CMFRI
bulletin 41

DECEMBER 1987

SEAWEED RESEARCH AND UTILIZATION IN INDIA

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CHEMICAL COMPOSITION OF SEAWEEDS

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Considerable work has been done on the chemical aspects of Indian seaweeds during the last three decades, of which those up to 1970 have been reviewed by Umamaheswara Rao (1970). In this chapter the information so far collected on the mineral constituents, carbohydrates and other chemicals is presented.

Mineral Constituents

As seaweeds are utilized as food and fertilizer, many studies have been made on their chemical composition, such as by Chidambaram and Unny (1947 and 1953) and Joseph et al (1948). Chidambaram and Unny (1953) have analysed *Sargassum, Turbinaria* and *Gracilaria* collected from Madras for estimating the gross contents such as moisture, soluble and insoluble materials and protein. The compositions as given by them are as follows:

	Sargassum	*Turbinaria*	*Gracilaria*
Moisture (in air-dried material)	11.7%	6.13%	10.71%
Loss on ignition	61.63%	63.07%	71.59%
Insolubles	0.17%	0.50%	2.41%
Solubles	26.4%	30.30%	15.29%
Nitrogen	1.02%	0.96%	1.48%

In the Central Marine Fisheries Research Institute, studies were carried out on the chemical composition of the marine algae growing in the vicinity of Mandapam (Pillai 1955 a, 1956 and 1957 a, b). Detailed information was gathered on the water-soluble minerals, trace elements (Pillai 1956), different forms of sulphur and nitrogen and aminoacids (Pillai 1957 a, 1957 b) occurring in elevan green, brown and red seaweeds, namely *Chaetomorpha linum, Enteromorpha intestinalis, Gracilaria lichenoides (= G. edulis), Chondria dasyphylla, Acanthophora spicifera, Laurencia papillosa, Hypnea musciformis, Sarconema furcellatum, S. filiforme, Rosenvingea intricata* and *Padina tetrastromatica*. Sitakara Rao and Tipnis (1967) analysed ten species of marine algae of the Gujarat coast Recently Zingde et al (1976) studied the distribution of a few trace elements such as arsenic, copper, zinc and manganese in marine flora and fauna of Goa. Parekh et al (1977) studied the chemical composition of 27 species of green seaweeds of Saurashtra coast. Significant variations in chemical composition were observed among the different genera of seaweeds. The same species collected from different localities at different periods also showed considerable variations. The biochemical contents of *Ulva lactuca, Sargassum swartzii* and *Gelidiella acerosa* from Port Okha were studied in relation to eclogical factors by Murthy and Radia (1978), and presented the month-wise protein, fat carbohydrate, crude-fibre, sodium, potassium, calcium and phosphorus contents of these species. Dhargalkaar (1979), estimating the major metabolites such as proteins, carbohydrates and lipids, found carbohydrate decreasing in *Ulva reticulata* in December, probably due to the spore formation and extensive growth of thallus. Protein values also followed the same trend while lipid did not show any significant seasonal variation. But C:N ratio and protein values showed inverse relationship. Seventeen species of marine algae collected from five localities of Goa were analysed by Agadi et al (1978) for Co, Cu, Fe, Mn, Ni, Pb and Zn. All the seven metals showed considerable variations in their concentration. Seasonal variations in biochemical composition of some seaweeds from Goa coast was followed by Sumitra Vijayaraghavan et al (1980). She found that the carbohydrate contents in *Chaetomorpha media, Dictyota dichotoma, Ulva fasciata, Padina tetrastromatica, Hypnea musciformis* and *Gracilaria corticota* were almost similar, whereas caloric content, organic carbon and lipids were high in *Hypnea musciformis* and protein was rich in *Padina tetrastromatica Chaetomnrpha media* and *Ulva fasciata*. The biochemical constituents in these species in general did not show marked seasonal variations owing to the like reproductive pattern of the algae. Dhargalkar et al (1980) estimated protein. carbohydrate and organic carbon in 43 marine algal species from different stations along the Maharashtra coast. These species showed variation in their biochemical contents. Protein varied from 10% to 33%. Compared to brown algae, the green and red algae were rich in protein and carbohydrate. Chlorophyceae had the maximum organic carbon, average value being 33%. C:N ratio varied from 5.2 to 29.8 and showed inverse relationship with protein.

Solimabi et al (1980) studied the seasonal changes in biochemical constituents namely carbohydrate, protein ond sulphate of *Hypnea musciformis* from Goa coast. Carbohydrate varied from 31% to 50% with maximum values in October, November and May and minimum in January and February. Protein ranged from 9.92% to 17% and showed a gradual increase from October to May. The sulphate content varied from 12.48% to 20.8% with the peak value in January.

Neela (1956) estimated the protein, fat calcium, phosphorus, iron, iodine and vitamin-C contents in *Gracilaria* sp., *G. lichenoides, Hypnea* sp. and *Ulva lactuca*. The chemical composistion of *Porphyra* growing on Visakhapatnam coast has been worked out by Tewari et. al (1968), comparing with that of Japanese species. Results obtained on the major constituents and trace elements of algae studied by these workers are shown in Tables 2 and 3. Pillai (1956) and Sitakara Rao and Tipnis (1967) estimated the water-soluble constituents from dry algae and Kappanna and Visweswara Rao (1963) from the ash of the algae.

Seaweeds like *Sargassum* and *Turbinaria* composted with fishoffal and shark-liver oil sediments in the ratio 15: 3: 4 by weight for a period of three months (Chidambaram and Unny 1947) showed that they contained 2.4% nitrogen, 3.5% potash and 0.7% phosphate. The nitrifiability of the organic nitrogen from *Ulva lactuca* and drift weeds collected from Veraval were studied by Mehta et al, (1967). Pillai (1955 b) carried out some interesting experiments to study the influence of water soluble extracts of seaweeds on the growth of blue-green algae. In these investigations considerable increase in growth was noticed when extracts of *Gracilaria lichenoides, Chondria dasyphylla* and *Hypnea musciformis* were added to the blue-green algal cultures.

Other chemical studies on Indian seaweeds are those of Langalia et al (1967) on the alkali contents of marine algae and Sitakara Rao and Tipnis (1967) and Dhandhukia and Seshadri (1969) on the arsenic content of seeweeds. Higher concentrations of arsenic, ranging from 14-68 ppm, were reported from brown algae whereas less than 1-2 ppm were observed in green and red algae (Dhandhuria and Seshadri 1969). Information regarding the naturally occurring radioactive substances in species of *Enteromorpha, Caculerpa* and *Gracilaria* was given by Unni (1967).

Quantitative Changes in Mineral Constituents

Marked changes in the chemical constituents were found to occur with change of seasons, environmental conditions as well as in the various phases of the plant's growth and fruiting cycle. Pillai (1956; 1957 a, b) studied the seasonal variations in the major and minor constituents of 11 green, brown and red algae. The maximum values obtained in different months as well as the seasonal range in the quantities of some of the major constituents are given in Table 4. Quantitative changes in the inorganic constituents were noticed in different growth stages of plant by Pillai (1956; 1957 a,

Table 2

Water soluble minerals in Indian seaweeds (g / 100 g of dry weed)

Plant	Sodium	Potassium	Calcium	Magnesium	Chloride	Nitrogen	Sulphate	Author
GREEN ALGAE								
1. *Enteromorpha intestinalis*	1.16	0.71	0.51	0.41	2.40	0.38	4.00	Pillai, 1956
2. *Ulva lactuca*	1.71	1.58	0.63	1.64	0.79	—	12.10	Sitakara Rao and Tipnis, 1967
3. *U. rigida*	1.11	0.68	0.34	0.98	0.27	—	7.74	-do-
4. *Cladophora monumentalis*	0.57	3.59	0.52	0.07	2.90	—	2.41	-do-
5. *Boodlea composita*	4.82	4.09	0.41	0.12	5.19	—	4.43	-do-
6. *Codium dwarkense*	10.74	2.35	1.19	0.18	15.63	—	5.99	-do-
BROWN ALAGE								
7. *Padina australis*	1.28	0.93	0.50	0.50	2.40	0.60	1.80	Pillai, 1956
8. *P. gymnospora*	1.40	1.06	0.16	0.02	0.87	—	1.39	Sitakara Rao and Tipnis, 1967
9. *Colpomenia sinuosa*	0.56	8.85	0.12	0.04	0.53	—	1.33	-do-
10. *Cystophyllum spp*	1.20	1.25	0.02	0.02	0.84	—	2.54	-do-
11. *Sargassum cinereum v. berberifolia*	1.67	7.35	0.02	0.08	7.20	—	1.50	-do-
12. *S. johnstonii*	1.47	1.67	0.02	0.01	1.39	—	1.82	-do-
RED ALGAE								
13. *Porphyra (P vietnamensis)*	5.66	1.11	0.30	0.45	3.58	—	0.11	Tewari *et. al.* 1968
14. *Gelidium micropterum (= Gelidiella acerosa)*	0.08	0.02	0.28	0.07	0.09	1.34	0.73	Kappanna and Visweswara Rao, 1963
15. *Gracilaria lichenoides*	0.23	2.01	0.40	0.16	3.84	0.70	4.50	Pillai, 1956
16. *G. lichenoides*	1.23	0.93	0.57	0.02	1.26	2.14	3.65	Kappanna and Visweswara Rao, 1963
17. *Sarconema furcellatum*	0.56	0.40	0.51	0.41	2.40	0.93	2.90	Pillai, 1956
18. *Acanthophora spicifera*	0.32	0.18	0.42	0.38	3.06	0.74	2.00	-do-
19. *Laurencia papillosa*	1.16	0.82	0.61	0.31	2.40	1.00	3.80	-do-

Table 3

Minor constituents in Indian seaweeds (mg/100g of dry weed)

Plant	Iron	Copper	Manganese	Boron	Zinc	Phosphorus	Author
GREEN ALGAE							
1. *Enteromorpha intestinalis*	14.00	0.25	13.00	0.60	4.40	—	Pillai, 1956
2. *Ulva lactuca*	0.37	0.89	8.23	15.60	0.74	277.60	Sitakara Rao and Tipnis. 1967
3. *U rigida*	257.20	4.66	38.40	10.00	1.62	286.30	do
4. *Chaetomorpha linum*	21.70	0.50	38.50	0.44	3.00	—	Pillai, 1956
5. *Cladophora monumentalis*	144.45	0.54	6.15	23.54	2.27	116.20	Sitakara Rao and Tipnis, 1967
6. *Boodlea composita*	468.55	1.05	17.62	4.50	1.86	258.35	do
7. *Codium dwarkense*	60.60	0.73	2.31	1.10	1.97	205.70	do
BROWN ALGAE							
8. *Padina australis*	50.40	1.12	45.00	1.10	4.40	—	Pillai, 1956
9. *P gymnospora*	456.10	1.96	24.75	3.21	3.46	28.63	Sitakara Rao and Tipnis, 1967
10. *Colpomenia sinuosa*	249.70	1.47	0.04	4.02	0.13	98.36	do
11. *Rosenvingea intricata*	22.40	0.50	57.50	0.74	3.20	—	Pillai, 1956
12. *Cystophyllum spp*	30.07	0.02	13.80	2.58	0.70	197.95	Sitakara Rao and Tipnis, 1967
13. *Sangassum cinereum v. berberifolia*	224.05	1.45	4.19	0.24	1.08	3.02	do
14. *S. Johnstonii*	107.40	0.61	9.07	1.64	2.14	203.60	do
RED ALGAE							
15. *Gracilaria lichenoides*	28.00	1.00	55.00	1.43	8.30	—	Pillai, 1956
16. *Sarconema filiforme*	19.60	0.65	18.70	0.73	6.40	—	do
17. *S. furcellatum*	14.00	3.00	39.00	0.94	5.80	—	do
18. *Hypnea musciformis*	28.00	0.90	19.50	0.80	8.00	—	do
19. *Chondria dasyphylla*	30.80	0.90	17.50	0.85	6.80	—	do
20. *Acanthophora spicifera*	28.00	1.20	8.50	0·43	7.00	—	do
21. *Laurencia papillosa*	37.80	0.50	24.00	0.46	5.50	—	do

Table 4

Seasonal maxima and minima in the mineral contents of eleven Indian marine algea

(From Pillai, 1956, 1957 a, b)

Mineral	Month		g/100g	
	Maximum	Minimum	Maximum	Minimum
		I. *Enteromorpha intestinalis*		
Potassium	June	December	1.35	0.65
Sodium	October	April	0.75	0.35
Magnesium	December	April	0.70	0.15
Calcium	March	October	0.85	0 25
Chloride	February	September	1.40	0.75
Nitrogen	December	August	0.38	0.10
Sulphate	April	October	4.00	1.30
		II. *Chaetomorpha linum*		
Potassium	June	December	1.55	0.60
Sodium	November	-do-	0.75	0.25
Magnesium	May	-do-	0.30	0.20
Calcium	June	October	0.35	0.20
Chloride	May	November	1.85	0.50
Nitrogen	-	-	-	-
Sulphate	June	December	4.30	1.30
		III. *Padina australis*		
Potassium	January	August	2.00	0.80
Sodium	December	July	1.45	0.65
Magnesium	March	December	0.65	0.40
Calcium	February	July	0.65	0.30
Chloride	December	August	2.25	0.95
Nitrogen	October	May	0.60	0.15
Sulphate	November	April	1.70	1.00
		IV. *Rosenvingea intricata*		
Potassium	December	April	4.40	1.75
Sodium	October	-do-	1.85	0.55
Magnesium	January	July	0.90	0.30
Calcium	February	September	0.85	0.25
Chloride	February	May	2.75	0.75
Nitrogen	-	-	-	-
Sulphate	May	October	1.10	0.40
		V. *Gracilaria lichenoides*		
Potassium	June	August	3.25	0.80
Sodium	November	-do-	0.40	0.15
Magnesium	January	April	0.70	0.25
Calcium	December	-do-	0.50	0.10
Chloride	February	August	2.55	0.75
Nitrogen	December	April	0.73	0.18
Sulphate	April	May	4.40	1.20

Mineral	Month		g/100g	
	Maximum	Minimum	Maximum	Minimum
		VI. *Sarconema filiforme*		
Potassium	June	September	2.45	0.80
Sodium	December	August	0.50	0.20
Magnesium	September	December	0.45	0.20
Calcium	May	November	1.10	0.30
Chloride	March	April	2.00	0.25
Nitrogen	-	-	-	-
Sulphate	October	December	3.40	1.30
		VII. *Sarconema furcellatum*		
Potassium	May	August	3.20	0.85
Sodium	November	January	1.40	0.25
Magnesium	April	August	0.70	0.20
Calcium	October	-do-	0.60	0.35
Chloride	November	May	2.05	0.30
Nitrogen	-do-	July	0.93	0.10
Sulphate	May	January	3.00	1.80
		VIII. *Hypnea musciformis*		
Potassium	May	December	2.65	0.80
Sodium	January	April	0.25	0.05
Magnesium	August	-do-	0.55	0.20
Calcium	February	-do-	1.00	0.35
Chloride	January	September	2.50	0.50
Nitrogen	November	March	0.93	0.13
Sulphate	September	June	3.20	2.50
		IX. *Chondria dasyphylla*		
Potassium	June	September	3.05	0.07
Sodium	November	January	0.75	0.20
Magnesium	November	April	0.55	0.30
Calcium	June	-do-	0.95	0.10
Chloride	August	-do-	2.10	0.85
Nitrogen	November	-do-	1.00	0.18
Sulphate	May	September	4.40	1.20
		X. *Acanthophora spicifera*		
Potassium	May	September	2.60	0.65
Sodium	December	April	1.35	0.20
Magnesium	-do-	-do-	0.70	0.25
Calcium	August	December	0.95	0.25
Chloride	May	October	2.05	0.85
Nitrogen	-do-	February	0.73	0.25
Sulphate	July	January	2.10	1.50
		XI. *Laurencia papillosa*		
Potassium	February	September	2.55	0.35
Sodium	December	April	1.35	8.28
Magnesium	September	October	0.70	0.35
Calcium	August	April	0.90	0.35
Chloride	Februay	-do-	0.95	0.25
Nitrogen	November	May	1.00	0.18
Sulphate	June	September	3.90	2.00

b) and in plants collected from different localities (Tables 2 and 3). Patel and Joshi (1967) determined seasonal fluctuations of carbohydrates, nitrogen and other major chemical consitutents of *Ulva lactuca* and discussed the relationship between the chemical changes in the plant and in the metabolic environment and atmospheric temperature.

Iodine

Iodine is still extracted in small quantities from brown seaweeds in Japan, Norway and France, and from red seaweeds like *Phyllophora nervosa* in Russia. As seaweeds are good source to meet dietary requirements of iodine, goitre caused by iodine deficiency is less prevalent in countries where marine algae form part of the diet. The iodine that occurs in seaweeds is in the readily available from and, as such, is superior to the mineral iodine (Thivy 1960).

Some species of seaweeds, especially red and brown varieties, have the ability to accumulate iodine and thus are a more concentrated source of it.

Laminaria, Phyllophora and *Ecklonia* are the seaweeds from which iodine is extracted in Japan, Britain and other countries.

The iodine content of the Indian *Sargassum* was studied by Joseph et al. (1948). Pillai (1956) estimated in a more elaborate way the iodine contents of eleven species of algae growing around Mandapam. The iodine contents of five genera which are relatively richer in iodine, viz *Gelidium, Myriogloea, Sargassum, Asparagopsis,* and *Udotea,* are as follows:

Gelidium	38—54 ppm
Myriogloea	100—140 ppm
Sargassum	40—160 ppm
Asparagopsis	440—550 ppm
Udotea	215 ppm

The quantity of iodine present in many green, brown and red algae of the Gujarat coast was determined by Pillai (1956), Kappanna and Sitakara Rao (1962), Sitakara Rao and Tipnis (1967) and Dave et. al (1969). Values obtained by these authors along with the localities from where the seaweeds were collected are shown in Table 5. The iodine content was observed to to be generally lower in the brown algae than in the red and green (Solimabi and Das 1977) (Table 5). But the brown algae *Myriogloea sciurus* and *Padina australis* are exceptions in that 104.5 mg and 500 mg of iodine were respectively, reported, from these. (Table 5). Maximum quantity of 566.70 mg/100 g was observed in a small red alga, *Asparagopsis.* Other algae in which high amounts of iodine (above 200 mg/100 g) were observed are *Udotea indica, Gracilaria lichenoides* and*Sarconema furcellatum.* Solimabi et al (1981) found that the iodine content in 16 species of algae (red, brown and green) of the Andaman Sea varied from 0.003% to 0.0119%.

Proteins, Peptides an Free Amino Acids

The protein contents in the marine algae were estimated by Chidambaram and Unny (1953), Neela (1956), Pillai (1957 a) and Sitakara Rao and Tipnis (1964, 1967). In the species of *Sargassum, Turbinaria* and *Gracilaria* analysed by Chidambaram and Unny (1953) the protein content was found to be less than 10%. Data collected on the protein contents of different green, brown and red algae are summarised in Table 6. It may be seen from this that protein is high in the green and red algae than in the brown algae. In *Ulva fasciata, Acanthophora muscoides* and *Centroceras clavulatum* protein was estimated to be 22-26%. Lewis and Gonzalves (1960) reported more than 28% protein in the algae collected from Bombay coast. Dave and Parekh (1975), studying 8 genera of green algae of Saurashtra coast, found significant variation in protein in same species of algae grown in different localities and at different periods. The algae which form rich sources of protein are *Ulva rigida, U. fasciata, U. stenophylla, Caulerpa scalpelliformis, Cladophora monumentalis* and species of *Bryopsis.*

Table 5

Iodine contents of Indian seaweeds

	Species	Locality	mg of iodine/ 100 g dry weed	Author
GREEN ALGAE				
1.	*Enteromorpha intestinalis*	Mandapam	58.00	Pillai, 1956
2.	*Entermorpha spp*	Porbandar	4.16	Dave *et. al.* 1969
3.	*Ulva fasciata*	Veraval	7.40	-do-
4.	*U. lactuca*	Okha	3.31	-do-
5.	*U. lactuca*	Porbandar	6.27	-do-
6.	*U. rigida*	Gopnath	4.83	Sitakara Rao and Tipnis, 1967
7.	*Chaetomorpha linum*	Mandapam	72.00	Pillai, 1956
8.	*Cladophora expansa*	Porbandar	18.06	Dave *et. al.*, 1969
9.	*C. monumentalis*	Okha	64.64	Sitakara Rao and Tipnis, 1967
10.	*Cladophora spp*	Porbandar	18.83	Dave *et. al.*, 1969
11.	*Boodlea composita*	Okha	29.77	-do-
12.	*Udotea indica*	-do-	215.30	-do-
13.	*Halimeda tuna*	-do-	31.30	-do-
14.	*Codium dwarkense*	-do-	5.31	Sitakara Rao and Tipnis, 1967
15.	*Chamaedoris auriculata*	Veraval	10.43	Dave *et. al.*, 1969
BROWN ALGAE				
16.	*Myriogloea sciurus*	Okha	104.50	Kappanna and Sitakara Rao, 1962
17.	*Stoechospermum marginatum*	Okha	5.44	Dave *et. al.*, 1969
18.	*Spatoglossum variabile*	-do-	16.44	Kappanna and Sitakara Rao, 1962
19.	*Dictyopteris australis*	-do-	23.48	Dave *et. al.*, 1969
20.	*Dictyopteris* spp	-do-	25.81	-do-
21.	*Padina australis*	Mandapam	500.00	Pillai, 1956
22.	*P. gymnospora*	Okha	7.95	Dave *et. al.*, 1969
23.	*Colpomenia sinuosa*	-do-	8.99	Sitakara Rao and Tipnis, 1967
24.	*Cystophyllum* spp	Porbandar	34.19	Dave *et. al.*, 1969
25.	*Cystophyllum* spp	Veraval	16.53	-do-
26.	*Sargassum cinereum v. berberifolia*	Sikka	33.20	Sitakara Rao and Tipnis, 1967
27.	*S. johnstonii*	Okha	39.80	Sitakara Rao and Tipnis, 1967

Species	Locality	mg of Iodine/ 100 g dry weed	Author
28. *S. swartzii*	Okha	28.18	Dave *et. al.*, 1969
29. *S. tenerrimum*	-do-	37.21	-do-
30. *S. vulgare*	Porbandar	29.29	-do-
RED ALGAE			
31. *Scinaia indica*	Okha	5.62	Kappanna and Sitakara Rao 1962
32. *Asparagopsis taxiformis*	-do-	499.30	Dave *et. al.*, 1969
33. *Asparagopsis* spp	-do-	556.70	-do-
34. *Gelidiella acerosa*	Porbandar	54.00	-do-
35. *Amphiroa anceps*	Okha	5.15	-do-
36. *Halymenia venusta*	-do-	25.00	-do-
37. *Gracilaria corticata*	Porbandar	18.41	-do-
38. *G. foliifera*	Okha	8.07	-do-
39. *G. lichenoides*	Mandapam	208.00	Pillai, 1956
40. *Sarconema filiforme*	-do-	107.00	-do-
41. *S. furcellatum*	Okha	8.63	Kappanna and Sitakara Rao, 1992
42. *S. furcellatum*	Mandapam	357.00	Pillai, 1956
43. *Solieria robusta*	Okha	15.54	Kappanna and Sitakara Rao, 1962
44. *Agardhiella tenera*	-do-	12.65	-do-
45. *Hypnea musciformis*	Mandapam	100.00	Pillai, 1956
46. *H. musciformis.*	Okha	12.74	Dave *et. al.*, 1969
47. *Centroceras clavulatum*	-do-	20.79	-do-
48. *Heterosiphonia muelleri*	-do-	10.01	Kappanna and Sitakara Rao, 1962
49. *Polysiphonia ferulacea*	-do-	39.06	-do-
50. *Polysiphonia* spp	-do-	4.78	-do-
51. *Acanthophora delilei*	-do-	5.78	-do-
52. *A. spicifera*	Mandapam	90.00	Pillai, 1956
53. *Laurencia papillosa*	-do-	137.00	-do-

Table 6

Protein contents of Indian seaweeds

Seaweed	Protein/ 100 g of seaweed	Author
GREEN ALGAE		
1. *Ulva fasciata*	25.48	Sitakara Rao and Tipnis 1964
2. *U. lactuca*	7.69	—
3. *U. rigida*	22.42	—
4. *Cladophora monumentalis*	16.28	—
5. *Boodlea composita*	10.32	—
6. *Udotea indica*	13.00	—
7. *Codium dwarkense*	7.22	—
8. *Chamaedoris auriculata*	13.67	—
BROWN ALGAE		
9. *Dictyopteris australis*	8.14	—
10. *Spatoglossum variabile*	15.66	—
11. *Padina gymnospora*	12.27	—
12. *Colpomenia sinuosa*	6.62	—
13. *Cystophyllum* spp	11.21	—
14. *Sargassum cinereum* v. *berberifolia*	9.61	—
15. *S. johnstonii*	10.90	—
16. *S. tenerrimum*	12.14	—
RED ALGAE		
17. *Porphyra* sp.	16.01	Tewari *et.al* 1968
18. *Scinaia indica*	12.51	Sitakara Rao and Tipnis, 1964
19. *Asparagopsis taxiformis*	16.19	—
20. *Gracilaria lichenoides*	7.62	Neela, 1956
21. *Hypnea* spp.	7.50	—
22. *Centroceras clavulatum*	20.12	Sitakara Rao and Tipnis, 1964
23. *Acanthophora muscoides*	21.83	—

Extensive works were carried out by Lewis and Gonazalves (1959 a-c, 1960, 1962 a-c) and Lewis (1962 a, b, 1963 a-d and 1967) on aminoacids present in free state and on portein and peptide hydrolysates in many green, brown and red seaweeds. Lewis (1967) pointed out that Indian marine algae have all the essential aminoacids needed in human diet, including methionine and triptophane, which are not available in vegetable food materials.

Extraction of protein : Parekh and Visweswara Rao (1964) devised a method to extract proteins from the green alga *Ulva rigida*. The powdered seaweed is first treated with either-water mixture (1:4 ratio) for about 3 hours and then with 1 N sodium hydroxide solution. The protein is then precipitated with 10% solution by trichloro acetic acid at pH 4-5. The precipitated protein is washed, dried and powdered. Among the different precipitating agents tried by these authors, trichloro acetic acid gave best results, giving a concentrate containing 60% of protein.

Vitamins

Different vitamins, such as Vitamin-B 12, Vitamin C, Vitamin-D and Vitamin-E, have been reported from marine algae growing in other parts of the world. In India, a few studies were made on the ascorbic acid content (Vitamin-C). The results obtained by Thivy (1960) on the algae of Mandapam are presented in Table 7. As revealed by this study, the amount of ascorbic acid present in *Sargassum myriocystum* is high and is, infact, more than that present in citrus fruit. Variation in ascorbic acid content in relation to growth and reproduction of *Ulva fasciata* was studied by Subbaramaiah (1967). Highest concentration, 2.4 mg/g, was in very young plants of about 5mm in length. With increase in length of the frond, the ascorbic acid content was found to decrease, diminishing to 0.73mg/g in plants more than 7.0 cm in length. The concentration of Vitamin-C was higher in the reproductive parts of thallus than in the vegetative parts.

Table 7

Ascorbic acid content in Indian marine algae (From Thivy, 1960)

Alga	mg/100g of fresh weed
Chaetomorpha brachygonia	5.92
Cladophora fritschii	6.04
Ulva reticulata	5.69
Ulva lactuca	6.10
Enteromorpha prolifera	0.22
Padina australis	7.86
Sargassum myriocystum	66.60
Hypnea musciformis	8.58
Gracilaria lichenoides	7.25
Acanthophora spicifera	4.00
Laurenica papillosa	5.92

Bromine

Nineteen species of seaweeds consisting of green, red and brown algae, from Goa coast were examined by Naqvi et.al (1979) for bromine content. The bromine content, on a dry-weight basis, varied between 0.024% and 0.247% in the green algae, 0.020% and 0.4% in the red algae and 0.015%- 0.055% in the brown algae (Table 8) Only two species namely *Chondria armata* and *Codium elongatum, had* relatively high bromine content, 0.4% and 0 247%, respectively. The bromine content of 16 species of algae (red, brown and green) of the Andaman Sea varied between 0.008% and 0.128%) (Solimabi et. al. 1981).

Carbohydrates

Laminarin, mannitol, fucoidin, alginic acid, agar, carrageen an and many other varieties of carbohydrates were isolated from green, brown and red algae elsewhere (Black 1954, Percival 1968). In India, on the other hand, much attention was paid only on the economically important carbohydrates, namely agar and algin. Investigations carried out on these and a few other carbohydrates are given below.

Agar and agaroid: During and after the Second World War, some a attempts were made to extract agar from Indian seaweeds (Bose et al 1943; Chakraborty 1947; Joseph and Mahadevan 1948; Karunakar et al 1948). These authors used different techniques for purification of agar gel. In the method developed by Bose et al (1943), the whole weed was leached for 18 hours before extraction and the gel was maintained at 60°C to remove the suspended impurities, Starch present in the gel was removed by treating with 0.2% acetic acid for 1 hour and then washing the gel in water. Karunakar et al (1948) employed bacterial method for purification of gel and Chakraborty (1945) used freezing technique to remove the suspended material. Mahonty (1956) found that heating under pressure at 230°F was necessary for the removal of impurities in the gel of *Gracilaria verrucosa*.

At Central Marine Fisheries Research Institute, more detailed investigations were made to extract agar-agar from different species of *Gracilaria* and from *Gelidiella acerosa* and to know physical properties of the agar obtained from them (Thivy1951, 1960). As a result, *Gelidiella acerosa* was found to be an excellent source for manufacture of high quality agar The yield, gel strength and other physical properties of agar-agar obtained from these species are summraised in Table 9.

Table 8

Bromine content of marine algae from the coast of Goa (From Naqvi et. al. 1979)

Species	Bromine % (on dry weight basis)
CHLOROPHYTA	
Cladophora sp	0.024
Chaetomorpha media	0.105
Enteromorpha sp	0.032
Caulerpa racemosa	0.130
Caulerpa sertularioides	0.027
Codium elongatum	0.247
RHODOPHYTA	
Gracilaria corticata	0.078
Hypnea musciformis	0.027
Acanthophora spicifera	0.095
Chondria armata	0.400
Chondrococcus sp	0.054
Corallina sp	0.020
Centroceras clavulatum	0.063
PHAEOPHYTA	
Sargassum tenerrimum	0.040
Dictyota dumosa	0.022
Padina tetrastromatica	0.022
Spatoglossum asperum	0.055
Dictyota bartayresii	0.015
Dictyopteris ausrtalis	0.039

Table 9

Yield and physical properties of agar obtained from Gelidiella *and* Gracilaria *species*

Agarophyte	Yield (%)	Gel strength (1.5% solution)	temp. (1.5% solution)	Melting temp. (1.5% solution)
Gelidiella acerosa	45	300 g/cm²	40°C	92°C
Gracilaria lichenoides	43	120 g/cm²	45°C	84°C
G. crassa	23	140 g/cm²	48°C	84°C
G. corticata	38	20 g/cm²	44°C	68°C
G. foliifera	12	15 g/cm²	40°C	—

Pillai (1955 C), during the course of chemical studies on marine algae carried out in Central Marine Fisheries Research Institute, observed that in *Gracilaria lichenoides* there were 60–90% of minerals and a good amount of sulphur, nitrogenous matter and carbohydrates occurring in water-soluble form and these compounds, which come as impurities while extracting agar, could be removed by pulverising, soaking and washing the weed. Based on this important observation, a cottage industry method was developed in the Institute for manufacture of pure agar from *Gracilaria lichenoides* (Pillai 1955 c and Thivy 1960), of which the details are given in the Appendix II. In this method, the impurities are removed from the seaweed before extraction and not from the gel. The leaching process will minimise the cost of production since large-scale equipments are not used for freezing the gel. The yield from the pulverised weed is also higher than that obtained by the earlier methods reported.

Another method was also described by Thivy (1960) for the extraction of agar-agar from *Gelidiella acerosa* (= *Gelidium mycropterum*), in which freezing technique is employed to retain the coldwater-soluble fraction of agar, but, without being able to remove the impurities from the weed effectively as in the case of *Gracilaria lichenoides* (= *G. edulis*).

Several methods were described subsequently for large-scale extraction of agar, with minor modifications in the process given by Thivy. Kappanna and Visweswara Rao (1963) suggested that the quality of agar could be improved by freezing and thawing. In the pilot-plant trials condcuted later, Visweswara Rao, et. al. (1965) soaked the pulverised weed overnight in fresh water before wet-grinding and extracting the agar. Details of this method is given in Appendix III. The method suggested by Srinivasan and Santhanaraja (1967) is more or less similar to the one described by Kappanna and Visweswara Rao (1963) but for the seaweed having been pulverised into fine powder before extraction. To eliminate the cost of freezing, Desai (1967) suggested 90% industrial alcohol for the flocculation of agar from filtrate.

Monthly variations in agar content in *Gracilaria lichenoides* were reported by Pillai (1955 c). Changes were noticed in the gel-like extractives (Pillai, 1957 b) obtained from the red algae *Chondria dasyphylla, Acanthophora spicifera, Laurencia papillosa, Hypnea musciformis* and *Sarconema filiforme* in close relationship with the changes in the hot-water fraction of sulphur and organic extractives of these.

Some preliminary studies were also made by Thivy (1951) and Pillai (1957) on the agaroid content of species of *Hypnea, Spyridia, Sarconema, Acanthophora, Leurenica* and *Chondria.* The available information indicates that the yield of *Sarconeme filiforme* extractive was 10% with a gel strength of 5g/cm² and a gelling temperature of 38°C for 1.5% solution.

Rama Rao (1970), studying the seasonal changes in yield and gel strength of the agar from *Hypnea musciformis* in relation to the growth cycle of the alga, found the phycocolloid content to be increasing gradually from less than 35 g/100 g dry alga to about 48 g/100 g from October to March. The gel strength of 1.5%, 2% and 2.5% solutions increased from October with maximum values in March. The maximum yield of agar and gel strength were observed during October-March, when peak vegetative activity was prevalent as was indicated by fresh and dry weights of the plant. In *Gelidiella acerosa* periodicity in the production of agar was observed by Thomas et. al. (1975). Yield and gel strength of agar showed two peak values of 50% and 367 g/cm² in May-June and 53% and 286 g/cm² in September-October. The yield and gel strength of agar attained highest levels about a month prior to the peak periods of growth. Gelling and melting temperatures of agar varied from 44.5° to 52 5° C and 81° to 84° C, respectively. Seasonal variations in gelling and melting temperatures were irregular and peak values occurred at the same time as that of yield and gel strength. As for *Gracilaria edulis*, the yield and quality of agar were determined by Thomas and Krishnamurthy (1976) in cultivated plants (from 4 harvests). Extraction was carried out for periods ranging from one to six hours. The maximum yield was obtained in four-hour extraction. Though the percentage yield of agar in all the harvests was more or less uniform, it was found that gel strength and gelling and melting temperatures were greater in the agar obtained from the second and third harvests. The extractions over 2 to 4 hours gave a product with increased gel strength and gelling and melting points. In order to determine the most suitable time for harvesting the plants, the agar was extracted from monthly samples. It is evident from the results that the best yield of agar was from plants harvested 3 months after planting. The data ragarding the details of agar obtained from plants of different age are as follows:

Age of plant	Percentage yield	Gel strength (g/cm^2) of 1 5% agar	Gelling temp (°C)	Melting temp (°C)
One month	40	31	42	73
Two months	38	36	42	75
Three months	33	119	45	82
Four months	32	85	43	80
Five months	31	85	43	78

* Duration of extraction was 2h in all the cases.

Thomas (1977) reported seasonal variation in yield and physical properties of agar-agar from *Gracilaria verrucosa*. A maximum yield of 43% with highest gel strength of 173 g/cm² was seen in July. The yield was lowest (26%) in March and gel strength lowest (95 g/cm²) in September. Gelling temperature of agar varied between 40° and 44° C and melting temperature between 80° and 83°C.

Listing the phyco-colloid contents and their properties in 6 species of red algae, viz. *Gelidiella indica, Gracilaria corticata, G. fergusonii, G. foliifera, Acanthophora spiciiera and Laurencia papillosa, Subba Rao et. al* (1977) gave the methods of phycocolloid extraction from these species. According to them, the yield and physical properties of agar-agar from *Gelidiella indica* and 3 species of *Gracilaria* are as follows:

Seaweed	Percentage yield	Physical properties of 1.5% phyco colloid		
		Gel strength (g/cm^2)	Gelling temp. (°C)	Melting temp. (°C)
Gelidiella indica	44	30	52	76
Gracilaria corticata	44	19	33	51
G. fergusonii	35	19	22	38
G. foliifera	25	31	41	68

The maximum yield obtained from *Acanthophora spicifera* was 12% and from *Laurencia papillosa* 19%.

A comparative study was made (Chennubhotla *et al* 1977 a) on the yield and physical properties of agar-agar from three different agarophytes, namely *Gelidiella acerosa*, *Gracilaria edulis*, *G. verrucosa*. The results were as follows:

	Percentage yield	Physical properties of 1.5% agar		
		Gel strength ($g\ cm^2$)	Setting temp (°C)	Melting tem (°C)
Gelidiella acerosa	40	125	46	73
Gracilaria edulis	55	63	48	65
G. verrucosa	23	41	40	55

Similar studies were conducted also on three blends, B I, B II, B III, made by compounding the aforesaid three species in the following proportions;

	B I	B II	B II
Gelidiella acerosa	45%	25%	25%
Gracilaria edulis	15%	50%	25%
G. verrucosa	40%	25%	50%

The yield was found to be highest in Blend III, but gel strength and setting and melting temperatures were low. In Blend II, the gel strength and setting and melting temperatures were maximum, and were nearer to those of the agar trom *Gelidiella acerosa*, and *G. pusillum* from Saurashtra coast yielded 24% agar with a gel strength of 169 g/cm^2, and the same species grown in culture yielded 22% agar having a gel strength of 210 g/cm^2 (Mairh and Sreenivasa Rao 1978). The yield and gel strength of agar extracted from *Gracilaria corticata* and *Pterocladia heteroplatos* (= *Gelidium beteroplatos)* collected from Visakhapatnam area (Umamaheswara Rao 1978) are given below:

Seaweed	Yield (%)	Gel strength 1.0%	(g/cm^2) 1.5% sol
Gracilaria corticata	44.64	64	134
Pterocladia heteroplatos (= *Gelidium heteroplatos)*	15.57	297	602

Oza (1978) studied the seasonal variations in the gel strength and gelling and melting temperatures of agar from *Gracilaria corticata* occurring in Veraval coast. The yield of agar varied between 14.5% and 22.5% in different months. The lowest yield was in August, September, October and May whereas the highest yield was in June-July and November-April. The low yield coincided with shedding of branches after liberation of tetraspores in August-September. The gel strength showed a minimum value of 17 g/cm^2 in July and maximum value of 27 g/cm^2 in November. During August, September and November, the gel strength remained more or less the same, varying only between 20 and 25 g/cm^2. The melting temperature of phycocolloid showed a narrow range of monthly variation, from 60° to 62°C, and gelling temperature from 40° to 42°C.

Rama Rao and Krishnamurthy (1978) reported seasonal variation in yield and gel strength of phycocolloid from *Hypnea musciformis* and *Hypnea valentiae*. The yield of phycocolloid in *Hypnea musciformis* varied between 49.9% in March and 27.2% in May. The gel strength was better (37.4 g/cm^2 to 75.0 g/cm^2) when the yield was high (48.4%) and poor (30.05-52.3 g/cm^2) when the yield was low (27.2%). The yield of phycocolloid in *Hypnea valentiae* varied between 38.95% in April and 27.2% in August in a year. A correlation between the yield and the gel strength was also noticed, the latter being high in April (86.27-151.25 g/cm^2) when the yield was high (38.95%) and low in October (30.11 to 50.19 g/cm^2) when the yield was lowest (30.10%). Thus, the maximum values of yield and gel strength of agar approximately coincided with the luxuriant growth of alga.

Chennubhotla et al (1979) studied the seasonal variations in the yield and physical properties of agar-agar from some of the commonly occurring agarophytes around Mandapam, the result obtained of which are presented below:

The monthly variations in carrageen content of *Hypnea musciformis* from Goa coast were studied by Solimabi et al (1980). The maximum yield of 51.6% was obtained in

Seaweed and Location	Max. yield of agar (%)	Month of yield	Gel strength (g/cm^2)	Gelling temp. (°C)	Melting temp. (°C)
Gelidiella acerosa					
Pudumadam	48.0	Jan.	316	36-44	62-86
Kilakarai	46.8	Nov.	320	42-49	61-83
Krusadai	50.8	Jan.	325	43-52	67-84
Gracilaria edulis					
Rameswaram	49.2	Sept.	111	41-57	46-69
Krusadai	45.0	Nov.	139	44-50	61-78
G. corticata					
Pudumadam	42.8	June.	22	40-49	49-60
G. foliifera					
Rameswaram	50.4	Sept.	55	38-51	48-70

December and minimum of 29.23% in May. The carrageen content increased from October to December and then declined. The low values of phycocolloid from February to May coincided with the decline in vegetative growth of the alga.

Kaliaperumal and Umamaheswara Rao (1981) studied the phycocolloid of *Gelidium pusillum* and *Pterocladia heteroplatos* growing in the intertidal habitats of Visakhapatnam coast. The yield and properties of agar extracted from these two gelidioid algae are given below.

Species	Yield	Gel strength (g/cm^2) 1.0% conc.	1.5% conc.	Gelling temp (°C) 1.5% conc.	Melting tem(°C) 1.5% conc.
Gelidium pusillum	50.0	175	276	38	86
Pterocladia heteroplatos	35.1	167	288	38	83

The yield of agar from *Pterocladia heteroplatos* varied from 32.2% to 37.9% without any marked seasonal pattern, except that high values were obtained between November and March. The gel strength of 1.0% and 1.5% agar solutions also varied slightly in different months with high values in the period from November to February and in August. Though there was no seasonal change in the gelling temperature, the melting temperature varied in different months between a minimum of 76°C and a maximum of 88°C, the high values being between March and June.

The sulphate content of seaweed plays a major role in determining the gel strength of agar. Marked increases in the stability and gel strength of agar were observed in the experiments conducted by Doshi and Sreenivasa Rao (1967 a, b) by exposing the seaweed samples to cobalt-60 gamma radiations. Small doses varying between 0 5X10^{18} eV./g and 3.0X10^{18} eV /g increased the gel strength (1-2.5 times) in *Gelidiella acerosa, Gelidium micropterum* and *Gracilaria millardetii* (Doshi and Sreenivasa Rao 1967 b). These changes caused by radiations have been described to be due to breaking up of the organic sulphate fraction in the agar molecule. As such, the sulphate content present in the extractives of *Gelidium* spp. *Gelidiella acerosa, Gracilaria foliifera, G. millardetii, G. corticata, Hypnea musciformis* and *Furcellaria sp.* was precipitated with barium chloride and gel strength of agar was determined (Doshi et al 1968). The increase in gel strength was found corresponding with the decrease in the sulphate content.

Rama Rao and Krishnamurthy (1968) found that the physical properties of phycocolloids were alterable by the addition of pottassium chloride. They found that there was no gel formation in 1.0% solution of extractive from *Hypnea musciformis.* But addition of 0.5% potassium chloride to the extractive resulted in a remarkable increase in gel strength. These authors therefore suggested that, for the preparation of *Hypnea* agar, potassium chloride should be added before filtering the hot extract and the gel obtained be subjected to repeated freezing and thawing. Nevertheless, Thomas and Krishnamurthy (1976) did not find such increase in gel strength on addition of 0.5% potassium chloride in the agar from *Gracilaria edulis.* Subba Rao et al (1977) obtained two fractions, the upper soluble and lower insoluble, when the extractives of *Acanthophora spicifera* and *Laurencia papillose* were treated with 0.5% potassium chloride. The effect of pH on the yield and properties of agar extracted from *Gelidium pusillum* and *Pterocladia heteroplatos* was determined, by Kaliaperumal and Umamaheswara Rao (1981). In general, there was no marked difference in yield, gel strength and gelling and melting temperatures of the phycocolloid extracted in acidic and alkaline pH ranging from 5 to 10. However, the melting-temperature values were not uniform in these algae and the gel strength was slightly more in the alkaline pH.

Alginic acid: Some studies were made on Indian alginophytes. Alginic acid content present in the brown algae of Mandapam (Valson 1955), Gujarat (Kappanna et al 1962), Goa (Solimabi and Naqvi 1975) and Andhra (Umamamaheswara Rao, 1978) coasts was determined. Data gathered on the alginic acid content of Indian brown seaweeds along with the localities from where the weeds have been collected are shown in the Table 10. Values of Valson (1955) and Kappanna et al (1962) presented in Table 10 are based on the titration method of Cameron et al (1948) and those of others, except Solimabi and Naqvi (1975), Durairaj et al (1978) and Umamaheswara Rao (1978), are on the maximum yield obtained from fully grown plants.

Table 10

Alginic acid content in Indian brown seaweeds

Seaweed	Locality	Yield of alginic acid (%)	Author
Dictyota spp	Sikka	5.50	Kappanna *et. al*, 1962
D. bartayresiana	Goa	22.94	Solimabi and Naqvi, 1975
D. dumosa	,,	13.34	,,
D. dichotoma	Andhra Pradesh	21.79	Umamaheswara Rao, 1978
Padina spp	Mandapam	10.35	Valson, 1955
P. tetrastromatica	Goa	8.48	Solimabi and Naqvi, 1975
,,	Andhra Pradesh	23.34	Umamaheswara Rao, 1978
P. gymnospora	Pudumadam (Mandapam)	24.80	Chennubhotla *et. al.*, 1977 b
Cystophyllum muricatum	Mandapam	15.63	Valson, 1955
,,	Sikka	19.74	Kappanna *et. al*, 1962
Cystoseira indica	Port Okha	15.60	Mairh, 1982
Hormophysa triquetra	Mandapam	18.22	Valson, 1955
Colpomenia sinuosa	Goa	16.65	Solimabi and Naqvi, 1975
Spatoglossum asperum	,,	17.14	,,

Table 10 contd.

Seaweed	Locality	Yield of alginic acid (%)	Author
Stoechosperum marginatum	Pudumadam	23.80	Kalimuthu *et. al.*, 1980
Sargassum cinereum v. *berberifolia*	Dwarka	29.17	Kappanna *et. al.*, 1962
S. ilicifolium	Andhra Pradesh	34.93	Umamaheswara Rao, 1978
,,	Mandapam	30.80	Chennubhotla *et. al.*, 1982
S. johnstonii	Okha	22.34	Kappanna *et. al.*, 1962
S. myriocystum	Pamban	34.60	Chennubhotla *et. al.*, 1982
,,	Pudumadam	26.07	Kalimuthu, 1980
,,	Andhra Pradesh	32.34	Umamaheswara Rao, 1978
S. tenerrimum	Dwarka	4.85	Kappanna *et. al.*, 1962
,,	Okha	10.08	,,
,,	Sikka	14.77	,,
,,	Saurashtra coast	10.39	Chauhan, 1970
,,	Goa	15.16	Solimabi and Naqvi, 1975
S. vulgare	Andhra Pradesh	25.46	Umamaheswara Rao, 1978
S. wightii	Mandapam	31.70	Umamaheswara Rao, 1969 c
Sargassum spp	Mandapam	19.22	Valson, 1955
Sargassum spp	Hare Island (Off Tuticorin)	25.00	Durairaj *et. al.*, 1978
Turbinaria conoides	Mandapam	18.08	Valson, 1955
,,	,,	35.60	Umamaheswara Rao, 1969 c
T. decurrens	,,	26.30	Kaliaperumal and Kalimuthu, 1976
T. ornata	,,	32.18	Umamaheswara Rao and Kalimuthu, 1972

Sadasivan Pillai and Varier 1952 studied the structure and properties and the optimum conditions for preparation of the alginic acid from *Sargassum tenerrimum* and *S. wightii*. Later, Pillai (1957 c) at the Central Marine Fisheries Research Institute described a simple method for the extraction of alginic acid from *Sargassum* species. Of the different bleaching agents tried in this study, potassium permanganate was found most suitable for alginic acid. Bleaching was effected by treating the precipitate of alginic acid with potassium permanganate solution in the presence of hydrochloric acid. This method is given in Appendix IV. A cottage-industry method was also reported for the extraction of calcium alginate and alginic acid by Sadasivan Pillai (1961), which is given in Appendix V. In a study conducted on brown seaweeds of Saurashtra coast, Visweswara Rao and Mody (1964) observed that the alginic acid obtained from calcium alginate was superior to the alginic acid precipitated directly from the extract of sodium alginate. Details of this method is given in Appendix VI. A method for the production of commercial grades of sodium alginate using 90% industrial alcohol to coagulate sodium alginate was reported by Desai (1967). Other workers (Shah et al 1967) also pointed out that alcohol coagulation gave alginates high viscosity. However, this method may not be economical because of the large quantities of alcohol required for separation of sodium alginate. Preparation of sodium alginate with improved viscosity from *Sargassum* spp has been reported by Durairaj et al (1978).

Some preliminary experiments, that has yielded some favourable results, were conducted by Pillai (1964) to control flavour changes, oxidation of fat, dehydration, etc, in frozen seafoods during storage, using sodium alginate as coating material. In these experiments fishes like *Sardinella gibbosa*, *Elops* sp. *Sillago* sp. and two species of prawns were coated with an alginate gelly prepared by mixing 2.5%solution of sodium alginate, sodium and phosphate salts and citric acid and were quick frozen and stored at low temperature.

Seasonal changes in the alginic acid contents and viscosity of sodium alginates of four species of *Sargassum* collected from Gujarat coast was studied by Shah et al (1967). They observed increase in degree of polymerisation with increase in growth of plants. Variations in the alginic acid contents of *Sargassum wightii* and *Turbinaria conoides* growing in Gulf of Mannar were followed by Umamaheswara Rao (1969 c) for two and a half years. In *Sargassum wightii* the alginic acid content varied from 21.3% to 31.7% and in *Turbinaria conoides* from 23.2% to 35.6%. Peak quantitites were found in these two brown algae during their maximum growth periods, from October to December or to January. Chauhan (1970) studied the variations in alginic acid content in relation to growth in two species of *Sargassum*. In *Sargassum tenerrimum* the alginic acid was found to vary from 7.1% to 10.39%, maximum in mature plants and minimum in young plants. But, Umamaheswara Rao and Kalimuthu (1972) found marked changes in the yield of alginic acid during the growth and development phases of *Turbinaria ornata*. They obtained high yield of alginic acid from both young and fully grown plants with minor variations from month to month Kaliaperumal and Kalimuthu (1976), however, observed more marked monthly changes in the alginic acid content of *Turbinaria decurrens*, in which the yield during one year from March to February varied from 16.3% to 26.3%, with low values in April and May. Chennubhotla et al (1977 b) studied the seasonal variation of alginic acid in *Padina gymnospora* for two years. The yield varied from 9.4% in September to 24.8% in following March. The alginic acid in *Stoechospermum marginatum* collected from Pudumadam varied from 14.5% to 23.8%, with maximum yield from September to December (Kalimuthu et al 1980). In *Sargassum myriocystum*, also collected from Pudumadam, the alginic acid content varied from 14.26% to 26.07%, with irregular yield during the entire period of study (Kalimuthu 1980). The alginic acid content in *Sargassum ilicifolium* collected from Mandapam ranged from 22.3% to 30.8% and that in *S. myriocystum* collected from Pamban ranged from 15.9% to 34.5%. In these two algae the yield of alginic acid was generally high during July to September, which almost coincided with the peak growth of the algae (Chennubhotla et al 1982). The alginic acid content in *Cystoseria indica* varied from 7.3% to 15.3% of dry weight (Mairh 1982), yielding highest value in September, when the aerial branches were mostly defoliated and the rhizomatous branches predominated. The next best values were found in June-July and November-December (about 10%), when the alga reached harvestable size and attained fruiting stage.

Mannitol

Mannitol, a sugar alcohol present in the cell sap of brown algae, has been reported from many brown seaweeds. Mannitol was extracted with 80% ethyl alcohol from two spicies of *Sargassum* growing at Cape Comorin by Varier and Sadasivan Pillai (1952), the details of which are given in Table 11. Highest values obtained of the mannitol contents of *Padina gymnospora* (Cheneudbhotla et. al. 1977 b), *Stoechospermum marginatum* (Kalimuthu et al 1980), *Sargassum myriocystum* (Kalimuthu 1980; Chennubhotla et al 1982), *S. ilicifolium* (Chennubhotla et al 1982), S. *wightii* and *Turbinaria conoides* (Umamaheswara Rao 1969 c), *T. ornata* (Umamaheswara Rao and Kalimuthu 1972) and *T. decurrens* (Kaliaperumal and Kalimuthu 1976) by the titration method of Cameron et al (1948) are also given in in this table. Shah and Rao (1969) determined the mannitol contents of several species of

Table 11

Mannitol content in Indian brown seaweeds

Seaweed	Locality	Mannitol (%)	Authors
Padina gymnospora	Pudumadam (Mandapam)	2.1	Chennubhotla *et. al.*, 1977 b Kalimuthu *et. al.*, 1980
Stoechospermum marginatum	,,	2.8	Kalimuthu, 1980
Sargassum myriocystum	Pudumadam	5.0	Chennubhotla *et. al.*, 1982
,,	Pamban	5.0	,,
S. ilicifolium	Mandapam	5.0	Varier and Sadasivan Pillai, 1952
S. tenerrimum	Cape Comorin	9.4	,,
S. wightii	,,	7.3	Umamaheswara Rao, 1969 c
,,	Mandapam	6.2	,,
Turbinaria conoides	,,	7.4	Umamaheswara Rao & Kalimuthu, 1972
T. ornata	,,	7.1	,,
T. decurrens	,,	8.7	Kaliaperumal and Kalimuthu, 1976

Table 12

Values of Mannitol contents in different species and date of collection (Shah and Rao 1969)

Species	Habitat	Date of collection	Mannitol(%)
Sargassum swartzii	Okha Port reef	July. 1967	4.3
S. tenerrimum	,,	Dec. 1967	4.6
,,	Mandapam Camp	Nov. 1968	2.7
Sargassum (drift)	Idinthakarai	Sept. 1965	4.1
,,	,,	Oct. 1965	3.7
,,	,,	Nov. 1955	4.0
,,	,,	Dec. 1965	4.4
,,	Pamban	Aug. 1965	2.5
,,	,,	Nov. 1965	3.4
S. wightii	Mandapam Camp	Nov. 1968	6.2
S. johnstonii	Okha Port reef	Dec. 1967	Traces
S. cinereum	Sikka	-	12.9
Turbinaria sp,	Pamban	Oct. 1965	2.6
Cystoseiraceae	Okha	Aug. 1967	Traces

brown seaweeds obtained from different localities, of which the data are given below.

The mannitol contents of 15 species of brown algae collected from various localities of Saurashtra coast such as Okha, Porbandar, Chorwad and Veraval from August 1964 to March 1966 were determined by Mehta and Parekh (1978). Variations in mannitol content were observed among different genera of the seaweeds. The same species collected from different locations and at different periods also showed considerable variation. The maximum values of mannitol content in different species with the place and month of collection for each seaweed is given in Table 13.

Table 13

Maximum values of mannitol contents in different species of algae.

Alga	Place of collection	Month of collection	Mannitol content
Dictyota bartayresiana	Okha Port	March	7.10
Dictyopteris australis	Porbandar	December	7.37
Iyengaria stellata	Okha Port	January	7.32
Levringia boergesenii	Okha Port	March	10.80
Padina tetrastromatica	Porbandar	December	5.63
Sargassum cinctum	Porbandar	December	11.53
S. swartzii	Porbandar	December	11.11
S tenerrimum	Okha Port	November	3.56
S. vulgare	Porbandar	December	11.59
Spatoglossum asperum	Okha Port	August	7.63
S. variabile	Okha Port	January	9.70
Stoechospermum marginatum	Okha Port	March	16.00
Cystophyllum sp.	Okha Port	November	5.63
Cystoseira indica	Porbandar	December	15.16
Hydroclathrus clathratus	Porbandar	December	6.50

Seasonal variation in the mannitol content was also recorded in different brown seaweeds by various workers. The amount of mannitol varied from 1.2 to 6.2% in *Sargassum wightii* and from 1·78 to 7.4% in *Turbinaria conoides* (Umamaheswara Rao 1969 c). Unlike the alginic acid, mannitol accumulated in the plants during the vegetative phase of the growth cycle and decreased to minimum during the maximum growth and fruiting periods of the algae. Monthly changes of mannitol in *Turbinaria ornata* was reported by Umamaheswara Rao and Kalimuthu (1972). From the seasonal trends followed for four years, they found high mannitol content occurring during the early stages of growth, roughly from February to May. The amount of mannitol decreased with the development of receptacles. The estimated mannitol content in *T. decurrens* varied from 1.5% to 8.7% and the monthly changes were somewhat irregular (Kaliaperumal and Kalimuthu 1976). But, in general, the mannitol content of this alga appeared to be high during peak growth cycle. The mannitol content showed a variation from 0.5% in July to 2.1% in December in *Padina* *gymnospora*, (Chennubhotla et. al 1977 b). In *Stoechospermum marginatum* the amount of mannitol varied from 1.2% to 2 7%. The mannitol content was found to be highest in October and during the months of May and June secondary peaks were noted (Kalimuthu et. al 1980). In *Sargassum myriocystum* collected from Pudumadam, the mannitol content ranged from 1.8% to 5.0% and the yield was irregular throughout the period of investigation (Kalimuthu 1980). Mannitol content ranged from 2% to 5% in *S ilicifolium* collected from Pamban. There was no relationship between the seasonal changes of the mannitol and growth in these two species studied by Chennubhotla et. al (1982).

From the studies conducted by various workers on the variations in growth, yield of agar, algin and mannitol in many agarophytes and alginophytes of different localities, it is clear that the stature of plants at the time of collection in each locality determines the yield of agar or algin and monnitol.

TWELVE

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