<td>1.57</td>
<td>1.45</td>
<td>1.45</td>
<td>1.69</td>
</tr>
<tr>
<td>Thr</td>
<td>1.13</td>
<td>1.03</td>
<td>0.68</td>
<td>0.91</td>
<td>0.86</td>
<td>0.85</td>
<td>0.84</td>
<td>0.87</td>
</tr>
<tr>
<td>Val</td>
<td>1.07</td>
<td>0.86</td>
<td>0.79</td>
<td>0.81</td>
<td>0.88</td>
<td>0.75</td>
<td>0.97</td>
<td>1.18</td>
</tr>
</tbody>
</table>

1 Arg = Arginine; Hist = Histidine; Iso = Isoleucine; Leu = Leucine; Lys = Lysine; Met = Methionine; Phen = Phenylalanine; Thr = Threonine; Val = Valine; Cys = Cysteine; Tyr = Tyrosine; crude protein levels not stated
2 modified from Cagauan and Pullin (1991)
3 Alalade and Iyaiy (2006)

TABLE 3
Mean essential amino acid values (g/100 g protein) of four species of duckweed1 compared to FAO reference EAA pattern

<table>
<thead>
<tr>
<th>Amino acids</th>
<th>Mean ± SD</th>
<th>FAO reference protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arginine</td>
<td>4.54 ± 0.64</td>
<td>-</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.78 ± 0.42</td>
<td>-</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>3.61 ± 0.37</td>
<td>4.2</td>
</tr>
<tr>
<td>Leucine</td>
<td>6.68 ± 0.58</td>
<td>4.8</td>
</tr>
<tr>
<td>Lysine</td>
<td>4.01 ± 0.43</td>
<td>4.2</td>
</tr>
<tr>
<td>Methionine</td>
<td>0.90 ± 0.15</td>
<td>2.2</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>4.16 ± 0.39</td>
<td>2.8</td>
</tr>
<tr>
<td>Threonine</td>
<td>3.12 ± 0.40</td>
<td>2.8</td>
</tr>
<tr>
<td>Tryptophan2</td>
<td>-</td>
<td>1.4</td>
</tr>
<tr>
<td>Valine</td>
<td>4.39 ± 0.64</td>
<td>4.2</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>2.82 ± 0.44</td>
<td>-</td>
</tr>
</tbody>
</table>

1 L. gibba, S. polyrrhiza, S. punctata and W. columbiana
2 Destroyed during analysis
Source: modified from Culley et al. (1981)
Annex 2
Periphyton

Rich periphyton communities boost fish production. The distribution of periphytic fauna shows differences with regard to quantum and seasonal succession. Periphyton-supported aquaculture systems offer the possibility of increasing both primary production and food availability for fish; especially those low in the food chain. The culture of milkfish (Chanos chanos), a very popular cultured species in Indonesia, Philippines and Taiwan Province of China, is mainly based on periphytic “lab lab” as food, the production of which is enhanced by organic and inorganic fertilization (Juliano, 1985). The “acadjas” of West Africa (Welcomme, 1972), the brush parks of Sri Lanka (Senanayake, 1981) and the “Katha” fisheries of Bangladesh and India (Wahab and Kibria, 1994) are well-known examples of periphyton-based aquaculture systems.

Dempster, Beveridge and Baird (1993) have reported that Nile tilapia graze more efficiently on periphyton substrates than on micro-particles in the water column. Algal biomass is also higher in periphyton systems. Bhaumik et al. (2005) have reported that richness of periphytic structure in closed wetlands results in higher fish production (1,570 kg/ha/year) compared to open system (384 kg/ha/year). Lagoons provided with substrates for periphyton, supports eight times higher algal biomass compared to the surrounding lagoons (Konan-Brou and Guiral, 1994).

A range of substrate-supported aquaculture systems (Table 1) have been developed to reduce the cost of feeding fish (Azim et al., 2002a, 2002b; Keshavanath et al., 2002; Garg, 2005). In these systems additional substrates are provided for the growth of periphyton, which has positive effects on fish production. The association of microorganisms, algae and planktonic organisms attached as periphyton serve as food for fish and also act as an in situ water purifier ensuring better living conditions. Wahab et al. (1999) have reported 1.8 times higher production of carp kalbaush (Labeo calbasu) in ponds provided with scrap bamboo as substrate than from ponds without substrate. Similar results were also observed with rohu (Labeo rohita) (Azim et al., 2001), Mahseer (Tor khurdee) (Keshavanath et al., 2001) and milkfish (Chanos chanos) (Jana et al., 2006). Fish yield is linearly correlated with substrate area (Azim et al., 2004). Garg (2005) has reported that grey mullet (Mugil cephalus), milkfish (Chanos chanos), pearlspot (Etroplus suratensis) and Nile tilapia (O. niloticus) are suitable species for periphyton-based brackish water culture systems. Survival and growth of these four fish were higher in substrate-supported periphyton-based culture systems compared to the systems without substrate. The provision of additional substrates in fish culture ponds reduce the use of artificial feed, especially those species that thrive low in the food web.

### Table 1

<table>
<thead>
<tr>
<th>Fish species</th>
<th>Culture system</th>
<th>Substrate used</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilapia</td>
<td>Monoculture</td>
<td>Dense masses of branches</td>
<td>Welcomme (1972)</td>
</tr>
<tr>
<td>Sarotherodon melanotheron</td>
<td>Monoculture</td>
<td>Bamboo poles</td>
<td>Hem and Avit (1994)</td>
</tr>
<tr>
<td>Labeo calbasu</td>
<td>Monoculture</td>
<td>Scrap bamboo</td>
<td>Wahab et al. (1999)</td>
</tr>
<tr>
<td>Labeo fimbriatus</td>
<td>Polyculture</td>
<td>Bamboo, jutesticks</td>
<td>Azim et al. (2002a)</td>
</tr>
<tr>
<td>Labeo rohita</td>
<td>Monoculture</td>
<td>Sugarcane bagasse</td>
<td>Ramesh et al. (1999)</td>
</tr>
<tr>
<td>Cyprinus carpio</td>
<td>Monoculture</td>
<td>Paddy straw (Eichhornea sp.)</td>
<td>Ramesh et al. (1999)</td>
</tr>
<tr>
<td>Tor khudree</td>
<td>Monoculture</td>
<td>Bamboo poles</td>
<td>Keshavanath et al. (2002)</td>
</tr>
</tbody>
</table>
This technical paper presents a global review on the use of aquatic macrophytes as feed for farmed fish, with particular reference to their current and potential use by small-scale farmers. The review is organized under four major divisions of aquatic macrophytes: algae, floating macrophytes, submerged macrophytes and emergent macrophytes. Under floating macrophytes, Azolla, duckweeds and water hyacinths are discussed separately; the remaining floating macrophytes are grouped together and are reviewed as ‘other floating macrophytes’. The review covers aspects concerned with the production and/or cultivation techniques and use of the macrophytes in their fresh and/or processed state as feed for farmed fish. Efficiency of feeding is evaluated by presenting data on growth, food conversion and digestibility of target fish species. Results of laboratory and field trials and on-farm utilization of macrophytes by farmed fish species are presented. The paper provides information on the different processing methods employed (including composting and fermentation) and results obtained to date on different species throughout the world with particular reference to Asia. Finally, it gives information on the proximate and chemical composition of most commonly occurring macrophytes, their classification and their geographical distribution and environmental requirements.