9. References

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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

Aquatic macrophytes	CP (percent)	EAA (percent of protein)											References
		Arg	Hist	Iso	Leu	Lys	Met	Phen	Thr	Tryp	Val	Tyr	
Alligator weed (*Alternanthera philoxeroides*)	15.1	2.10*	1.10*	1.50*	1.90*	1.50*	0.60*	Trace*	1.60*	-	1.80*	-	Tacon (1987)
Arrowhead (*Sagittaria spp.*)	18.2	1.10*	0.60*	0.90*	1.70*	1.60*	0.20*	Trace*	1.00*	-	1.40*	-	Tacon (1987)
Azolla (*Azolla filiculoides*)	n.s.	6.62	2.31	5.38	9.05	6.45	1.88	5.64	4.70	2.01	6.75	4.10	Buckingham *et al*. (1978)
Azolla (*Azolla pinnata*) Bangkok strain	n.s.	11.14	2.19	3.64	7.10	5.77	1.27	4.61	2.82	0.23	4.62	-	Almazan *et al.* (1986)
Canadian pondweed (*Elodea canadensis*), Canada	14.1	6.95	1.35	4.26	7.45	5.68	1.63	4.47	3.76	1.70	5.32	3.48	Muztar, Slinger & Burton (1978)
Curlyleaf pondweed (*Potamogeton crispus*), Canada	12.9	6.36	1.40	4.89	8.14	5.12	2.72	4.81	3.72	0.31	5.74	3.14	Muztar, Slinger & Burton (1978)
Chara sp., Canada	6.1	3.94	0.82	3.28	5.57	3.77	0.82	3.44	3.61	1.48	4.43	2.13	Muztar, Slinger & Burton (1978)
Duck weed (*Lemna minor*), Canada	20.0	5.30	1.60	4.75	8.50	5.65	1.50	4.40	4.40	1.15	5.80	2.85	Muztar, Slinger & Burton (1978)
Eelgrass (*Vallisneria americana*), Canada	18.3	4.26	0.99	4.10	7.16	2.19	1.26	4.92	3.33	1.15	4.70	3.17	Muztar, Slinger & Burton (1978)
Eurasian water milfoil (*Myriophyllum spicatum*), Canada	12.8	7.04	1.87	5.76	9.92	7.37	2.12	7.54	4.75	0.60	7.37	3.90	Muztar, Slinger & Burton (1978)
Oxygen weed (*Hydrilla verticillata*)	n.s.	4.18	1.43	3.89	7.16	4.12	1.63	4.61	3.78	-	4.69	3.55	Boyd (1969)
Sago pondweed (*Potamogeton pectinatus*), Canada	19.7	4.32	1.12	3.55	5.99	6.45	1.02	4.57	3.15	0.92	4.42	2.54	Muztar, Slinger & Burton (1978)
Water hyacinth (*Eichhornia crassipes*)	n.s.	4.55	1.62	3.86	6.78	4.68	1.37	4.09	3.78	-	4.49	2.93	Boyd (1968)
Water lettuce (*Pistia stratiotes*)	n.s.	3.63	1.69	3.99	7.06	5.27	1.35	4.45	3.84	-	4.82	3.19	Boyd (1968)
Water spinach (*Ipomoea aquatica*)	n.s.	3.31	2.66	3.42	6.55	4.56	1.53	5.67	3.92	-	5.27	4.14	Peñaflorida (1989)
Water willow (*Justicia americana*)	17.6	3.00*	1.10*	2.50*	4.30*	2.80*	0.90*	2.80*	2.30*	-	2.90*	-	Tacon (1987)

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.

TABLE 2
Essential amino acid composition of Azolla species

Azolla species	**Amino acids[1] (percent DM)**								
	Arg	**Hist**	**Iso**	**Leu**	**Lys**	**Met + Cys**	**Phen + Tyr**	**Thr**	**Val**
A. microphylla[2]	1.90	0.47	1.07	2.29	1.62	0.43	2.17	1.13	1.07
A. caroliniana[2]	1.58	0.40	0.85	1.96	1.34	0.46	1.93	1.03	0.86
A. filiculoides[2]	1.04	0.28	0.57	1.42	1.04	0.47	1.29	0.68	0.79
A. nilotica[2]	1.56	0.37	0.84	1.71	1.27	0.52	1.51	0.91	0.81
A. pinnata var. imbricata[2]	1.43	0.33	0.76	1.79	1.15	0.21	1.57	0.86	0.88
A. mexicana[2]	1.33	0.32	0.75	1.66	1.06	0.51	1.45	0.85	0.75
A. pinnata var. pinnata[2]	1.32	0.32	0.81	1.71	0.96	0.23	1.45	0.84	0.97
A. pinnata[3]	1.15	n.s.	0.93	1.65	0.98	0.52	1.69	0.87	1.18

[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 Iyayi (2006)

TABLE 3

Mean essential amino acid values (g/100 g protein) of four species of duckweed[1] compared to FAO reference EAA pattern

Amino acids	**Mean ± SD**	**FAO reference protein**
Arginine	4.54 ± 0.64	-
Histidine	1.78 ± 0.42	-
Isoleucine	3.61 ± 0.37	4.2
Leucine	6.68 ± 0.58	4.8
Lysine	4.01 ± 0.43	4.2
Methionine	0.90 ± 0.15	2.2
Phenylalanine	4.16 ± 0.39	2.8
Threonine	3.12 ± 0.40	2.8
Tryptophan[2]	-	1.4
Valine	4.39 ± 0.64	4.2
Tyrosine	2.82 ± 0.44	-

[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
Various substrates used in periphyton-based culture system

Fish species	Culture system	Substrate used	Reference
Tilapia	Monoculture	Dense masses of branches	Welcomme (1972)
Sarotherodon melanotheron	Monoculture	Bamboo poles	Hem and Avit (1994)
Labeo calbasu	Monoculture	Scrap bamboo	Wahab *et al.* (1999)
Labeo fimbriatus	Polyculture	Bamboo, jutesticks	Azim *et al.* (2002a)
Labeo rohita	Monoculture	Sugarcane bagasse	Ramesh *et al.* (1999)
Cyprinus carpio	Monoculture	Paddy straw (*Eichhornea* sp.)	Ramesh *et al.* (1999)
Tor khudree	Monoculture	Bamboo poles	Keshavanath *et al.* (2002)

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 with 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.

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