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Fresh-water Plants: a Potential Source of Protein

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Exploitation of aquatic flora as a source of edible protein has received little attention. Large stands of vascular plants and non-planktonic algae are produced in many natural and impounded waters and frequently interfere with beneficial uses of water to such an extent that various control measures are necessary. In view of the problems associated with the control of water weeds and the worldwide need for additional sources of food, research to evaluate the nutritional value of aquatic plants is of importance.

As a result of studies on the mineral metabolism of lakes, a considerable amount of information was obtained on the mineral content of aquatic plants. Data on mineral composition have been reviewed (3). Workers in the United States reported that aquatic plants contain large amounts of crude protein and have lower fiber levels than forage plants (2, 12, 19). Some submersed water weeds have a high xanthophyll content and impart excellent yolk coloration when fed to poultry (8). However, practical applications have not resulted. In Europe and Asia, limited use of water weeds as fodder was reported (10, 16, 21), but no information on nutritive value was obtained. Available data indicate that aquatic plants may have value as a food and additional research has merit.

The present study was the preliminary phase of a program to determine the food value of aquatic plants. Data were obtained on the chemical composition of dried plants to evaluate their potential as roughages. Extractability of leaf protein was determined for several species. Leaf protein can be used in human or non-ruminant animal diets (22). Plants employed were selected according to their availability in the Auburn, Alabama, area; however, many of the species and most genera have a cosmopolitan distribution. Water hyacinth *(Eichornia crassipes),* probably the worst aquatic pest plant in almost all tropical nations, will be treated in a separate report.

Materials and Methods'

Samples. Plants were collected from sites in southeastern Alabama. Generally, samples of each species were obtained from one to three stands on a single spring date when the plants were in a lush green condition. Selected stands of three species were sampled at monthly intervals.

Emergent vegetation was cut to include only leaves or aerial shoots. Leaves were harvested from emergent plants with only floating leaves. Shoots were harvested from submersed plants. Collections of algae were hand picked at random from dense mats. Plant materials were collected from several places within a radius of a few meters. These materials were combined to compose a sample. Vegetation for protein extraction was stored on ice and processed within 30 min to 2 hr after harvest to prevent enzymatic destruction of protein. Samples for chemical analysis were also stored on ice, but in some cases it was necessary to hold the plants 18 hr before drying them.

In the laboratory, samples were placed in tap water, picked free of debris, and drained of adherent water. Three hundred to 500 g of fresh plants for chemical analysis were heated at 65 C for 72 hr in a forced-draft oven for dry matter determination. By use of a Wiley mill, dried plants were ground to pass a 0.5-mm mesh screen.

Chemical analyses. Macro-Kjeldahl nitrogen analyses (excluding nitrates) were made according to A.O.A.C. (1) using mercury as a digestion catalyst. Crude protein was calculated as Kjeldahl nitrogen x 6.25. Ash values were obtained by heating samples at 550 C for 6 hr in a muffle furnace. The procedure outlined by Crampton and Maynard

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(7) was followed for cellulose analysis. Tannin levels were estimated colorimetrically (23) following reaction with a phosphotungstic-phosphomolybdic compound. Crude fat (ether extract) was measured following continuous ether extraction for 4 hr in a Goldfisch fat extractor. Caloric values were determined with a Parr adiabatic oxygen bomb calorimeter.

Leaf protein amino acid analyses were made on solutions obtained from sealed tube hydrolysis of samples in 6N HCl for 22 hr at 110 C (11). Analyses were made with a Beckman-Spinco model 120 amino acid analyzer.

Leaf protein extraction—The laboratory scale extraction was conducted essentially as described by Byers (5). Five hundred to 1000 g fresh leaves were pulped with a food chopper. The pulp was squeTzed through a fine cotton cloth. A second extraction was made by adding water and repulping the fibrous residue from the first extraction.

Dry matter and Kjeldahl nitrogen analyses were made of the initial pulp and the final fiber. Protein nitrogen (trichloroacetic acid insoluble nitrogen) and nonprotein nitrogen (trichloroacetic acid soluble nitrogen) determinations were made on the extracts. Analytical results were used to make an extraction balance sheet from which the percentage leaf nitrogen extracted and the percentage leaf nitrogen extracted as protein nitrogen were calculated.

A sample of protein was precipitated from a portion of combined extracts by heating to 80 C in a water bath. This protein was centrifuged, washed, and freeze-dried. The dry cake was ground for chemical analysis.

Yield estimates of extractable crude protein were made for some species from extraction data and estimates of standing crop were obtained from several m^2 quadrant harvests per stand.

Leaf Protein

Extractability data and protein yield estimates are presented in Table I. Different 'stands of a particular species are designated numerically. Dates are not given for some species collected from only one stand, but these plants were green and succulent and apparently rather young. Amounts of extractable protein nitrogen ranged from 9.7 to 61.0% of the pulp nitrogen. Byers (5) classified plants as to whether more than 40%, 20 to 40%, or less than 20% of the leaf nitrogen was extractable as protein nitrogen. Values above 40% were obtained for young *Justicia americana* and *Alternanthera philoxeroides* specimens, all *Orontium aquaticum* samples, and all but one *Nymphaea odorata* extractions. Twelve species were in the intermediate range, and four gave less than 20%. Compared to crop plants (6), a larger percentage of the total extractable nitrogen was nonprotein.

More leaf protein was extractable from young than old *J. americana* specimens. This decrease in extractability was apparently related to the simultaneous decrease in pulp nitrogen and moisture content. On an areal basis, maximum dry matter yield (Stand 1) was obtained on August 3; however, considerably more protein was extractable on May 19 when the standing crop was relatively low. Extractability was also greater for early harvest of *Sagittaria latifolia, A. philoxeroides,* and *N. odorata.* This fact is particularly obvious from areal protein yields. Age had little effect on performance of *Orontium aquaticum.* A general decrease in protein extractability with age is common for terrestrial plants (6).

Most species from which protein was not readily extractable contained large quantities of mucilage. Several of these plants contained large amounts of nitrogen, so nitrogen content is not a reliable estimate of extractability for aquatic plants.

Areal yields of extractable crude protein ranged from 17 to 590 kg/ha. Results for *Justicia americana, Sagittaria latifolia,* and *Alternanthera philoxeroides* were similar to reported crop plant leaf protein yields (6).

Byers (5) also categorized plants on the basis of the nitrogen content of dried protein isolates: above 9%, 7 to 9%, and below 7%. All water weed preparations were below 9%, a value frequently obtained for legumes. Isolates from *Orontium aquaticum,* all but two *Justicia americana* preparations, and one *Sagittaria latifolia* sample contained between 7 and 9% nitrogen. Other preparations were below 7% nitrogen and several contained less than 5%. A higher proportion of terrestrial plant isolates (5, 9) were above 7% than were preparations from aquatic weeds. Byers (5) also reported a low crude protein content for leaf protein from several water weeds. The crude protein content of *J. americana* preparations decreased markedly with plant

TABLE I

LEAF PROTEIN EXTRACTION DATA AND PROTEIN YIELDS FOR AQUATIC PLANTS

Species		n[1]	Pulp D.M. (%)[2]	Pulp N in D.M. (%)	Extractability (%) Total N[3]	Extractability (%) Protein N[4]	N in dry leaf protein (%)	Yield (kg/ha) D.M.	Yield (kg/ha) Crude protein	Comments[5]
Justicia americana										A
Stand 1	May 19	2	13.1	3.64	76.2	53.6	8.82	5030	590	
	June 5	2	13.0	2.86	80.3	54.4	8.83	5570	576	
	July 1	2	16.4	2.40	72.6	48.6	6.70	6950	499	
	Aug. 3	5	17.5	2.23	72.4	43.1	6.25	7 100	427	
	Sept. 1	[illegible]	20.6	2.03	55.8	29.5	5.32	3740	141	
Stand 2	July 14	1	24.6	2.14	62.8	38.7	7.39	4760	247	
Stand 3	Aug. 1	1	18.5	2.50	56.2	37.0	7.64		—	
Sagittaria latifolia										A
Stand 1	June 6	1	11.8	2.91	47.7	26.1	7.28	7280	362	
	July 11	1	12.6	2.04	50.8	25.2	5.19	6560	211	
Stand 2	June 9	1	14.1	3.35	38.3	27.4	4.66		—	
Alternanthera philoxeroides										B
Stand 1	May 17	1	11.7	2.41	78.2	42.6	4.04	7420	478	
	Aug. 3	2	19.8	1.36	56.0	38.0	4.12	7400	234	
Stand 2	June 6	1	14.5	1.54	59.9	35.8	5.34		—	
Nymphaea odorata										B
Stand 1	June 15	1	14.5	2.50	65.9	61.0	5.75			
	Aug. 31	1	10.2	3.45	52.4	50.8	6.80			
Stand 2	July 5	1	10.6	2.55	39.3	36.2	6.02	1800	197	
Stand 3	Aug. 28	2	13.9	2.66	61.9	45.2	5.65	1620	121	
Orontium *aquaticum*										A
	June 9	1	11.0	3.35	59.5	41.9	8.53			
	Aug. 28	3	9.9	3.66	61.6	43.8	7.89		—	
Jussiaea decurrens		2	9.3	3.54	46.8	34.2	6.15	2350	177	C
Jussiaea peruriana		1	20.2	1.16	50.2	35.0	2.42	5050	128	C
Brasenia schreberi		1	6.8	2.53	40.0	35.8	4.93	790	45	C
Elodea *densa*		3	7.3	3.02	50.7	33.6	3.83			A
Nuphar advena		1	10.6	2.98	32.5	21.8	5.47			C
Polygonum sp.		1	14.8	1.82	31.5	20.3	3.50	7780	180	C
Nymphoides *aquaticum*		1	9.9	1.54	28.9	16.1	5.08	1800	29	B
Nelumbo lutea		1	17.0	1.92	24.8	13.9	3.98	990	17	A
Hydrocotyle sp.		1	6.8	3.11	66.2	28.1	4.62		—	A
Ceratophyllum demersum		2	4.9	3.39	53.0	32.2	3.81			A
Myriophyllum brasiliense		3	7.9	3.66	31.4	14.5	4.16			A
Najas *guadalupensis*		2	6.4	3.52	60.8	39.4	2.58			A
Hydrodictyon *reticulatum*		2	3.4	4.40	50.6	27.4	4.92			A
Spirogyra sp.		2	4.2	3.85	41.7	20.4	—			A
Pithophora sp.		2	18.1	1.79	30.0	15.2	1.42			A

[1] Number of samples.

[2] Dry matter.

[3] Percentage of pulp nitrogen extracted.

[4] Percentage of pulp nitrogen extracted as protein nitrogen.

[5] A = No difficulty in grinding or making extract.

B = No difficulty in grinding. Contained slight mucilage but extracted well.

C = Contained excessive mucilage. Difficult to grind and extract.

age, but similar results were not obtained for other species.

These estimates of protein extractability were ideal laboratory figures based on minimal losses of material during processing. In addition, slightly more protein was precipitated from the extract by trichloroacetic acid than by heating to 80 C (6), the method of coagulation used in large scale production (18). Laboratory efficiency is probably not possible with large scale machinery, but the data are indicative of species which lend themselves to extraction.

Mean crude fat, ash, cellulose, and caloric values for leaf protein from the five species for which good extractability was obtained are presented in Table II. The parameters differed greatly between species. In general, the isolates were high in fat and contained only small quantities of fiber. As expected in fat rich substances, the caloric content was fairly high.

Amino acid analyses are presented in Table III. All samples were somewhat low in lysine and methionine when compared with meat proteins (11). Phenylalanine was present in very small quantities in A. *philoxeroides* and S. *latifolia*. Otherwise, amino acid levels were similar to those for meat proteins and crop plant leaf protein isolates (11). Leaf protein from aquatic plants was of sufficiently high amino acid quality to be useful as a dietary supplement.

In addition to extracted protein, the fiber remaining after juice separation is a potential food material. Approximately one-half of the pulp dry matter was retained as fiber (Table IV), which contained enough crude protein to be useful as a feed. High cellulose levels would probably limit utilization except as roughage for ruminant animals.

Juice remaining after protein precipitation contains amino acids, nucleotides, inorganic nitrogen, and large amounts of soluble

TABLE II
MEAN NUTRITIONAL ANALYSES OF LEAF PROTEIN

Species	Dry wt. basis (%) Ash	Crude fat	Cellulose	Caloric content (Kcal/g dry wt)
Justicia americana	8.10	9.37	1.6	5.22
Orontium aquaticum	7.38	14.88	2.6	5.59
1Vymphaea *odorata*	4.24	8.57	8.3	4.94
Sagittaria *latifolia*	4.23	16.62		5.42
Alternanthera philoxeroides	12.47	7.68	5.9	4.58

TABLE III
ESSENTIAL AMINO ACID COMPOSITION OF AQUATIC PLANT LEAF PROTEIN[a]

Protein source	Crude protein (%)	Amino acids (% dry wt. basis) Arginine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Valine
Justicia *americana*	47.4	3.07	1.08	2.61	4.38	2.73	0.97	2.90	2.26	2.60
Justicia americana	52.3	3.24	1.11	2.50	4.55	2.94	0.91	2.80	2.45	3.04
Justicia americana	37.5	2.65	1.01	2.23	3.93	2.73	0.80	2.64	2.10	2.96
Orontium aquaticum	49.6	3.17	1.02	2.32	4.30	2.64	0.84	2.80	2.26	2.55
Nymphaea odorata	40.0	2.83	1.07	1.97	3.82	2.73	0.71	2.24	1.91	2.62
Alternanthera philoxeroides	31.4	1.12	0.63	0.94	1.72	1.61	0.20	Tr[b]	0.96	1.37
Sagittaria *latifolia*	42.8	2.14	1.14	1.46	1.87	1.52	0.56	Tr	1.57	1.80

Tryptophan analysis not obtained.
[b] Trace.

TABLE IV

AMOUNT OF PULP DRY MATTER (D.M.) RETAINED AS FIBER AFTER EXTRACTION AND NUTRITIONAL ANALYSES OF FIBER

Species	% Pulp retained as fiber	Dry weight basis (%)			
		D.M.	Crude protein	Crude fat	Cellulose
Justicia americana	51.0	30.7	11.5	2.44	39.7
Orontium aquaticum	49.9	21.4	22.3	4.98	40.6
Nymphaea odorata	53.5	20.9	14.7	2.03	29.3
Sagittaria *latifolia*	49.9	25.8	18.0	3.48	39.5
A*lternanthera* philoxeroides	51.7	20.2	8.2	1.20	29.0

carbohydrate (6). The juice would probably be an excellent substrate in which to grow microorganisms that could be recovered and used as animal food.

Dried Plants

Chemical analyses of dried aquatic plants from lush green stands are presented in Table V. Species are separated into three groups: (a) vascular plants that grow completely submersed in water, (b) vascular plants that have emergent leaves or leaf bearing shoots but otherwise submersed, and (c) non-plankton algae. The mean composition of all samples in each group are compared with each other and with mean values computed from 18 species of high quality roughages (17) in Fig. 1.

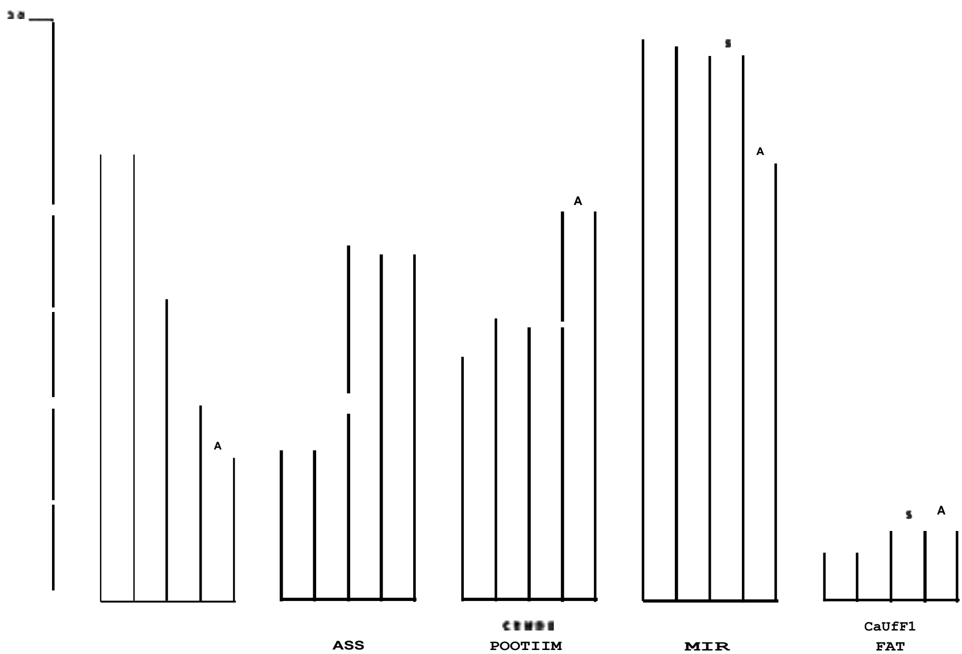

Fig. 1. Mean levels of dry matter, ash, crude protein, fiber, and crude fat for 18 roughage crops (R), 12 submersed aquatic weeds (S), 19 emergent aquatic weeds (E), and 8 algae (A). Roughage data were obtained from Morrison (17) and included the following crops: alfalfa, bermuda-grass, Ladino clover, redclover, corn fodder, cowpea, Johnson grass, Fescue, Lespedeza, Millet, Oat, Orchard grass, peanut hay, ryegrass, soybean hay, sudangrass, timothy, and vetch.

TABLE V

DRY MATTER (D.M.) AND PROXIMATE NUTRITIONAL ANALYSES OF AQUATIC PLANTS

Species	n[1]	D.M. (%)	Ash (%)	Crude protein (%)	Crude fat (%)	Cellulose (%)	Tannin (%)	Caloric content (Kcal/g)
			Dry weight basis					
Submersed vascular plants								
Myriophyllum brasiliense	4	13.7	11.2	14.1	3.78	20.6	11.9	3.69
M. spicatum	2	12.8	40.6	9.8	1.81	18.8	3.2	2.47
M. heterophyllum	1	10.0	15.5	8.5	2.67	32.7	3.2	3.35
Potamogeton diversifolius	1	9.8	22.7	17.3	2.87	30.9	[illegible]	3.40
P. crispus	2	11.8	16.0	10.9	2.85	37.2	7.2	3.61
P. nodosus	1	15.8	10.9	11.2	3.62	21.7	3.4	3.77
Elodea densa	3	9.8	22.1	20.5	3.27	29.2	0.8	3.35
Ceratophyllum demersum	2	5.2	20.6	21.7	5.97	27.9	1.9	3.71
Najas guadalupensis	1	7.3	18.7	22.8	3.75	35.6	1.4	3.55
Hydrotrida caroliniana	2	6.4	22.7	9.7	3.85	29.5	2.5	3.32
Cabomba caroliniana	1	7.0	9.6	13.1	5.42	26.8	15.6	3.78
Eleocharis acicularis	3	11.1	9.9	12.5	3.59	27.9	2.0	3.91
Emergent vascular plants								
Polygonum hydropiperoides	4	19.2	7.8	11.9	2.39	26.9	6.8	4.06
P. sagittatum	1	15.0	8.0	11.0	2.99	31.2	5.9	4.01
P. pensylvanicum	1	23.9	7.4	10.3	2.77	23.1	6.8	3.90
Jussiaea peruviana	2	18.5	7.8	9.4	7.10	27.5	15.0	3.89
J. diffusa	1	13.1	11.1	10.7	3.76	24.2	12.6	3.68
J. decurrens	4	11.8	11.7	19.1	3.93	29.5	4.1	3.88
Justicia americana	6	15.0	17.4	22.9	3.40	25.9	1.8	3.98
Orontium aquaticum	5	13.2	14.1	19.8	7.85	23.9	3.3	3.74
Sparganium americanum	1	10.9	11.4	23.7	8.11	20.5	3.7	4.17
Alternanthera philoxeroides	6	14.5	13.9	15.6	2.68	21.3	1.2	3.46
Sagittaria latifolia	6	15.0	10.3	17.1	6.71	27.6	2.5	4.12
Typha latifolia	3	22.9	6.9	10.3	3.91	33.2	2.1	3.69
Brasenia schreberi	4	10.4	8.8	12.5	4.71	23.7	11.8	3.79
Nymphoides aquaticum	3	10.3	7.6	9.3	3.29	37.4	2.9	3.95
Nymphaea odorata	5	13.7	9.2	16.6	5.38	20.7	15.0	3.95
Hydrolea quadrivalvis	1	11.0	9.3	11.1	3.85	22.8	2.9	4.00
Nuphar advena	3	12.0	6.5	20.6	6.25	23.9	6.5	4.30
Saururus cernuus	3	21.9	11.3	12.1	6.85	25.3	7.0	4.28
Hydrochloa carolinensis	3	19.4	6.1	10.4	2.78	22.0	0.8	4.10
Nelumbo lutea	2	16.8	10.3	13.7	5.25	23.6	9.2	3.74
Algae								
Spirogyra sp.	10	4.8	11.7	17.1	1.76	10.0	—	—
Pithophora sp.	17	14.9	27.4	16.7	6.04	17.6	0.5	2.89
Chara sp.	18	8.4	35.8	17.5	1.63	23.8	0.4	2.58
Rhizoclonium sp.	5		19.8	21.5	4.66	19.2		—
Hydrodictyon reticulatum	5	3.9	11.9	22.8	7.08	18.1	0.8	3.94
Oedogonium sp.	3	—	12.7	16.5	2.39	29.4		—
Nitella sp.	5	4.1	17.9	16.9	2.47	40.9	0.2	3.30
Lyngbya sp.	3		17.2	31.3	—	[illegible]	—	—

[1] Number of samples.

Dry matter values varied considerably within all three groups. Ranges were as follows: submersed plants, 5.2 to 15.8%; emergent plants, 10.3 to 23.9%; and algae, 3.9 to 14.9%. Emergent plants generally contain more dry matter than submersed plants and algae. Roughage crops have a much higher mean dry matter content than water weeds.

Ash values were generally higher in algae and submersed plants than in emergent vegetation. Elevated values for *Myriophyllum spicatum*, *Pithophora* sp., and *Chara* sp. were due to encrustations of calcium carbonate on external surfaces. Ash levels above 50% have been reported for *Pithophora* and *Chara* (4). Marl encrusted plants would be of limited food value except as a calcium supplement because of the percentage decrease in organic constituents. On the average submersed plants and algae contained about twice as much mineral matter as roughages, whereas emergent plants and roughages were of similar ash content.

The quantitative distribution of the elemental constituents in aquatic plant ash differed from that of the usual terrestrial vegetation (3). Because of marl deposition on external surfaces, samples of submersed weeds and algae contained comparatively large quantities of calcium. Levels of other macronutrients were similar in magnitude to land plants. Micronutrient values (particularly iron and manganese) in aquatic plants generally exceeded levels found in the terrestrial flora (3, 4, 15).

Crude protein content of the plants ranged from 8.5% for *Myriophyllum heterophyllum* to 31.3% for the cyanophycean alga, *Lyngbya* sp. Of 40 species analyzed, 9 contained more than 20% crude protein, and 20 had levels above 15%. The range and distribution of protein values were roughly equal for submersed and emergent plants. Comparatively, algae were superior to vascular plants in protein content. All mean algal values were above 16.7%. Additional data on crude protein concentrations in aquatic plants were obtained from the literature (Table VI). These values agreed well with data from the present study and added emphasis to the thesis that aquatic plants were rich in crude protein. The average content of crude protein in high quality roughages was slightly lower than that of vascular plants. Algae were considerably higher in crude protein than were roughages.

Since forage species decrease in protein content with age, crude protein measurements were made on samples of *Justicia americana*, *Alternanthera philoxeroides*, and *Pithophora* sp. taken from the same stand of each species at monthly intervals (Fig. 2). Protein declined rapidly with age in all three plants. Dry matter yields for the *J. americana* stand increased until August (Table I); however, because of the decrease in crude protein levels, the amount of harvestable crude protein remained relatively stable from May until August. Monthly means were 1,142, 1,198, 1,265, 1,150 kg crude protein/ha, respectively. Since protein digestibility usually declines as plants mature, optimum harvest time would probably be May or June. Similar studies would be needed for any species considered as a food plant.

Crude fat varied greatly with species. Most submersed plants and algae contained less than 4% fat, whereas nine (almost one-

TABLE VI
CRUDE PROTEIN CONTENT OF SOME VASCULAR AQUATIC PLANTS

Species	n[1]	Crude protein (%)
Elodea canadensis	3	26.8
Myriophyllum spicatum	3	25.8
Vallisneria spiralis[2]	3	15.2
Ceratophyllum demersum[3]	3	16.6
Najas flexilis	5	13.6
Potamogeton spp.[3]	5	13.4
Heteranthera dubia[3]	1	13.3
Nymphaea advena[3]	1	17.0
Typha latifolia[4]	5	12.9
Nelumbo lutea[4]	2	13.1
Lemna minor[5]	1	15.9
Salvinia rotundifolia[5]	1	25.3
Alternanthera philoxeroides[5]	14	19.0
Justicia americana[5]	5	24.7

[1] Number of samples.
[2] Nelson and Palmer (19).
[3] Gortner (12).
[4] Harper and Daniel (13).
[5] Denton, J. B. 1966. Relationships between the chemical composition of aquatic plants and water quality. M.S. Thesis, Auburn Univ., Auburn, Ala.

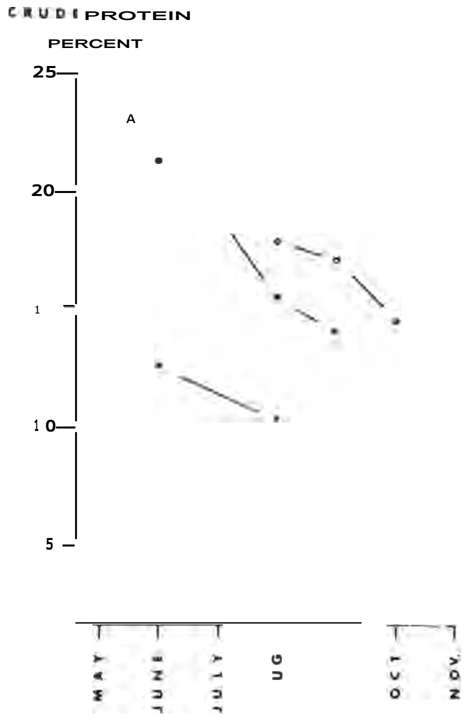

Fig. 2. Effect of age on the crude protein content of *Justicia americana* (A), *Pithophora* sp. (B), and *Alternanthera philoxeroides* (C).

half) of the emergent weeds had values above 4%. Other workers have reported several species of submersed plants to contain 0.78 to 4.28% crude fat (12, 19). Aquatic weeds appeared to contain slightly more fat than forage plants.

Vascular plants generally contained 20 to 30% cellulose, but a few species were almost 40% cellulose. Algae varied from 10.0 to 40.9% cellulose. These fiber values are slightly less than those for roughages.

Recent findings at Auburn University (E. D. Donnelly, personal communications) revealed that high concentrations of tannin interferes with protein digestibility. Plants containing more than 6 or 7% tannin (dry wt.) would be so low in digestibility as to be of little food value. Most high quality forages contain less than 2 to 3% tannin when harvested before maturity. Tannin concentrations tend to increase with age. Algae contained very small amounts of tannin, but 11 species of vascular plants contained more than 6%. Fortunately, most plants containing high levels of tannin were not particularly high in crude protein. Except for *Nymphaea odorata* and *Nuphar advena* which contained 15.00 and 6.47% tannin, respectively, all species having crude protein levels above 15% had less than 5% tannin.

Caloric values ranged from 2.58 to 4.30 Kcal/g, but most plants had levels above 3.25 Kcal/g. The caloric content decreased sharply with increasing ash levels (Fig. 3). When the caloric values were recalculated on an ash-free dry wt. basis, energy levels in the organic portion of the samples were not related to mineral accumulations. Ash-free caloric data fell within a fairly narrow range. Most values were grouped closely around 4.30 Kcal/g.

As previously indicated, data in Table V are from plants in lush green condition. Crude protein values decline as plants mature (Fig. 2), and it is expected that fiber and tannin levels will increase with age. The basic fertility of the water probably influences the nutritive quality of a particular species as much as age. All samples for the present study were collected from relatively fertile sites. It is hoped that the reported values are representative of the particular species, but fairly wide variation in most of the chemical parameters would be expected. The results indicate plants suitable for mole intensive pilot studies.

Discussion

Based on chemical analyses, several species of aquatic plants could probably be used as high protein content roughages. Dried plants also contain large quantities of trace minerals and could possibly be used as mineral supplements. Large amounts of leaf protein were readily extractable from a few species. This product might be useful as a protein supplement in human or non-ruminant animal diets. However, actual biological values for dried plants and leaf protein must be determined in feeding trials.

For a species of natural vegetation to be useful as food, large stands containing sufficient quantities of material to justify harvest must be present. Stands should also be monospecific so that the quality of the product is somewhat predictable. Many aquatic weeds fulfill these conditions. Stands of species such as *Alternanthera philoxeroidet,*

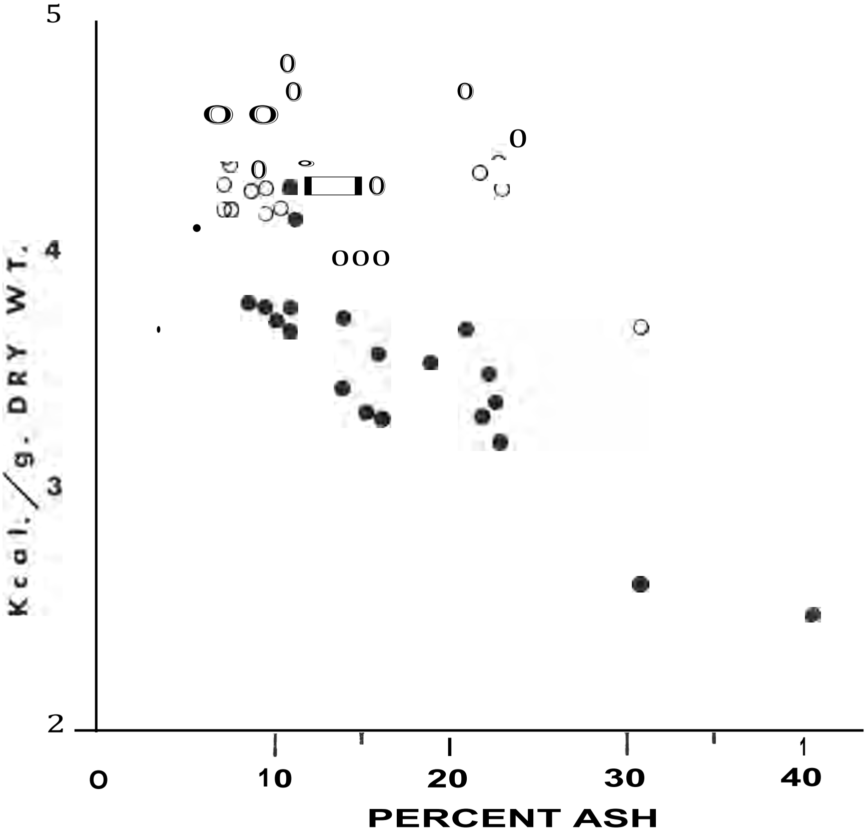

Fig. 3. Relation between ash content and caloric content on a dry weight basis (solid circles) and on an ash-free dry weight basis (open circles).

Justicia americana, Nuphar advena, Typha latifolia, and *Najas guadalupensis* often cover hundreds of hectares. Some information on standing crops is presented in Table 1. The large body of literature on standing crop and productivity of hydrophytes has been reviewed (3, 20, 24). Standing crop values for submersed plants and algae usually ranged from 1000 to 4000 kg dry wt./ha, while emergent plants equaled or exceeded that of many crop plants.

Aquatic plants contain large amounts of moisture (Table V) and would have to be at least partially dried prior to use as a roughage. The cost of removing large quantities of water by mechanical means would be prohibitive, but methods of air drying could be developed. For protein extraction, the high moisture content is desirable since extraction is generally facilitated by the addition of water.

Machines for harvesting aquatic plants as a control method have been developed (14); however, the operation and initial purchase of such machinery is costly. Manual labor is inexpensive in many tropical countries and hand harvesting would probably be economical.

Utilization of water weeds as food could probably alleviate protein shortages in local populaces of many developing nations, but it is doubtful that these plants could contribute greatly to the total food supply of any nation. Some plants included in this study have a cosmopolitan distribution, but suitable species will vary regionally. Exploratory research to assess the food value of the native aquatic flora should be initiated in nations that presently have severe protein shortages.

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