

Starvation Metabolism in the Cerithiids

Cerithidea (Cerithideopsilla) cingulata (Gmelin) and *Cerithium coralium* Kiener

by

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Abstract. The effect of starvation has been investigated in two tropical cerithiids, *Cerithidea (Cerithideopsilla) cingulata* (Gmelin, 1790) and *Cerithium coralium* Kiener, 1841. There was no mortality up to 28 days in *Cerithidea cingulata* and 14 days in *Cerithium coralium*; 50% mortality was recorded at 98 and 38 days in *Cerithidea cingulata* and *Cerithium coralium* respectively. Water content did not change significantly ($P > 0.05$) in either species during starvation. The body component indices of both species were found to decrease gradually with the period of starvation. Significant changes ($P < 0.05$) in the level and content of all the biochemical constituents (viz. carbohydrates, glycogen, protein, total ninhydrin positive substances [TNPS] and lipids) were observed in different body components of both the animals during starvation. Among the three tissues examined, the gonad-digestive gland complex contributed greatly to energy needs when the animals were exposed to starvation. "Carbohydrate-oriented" metabolism was noticed in both species. *Cerithidea cingulata* preferred lipids next to carbohydrates while *Cerithium coralium* utilized proteins after carbohydrates in all the body components. During starvation, oxygen consumption exhibited a decreasing tendency ($P < 0.05$) when considered per snail or per tissue weight in both species. Starvation also decreased the intercept values "a" (recalculated) in both species.

INTRODUCTION

Cerithidea (Cerithideopsilla) cingulata (Gmelin, 1790) and *Cerithium coralium* Kiener, 1841, inhabit the backwaters of Bhimilipatnam on the east coast of India ($83^{\circ}28'E$, $17^{\circ}54'N$), 35 km north of Visakhapatnam. There is an extensive, shallow backwater region adjoining the coast covering an area of 4.5 km^2 . A small river, Gousthani, and three freshwater creeks empty themselves into the backwater system. The backwater is connected to bay waters through a narrow entrance channel. The substratum of the backwater system is composed of medium-sized grains of sand (0.350–0.250 mm diameter). *Cerithidea cingulata* is found in the upper and middle reaches of the backwater system. During the hot weather season (March–June), these areas are partly dried up and stagnation occurs more frequently. *Cerithium coralium* inhabits the lower reaches of the backwaters where there is an abundant supply of algae and diatoms. The hydrographical conditions in the habitat of these two cerithiids also exhibit wide fluctuations

and, thus, they come from ecologically distinct regions (PRABHAKARA RAO, 1981). Therefore, several investigations have been carried out to understand the nature of the species' physiological adaptations by exposing them to temperature (PRABHAKARA RAO & PRASADA RAO, 1983a), salinity (PRABHAKARA RAO & PRASADA RAO, 1981, 1984a), oxygen tension (PRABHAKARA RAO & PRASADA RAO, 1983b), and atmospheric oxygen (PRABHAKARA RAO & PRASADA RAO, 1983c, d). In addition, the availability of food needed for growth and reproduction also plays a dominant role in the above system (PRABHAKARA RAO, 1981). Because these snails occur in large numbers in the field, there is a possibility of depletion of food resources. The closure of the operculum during adverse environmental conditions (PRABHAKARA RAO & PRASADA RAO, 1981) may also force these animals to starve for brief periods. Therefore, the present investigation was initiated to study the utilization of body biochemical constituents of *Cerithidea cingulata* and *Cerithium coralium* by subjecting them to starvation.

Table 1

Rates of oxygen consumption and mortality in *Cerithidea cingulata* and *Cerithium coralium* at different intervals of starvation (a: % mortality; b: oxygen consumption $\mu\text{L O}_2/\text{h} \pm \text{SD}$ and % decrease over initial value; c: weight specific oxygen consumption $\mu\text{L O}_2/\text{mg/h} \pm \text{SD}$ and % decrease over initial value; d: log "a" intercept values). $n = 10$; F -test, * $P < 0.05$.

No. of days	<i>Cerithidea cingulata</i>				<i>Cerithium coralium</i>			
	a	b	c	d	a	b	c	d
0	0	111.00 \pm 4.77	2.8460 \pm 0.1223	1.0011	0	68.00 \pm 3.54	1.9714 \pm 0.1011	0.6551
7	0	107.62 \pm 3.18 3.05	2.8320 \pm 0.0837 0.50	0.9877	0	65.56 \pm 2.12 4.99	1.9570 \pm 0.0633 0.73	0.6328
14	0	76.44 \pm 5.12* 31.14	2.1840 \pm 0.1463 23.26	0.8391	0	55.04 \pm 1.77* 20.23	1.8979 \pm 0.0610 0.11	0.5569
21	0	66.52 \pm 2.16* 40.07	2.0788 \pm 0.0675 26.96	0.7788	13	46.08 \pm 2.03* 33.22	1.8808 \pm 0.0829 0.13	0.4797
28	0	56.14 \pm 3.04* 49.42	2.0050 \pm 0.1086 29.55	0.7051	27	32.18 \pm 3.64* 53.36	1.7878 \pm 0.2022 7.80	0.3238
38	20	46.72 \pm 4.01* 57.91	1.7969 \pm 0.1542* 36.86	0.6253	50	16.28 \pm 4.07* 76.41	1.0853 \pm 0.2713* 44.95	0.0279
48	23	38.84 \pm 3.77* 65.01	1.6183 \pm 0.1571* 43.14	0.5451				
68	35	29.12 \pm 2.46* 73.77	1.3236 \pm 0.1118* 53.49	0.4200				
98	50	20.10 \pm 1.89* 81.89	1.0090 \pm 0.0945* 64.55	0.2590				

MATERIALS AND METHODS

Experimental Animals

Animals of both the species, *Cerithidea cingulata* and *Cerithium coralium*, were collected from the backwaters of Bhimilipatnam. Care was taken to select animals of approximately the same size (38 to 42 mg of dry weight of soft parts). They were brought to the laboratory and were cleaned thoroughly before using them for experimental work. Then they were equilibrated to laboratory conditions in an aquarium containing seawater (32‰) at $25 \pm 0.5^\circ\text{C}$ for 24 h.

During the first phase of the experiment, the effect of starvation was studied on the mortality rate of both the species. For this study, 100 animals of each species were placed in two different aquaria filled with Whatman-42 filtered seawater. The filtered seawater was aerated continuously and the water was changed daily. At 98 days of starvation 50% mortality was observed for *Cerithidea cingulata* and at 38 days of starvation for *Cerithium coralium*.

Sampling Technique

Changes in the biochemical constituents were studied by taking a set of 175 animals of each species in two different aquaria. Ten animals from each set were sacrificed to serve as controls (0 day). The rest of the animals were exposed to starvation stress as just described. The intervals at which successive samples of 10 each were taken for biochemical analysis were arranged depending on the mortality data of each species.

The experimental animals, after sacrificing at each interval, were dissected into body components, viz., foot, gonad-digestive gland complex (GDG complex) and viscera. The above body components were pooled separately for *Cerithidea cingulata* and *Cerithium coralium*. Because the gonad and digestive gland were found to be closely associated, they were taken together as the GDG complex. The different body components were weighed before and after drying in an oven at 90°C for 48 h to get wet and dry weights respectively. Then they were powdered and preserved in clean, dry glass vials placed in a desiccator. This dry powder was used for the estimation of total carbohydrates, glycogen, proteins, total ninhydrin positive substances (TNPS) and lipids.

Biochemical Analysis

Total carbohydrates and glycogen were estimated by the method of CARROL *et al.* (1956). LOWRY *et al.* (1951) was used for the determination of proteins. Total free amino acids were represented as total ninhydrin positive substances (TNPS) and these were estimated by using the method of MOORE & STEIN (1954). The procedure of chloroform:methanol (2:1) extraction was adopted for quantification of lipids (FOLCH *et al.*, 1957).

Biochemical Level and Content

The level of each biochemical class is presented on a milligram per gram dry weight basis. Nutrient content is calculated by multiplying the level times the body com-

Table 2

Effect of starvation on the water content and body component indices of *Cerithidea cingulata* and *Cerithium coralium*
(a: % water content; b: body component index).

No. of days	<i>Cerithidea cingulata</i>						<i>Cerithium coralium</i>					
	Foot		GDG complex		Viscera		Foot		GDG complex		Viscera	
	a	b	a	b	a	b	a	b	a	b	a	b
0	82 ± 3	0.791	75 ± 2	3.22	78 ± 2	5.61	80 ± 2	0.769	75 ± 4	3.01	77 ± 4	4.69
7	81 ± 2	0.776	74 ± 3	3.12	77 ± 1	5.47	80 ± 3	0.749	75 ± 5	2.87	76 ± 5	4.60
14	80 ± 3	0.761	71 ± 2	3.00	78 ± 2	5.34	80 ± 2	0.728	76 ± 3	2.71	77 ± 4	4.54
21	81 ± 1	0.741	71 ± 3	2.86	77 ± 3	5.22	83 ± 1	0.709	80 ± 2	2.56	81 ± 4	4.43
28	82 ± 3	0.719	70 ± 3	2.74	76 ± 2	5.09	81 ± 3	0.685	79 ± 3	2.36	80 ± 3	4.18
38	79 ± 4	0.699	70 ± 2	2.58	77 ± 2	4.94	80 ± 1	0.653	79 ± 4	2.10	82 ± 2	3.84
48	77 ± 3	0.659	69 ± 2	2.43	76 ± 1	4.76						
68	75 ± 4	0.614	68 ± 4	2.22	75 ± 3	4.55						
98	76 ± 3	0.549	66 ± 5	1.93	74 ± 2	4.20						

ponent index (the relative size of the particular body component on a weight basis for a hypothetical 100-g animal; dry weight of component/weight of the animal × 100) and expressed in grams (STICKLE, 1975).

Respiration

For each species, 10 animals of uniform size (as described earlier) were chosen and numbered serially from 1 to 10. After determining their initial oxygen consumption, they were placed in Whatman-42 filtered seawater (salinity 32‰, pH 8) for starvation. The animals of each species were maintained separately in glass troughs at a temperature of 25 ± 0.5°C with continuous aeration. Respiration of each species was studied individually at the same intervals of starvation at which biochemical samples were taken. Oxygen consumption of the animals was determined every 2 h over a period of 6 h by adopting the same method used by PRABHAKARA RAO & PRASADA RAO (1983c). Dissolved oxygen was estimated by using the Winkler method.

Statistical Evaluation

The values are given as the mean ± 1 SD. One-way analysis of variance (ANOVA) (SNEDECOR & COCHRAN, 1967) was employed to determine the significance of variation in biochemical level and content during starvation. The data were studied further by using Duncan's Multiple Range Test (SNEDECOR & COCHRAN, 1967). The same test was also used for the comparison of respiratory rates at different intervals of starvation.

RESULTS

Table 1 represents the mortality rates of *Cerithidea cingulata* and *Cerithium coralium* at different periods of starvation. In *Cerithidea cingulata*, there was no mortality up to 28 days of starvation, whereas mortality started at 21 days of starvation in *Cerithium coralium*. It is also interesting (Table 1) that the periods at which 50% mortality

occurred were different: 98 days of starvation for *Cerithidea cingulata* and 38 days for *Cerithium coralium*. The rest of the experiments were designed based on these results.

The percentage water contents of both species at different intervals of starvation are presented in Table 2. ANOVA reveals no significant difference ($P > 0.05$) in these values in all the body components of both the animals exposed to starvation. However, the percentage water content of all the tissues was found to be slightly higher in *Cerithidea cingulata* than *Cerithium coralium* (Table 2). The body component indices of both the animals are shown in Table 2. In both species there was a gradual decrease in the indices of different body components as starvation progressed and this decrease was high in the GDG complex (40% in *Cerithidea cingulata* and 30% in *Cerithium coralium*) when compared to the foot and viscera.

Biochemical Level

Figures 1–3 depict the changes in the level of biochemical constituents in the foot, GDG complex, and viscera respectively. Significant variations (ANOVA, $P < 0.05$) were found in all the biochemical constituents of different body components, and the data were further subjected to Duncan's analysis.

Foot: A significant decrease ($P < 0.05$) in total carbohydrates started from 28 days of starvation in *Cerithidea cingulata* and 21 days of starvation in *Cerithium coralium* (Figure 1). The glycogen values decreased significantly ($P < 0.05$) from 38 days of starvation in *Cerithidea cingulata* and 14 days of starvation in *Cerithium coralium*. The proteins of both the species followed the same trend as that of carbohydrates. A significant increase ($P < 0.05$) in the TNPS was observed from 14 days of starvation in *Cerithidea cingulata* and *Cerithium coralium*. The lipids started to decrease significantly ($P < 0.05$) from 48 days of starvation in *Cerithidea cingulata*. In *Cerithium coralium*, the significant ($P < 0.05$) decrease in lipids occurred from 21 days of starvation.

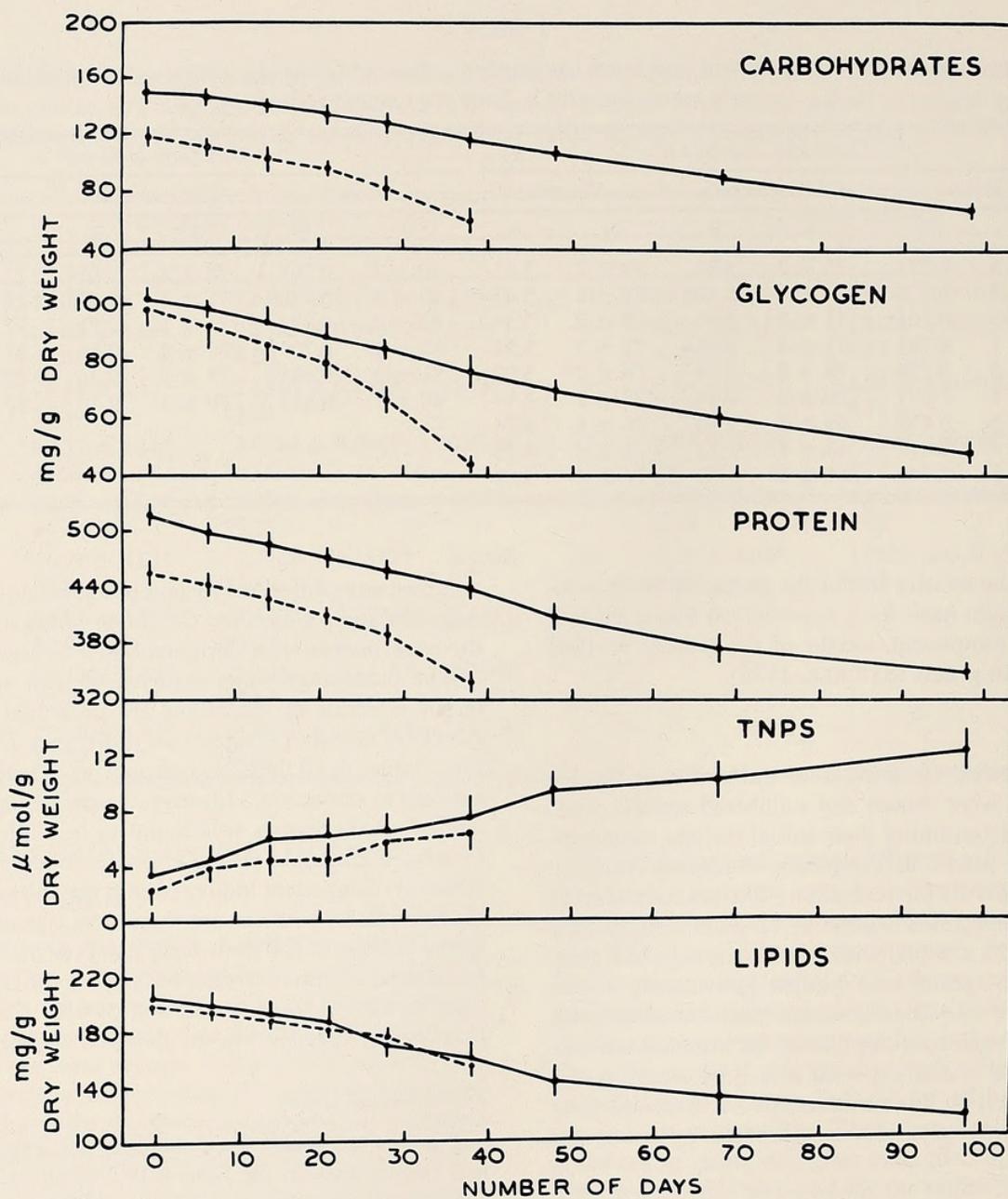


Figure 1

Changes in the levels of different biochemical constituents in the foot of *Cerithidea cingulata* (—) and *Cerithium coralium* (----). Vertical bars represent 1 SD.

GDG complex: In *Cerithidea cingulata*, the carbohydrates began to decrease significantly ($P < 0.05$) from 7 days of starvation and continued up to 98 days (Figure 2). The carbohydrates of *Cerithium coralium* exhibited a significant decrease ($P < 0.05$) from 14 days of starvation (Figure 2). The glycogen levels of both the species showed a significant fall ($P < 0.05$) from 21 days of starvation. The proteins of *Cerithidea cingulata* decrease little and the significant decrease was observed ($P < 0.05$) from 68 days and 98 days of starvation. TNPS values exhibited a significant increase ($P < 0.05$) from 14 days of starvation in *Cerithidea cingulata* and *Cerithium coralium*. The lipids of

Cerithidea cingulata started to decrease significantly from 48 days of starvation, but there was a significant decrease ($P < 0.05$) in the lipid content of *Cerithium coralium* from the 7th day onwards.

Viscera: The carbohydrates and glycogen of *Cerithidea cingulata* exhibited a significant decrease from 28 days and 48 days of starvation respectively. In contrast, a significant fall ($P < 0.05$) in the quantities of carbohydrates and glycogen was noticed from 21 days of starvation in *Cerithium coralium*. In *Cerithidea cingulata*, the protein content started to decrease significantly from 21 days of starvation

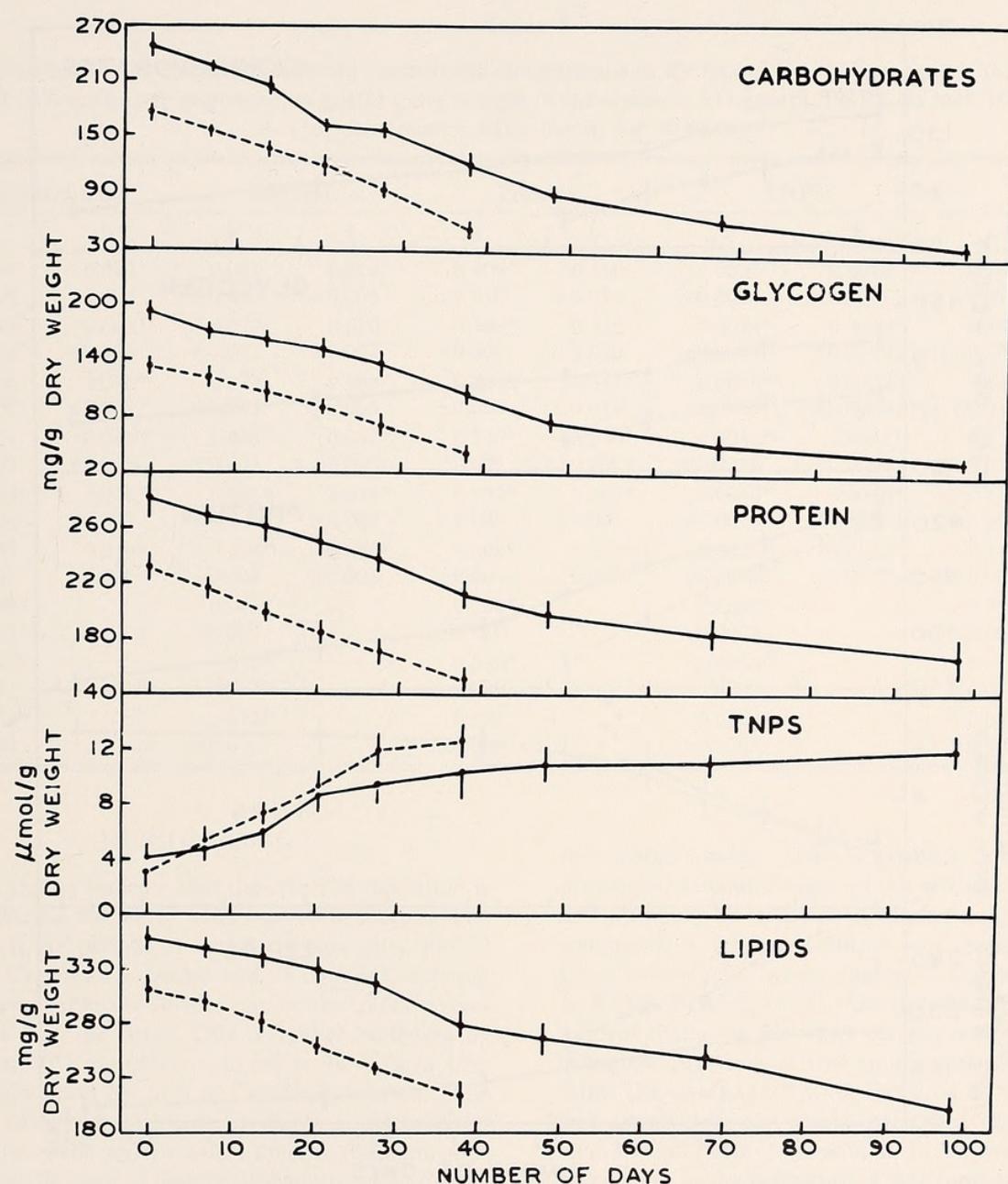


Figure 2

Changes in the levels of different biochemical constituents in the GDG complex of *Cerithidea cingulata* (—) and *Cerithium coralium* (----). Vertical bars represent 1 SD.

and TNPS quantities increased significantly from 14 days of starvation. A significant fall ($P < 0.05$) in the quantities of protein from 7 days of starvation coincided with the significant increase in TNPS values of *Cerithium coralium*. The lipid values of *Cerithidea cingulata* and *Cerithium coralium* showed a fall in their levels from 38 days and 21 days of starvation respectively.

Biochemical Content

Tables 3–5 present data on the different body biochemical contents of *Cerithidea cingulata* and *Cerithium coralium* at different periods of starvation. ANOVA showed sig-

nificant variations ($P < 0.05$) in biochemical composition during different periods of starvation. Duncan's analysis further proved (Tables 3–5) that carbohydrates, glycogen, proteins, and lipids decreased significantly ($P < 0.05$) with increasing periods of starvation in different body components of both the species. It is evident from Tables 3–5 that there are differences in the periods from where the significant decrease ($P < 0.05$) starts. There are also differences in these periods not only between levels and contents but also between the two species. However, TNPS content showed an increase in both the species with increasing starvation period (Tables 3–5).

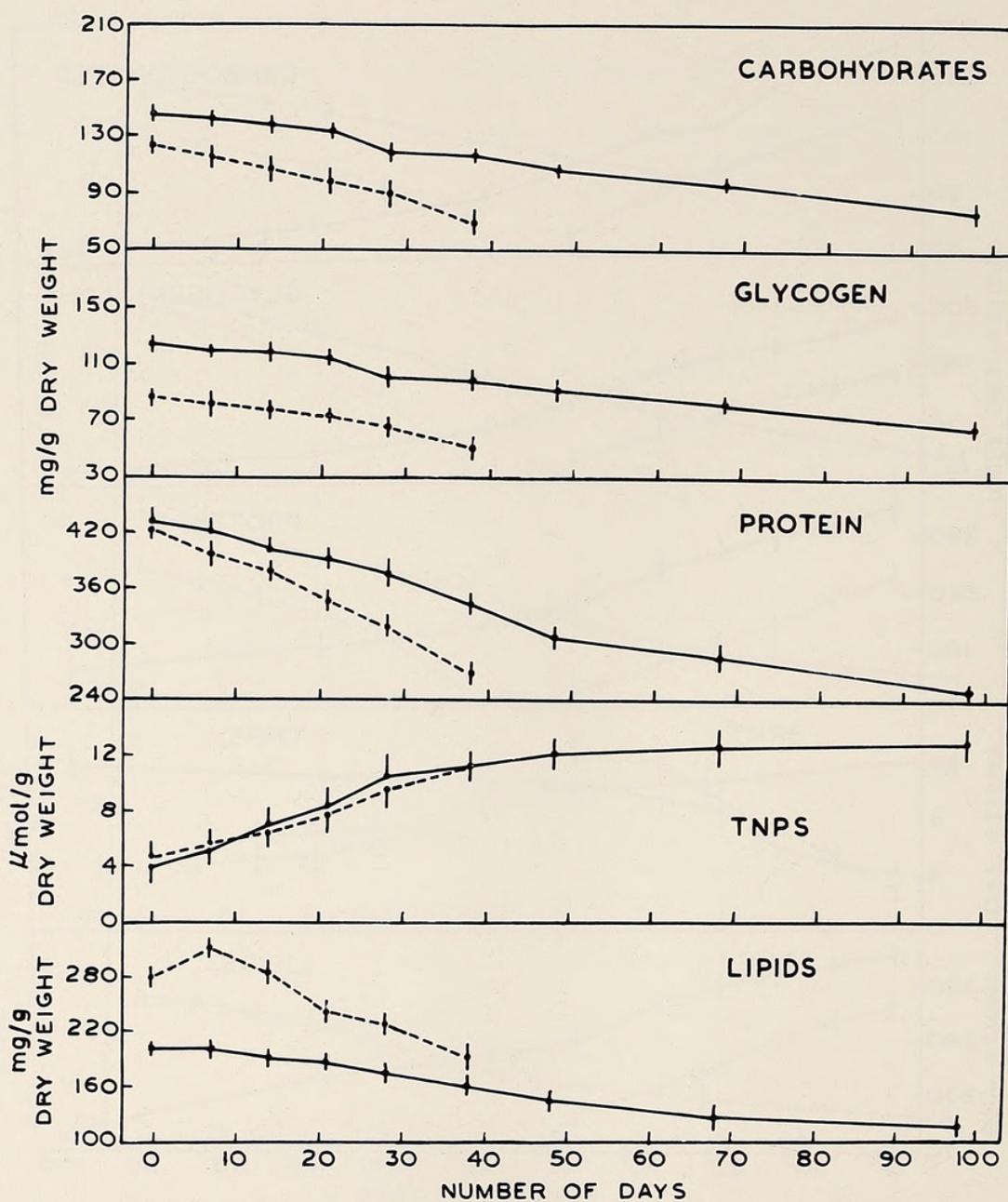


Figure 3

Changes in the levels of different biochemical constituents in the viscera of *Cerithidea cingulata* (—) and *Cerithium coralium* (---). Vertical bars represent 1 SD.

Respiration

The respiratory rates of *Cerithidea cingulata* and *Cerithium coralium* were studied at different intervals of starvation (Table 1). It is evident from the table that the percentage decreases in oxygen consumption are gradual with increases in the period of starvation in both the animals when calculated on a per animal basis. Duncan's Multiple Range Test revealed significant decreases ($P < 0.05$) in the oxygen consumption rates from day 14 of starvation in both the species (Table 1). When the oxygen

consumption values are presented on a tissue weight basis (tissue weight is deduced from the percentage decrease in dry tissue weight during starvation), the decrease, although gradual, is not as much as that of the per animal values in both the species (Table 1). The intercept values of log "a" in both the animals presented in the table are calculated using the exponential equation $Y = aW^b$, in which the regression coefficient "b" is taken from earlier investigations (PRABHAKARA RAO & PRASADA RAO, 1984b). It is clear from the table that there is a gradual decrease in the log "a" values as starvation progresses in both species.

Table 3

Effect of starvation on the content of different biochemical constituents in the foot of *Cerithidea cingulata* (a) and *Cerithium coralium* (b). All values are expressed as g/100 g dry weight of the tissue \pm SD except TNPS (m mol/100 g dry weight of the tissue \pm SD). F-test, * $P < 0.05$.

No. of days	Carbohydrates		Glycogen		Proteins		TNPS		Lipids	
	a	b	a	b	a	b	a	b	a	b
0	0.120 ± 0.005	0.092 ± 0.004	0.081 ± 0.003	0.076 ± 0.005	0.409 ± 0.010	0.350 ± 0.012	0.0027 ± 0.0008	0.0018 ± 0.0007	0.161 ± 0.010	0.154 ± 0.005
7	0.115 ± 0.004	0.085 ± 0.005	0.077 ± 0.002	0.070 ± 0.007	0.389* ± 0.009	0.332 ± 0.010	0.0034* ± 0.0009	0.0030 ± 0.0010	0.154 ± 0.009	0.147* ± 0.003
14	0.108 ± 0.003	0.076* ± 0.007	0.072 ± 0.005	0.063 ± 0.005	0.372* ± 0.008	0.311 ± 0.010	0.0046* ± 0.0009	0.0032* ± 0.0009	0.145 ± 0.011	0.138* ± 0.005
21	0.101 ± 0.005	0.068* ± 0.005	0.066 ± 0.003	0.057* ± 0.003	0.350* ± 0.009	0.290* ± 0.009	0.0046* ± 0.0010	0.0033* ± 0.0009	0.139 ± 0.010	0.130* ± 0.002
28	0.093 ± 0.004	0.056* ± 0.007	0.061* ± 0.003	0.046* ± 0.003	0.329* ± 0.009	0.267* ± 0.009	0.0046* ± 0.0010	0.0040* ± 0.0008	0.124* ± 0.008	0.120* ± 0.003
38	0.083 ± 0.003	0.039* ± 0.006	0.054* ± 0.004	0.029* ± 0.005	0.308* ± 0.009	0.221* ± 0.008	0.0052* ± 0.0009	0.0042 ± 0.0009	0.113* ± 0.009	0.101* ± 0.005
48	0.070* ± 0.005		0.046* ± 0.003		0.268* ± 0.010		0.0062* ± 0.0007			0.094* ± 0.007
68	0.057* ± 0.003		0.038* ± 0.002		0.230* ± 0.009		0.0066* ± 0.0009			0.079* ± 0.009
98	0.038* ± 0.004		0.027* ± 0.002		0.191* ± 0.006		0.0066* ± 0.0008			0.063* ± 0.007

DISCUSSION

The results clearly indicate that the effect of starvation is not much during the early stages in both species. The differences in the periods at which the mortality started (35 days in *Cerithidea cingulata* and 21 days in *Cerithium coralium*) reveal that the former can better tolerate starvation stress than the latter. This is further evidenced by the data that 50% mortality occurred at 98 days in *Cerithidea cingulata* and 38 days in *Cerithium coralium*. The reason may be their distribution: *Cerithium coralium* occurs towards wave-swept regions where there is abundant supply of food in the form of algae and diatoms while *Cerithidea cingulata* lives in the upper reaches of the estuary where there is less possibility for the growth of algae and other vegetation (PRABHAKARA RAO, 1981). *Cerithidea cingulata* may have a better inherent capacity for tolerance to starvation than *Cerithium coralium* because the body biochemical constituents were found to be higher in the former than the latter. Several other species of mollusks have been found to survive for various periods when exposed to starvation. In *Nucella lamellosa*, 90% survival was reported during 53 days of starvation (STICKLE & DUERR, 1970); *Morula granulata* exhibited 50% mortality in 70 days of starvation (UMA DEVI *et al.*, 1986); and 90% survival was observed during 50 days of starvation in *Lamellidens marginalis* (MASTANAMMA & RAMAMURTI, 1983).

There is no significant variation ($P > 0.05$) in the percentage water content of different body components in the

two species studied. This is possibly due to the higher proportion of bound water in the soft parts of the animal and this may be used for metabolic adjustments during starvation. A similar condition was reported in *Paratellphusa hydrodromus* when exposed to starvation (KOTAIAH & RAJABAINAIDU, 1973). Another reason for this insignificant change in the water content may be the presence of higher quantities of free amino acids in both the cerithiids (PRABHAKARA RAO & PRASADA RAO, 1983b); these free amino acids can retain water and prevent its escape from the soft parts of the animal. In *Morula granulata* also, no changes in the percentage water content were recorded during starvation (UMA DEVI *et al.*, 1986).

The present investigation suggests that the GDG complex serves as a storage organ in both species. The GDG complex indices in both species showed tremendous decreases when compared to the foot and viscera. Decreases in body component indices have also been reported in several other mollusks—*Nucella lamellosa* (STICKLE, 1971), *Morula granulata* (UMA DEVI *et al.*, 1986), *Thais haemastoma* (BELISLE & STICKLE, 1978), *Katharina tunicata* (GIESE & HART, 1967; HIMMELMAN, 1978), *Chiton iaticrus* (NAGABHUSHANAM & DESHPANDE, 1982) and *Cryptochiton stelleri* (LAWRENCE *et al.*, 1965)—when food reserves are utilized for energy purposes.

From Figures 1–3 and Tables 3–5, it is clear that the different biochemical constituents (viz., carbohydrates, glycogen, proteins and lipids) which form the reserve food

Table 4

Effect of starvation on the content of different biochemical constituents in the GDG complex of *Cerithidea cingulata* (a) and *Cerithium coralium* (b). All values are expressed as g/100 g dry weight of the tissue \pm SD except TNPS (m mol/100 g dry weight of the tissue \pm SD). F-test, * $P < 0.05$.

No. of days	Carbohydrates		Glycogen		Proteins		TNPS		Lipids	
	a	b	a	b	a	b	a	b	a	b
0	0.808 ± 0.045	0.533 ± 0.024	0.622 ± 0.039	0.406 ± 0.030	0.911 ± 0.052	0.698 ± 0.030	0.013 ± 0.003	0.009 ± 0.003	1.159 ± 0.032	0.930 ± 0.036
7	0.711 ± 0.019	0.456 ± 0.017	0.543 ± 0.031	0.353 ± 0.029	0.855* ± 0.037	0.626 ± 0.023	0.016* ± 0.003	0.015 ± 0.004	1.035* ± 0.034	0.358 ± 0.032
14	0.621 ± 0.036	0.371 ± 0.022	0.492 ± 0.030	0.290 ± 0.033	0.786* ± 0.045	0.545 ± 0.019	0.018* ± 0.004	0.020 ± 0.003	1.029* ± 0.030	0.764 ± 0.024
21	0.529 ± 0.029	0.312 ± 0.028	0.446* ± 0.034	0.236 ± 0.023	0.724* ± 0.037	0.476 ± 0.023	0.025* ± 0.003	0.024 ± 0.003	0.941* ± 0.034	0.666 ± 0.021
28	0.444* ± 0.033	0.229 ± 0.021	0.386* ± 0.038	0.177 ± 0.026	0.655* ± 0.030	0.406 ± 0.024	0.026* ± 0.004	0.028 ± 0.003	0.871* ± 0.027	0.569 ± 0.014
38	0.328* ± 0.036	0.118 ± 0.021	0.279* ± 0.034	0.095 ± 0.027	0.552* ± 0.031	0.319 ± 0.017	0.027* ± 0.003	0.027 ± 0.003	0.722* ± 0.034	0.454 ± 0.025
48	0.226* ± 0.032	0.185* ± 0.027	0.484* ± 0.029				0.027* ± 0.003		0.649* ± 0.034	
68	0.144* ± 0.024	0.115* ± 0.031	0.413* ± 0.024				0.024* ± 0.002		0.553* ± 0.024	
98	0.083* ± 0.019	0.075* ± 0.015	0.328* ± 0.027				0.023* ± 0.002		0.386* ± 0.023	

material are stored in different parts of the body in different proportions. When the snails are exposed to starvation, all of these stored food materials exhibit a tendency to decrease with time. During the early periods of starvation, the rate of decrease is slower when compared to the later periods in both species (Figures 1-3; Tables 3-5).

In *Cerithidea cingulata*, the greatest decrease was found for carbohydrates (89.75% for content and 82.87% for level) and glycogen (87.94% for content and 79.79% for level) of the GDG complex. The same trend was noticed in the GDG complex of *Cerithium coralium* (77.86% for content and 68.36% for level of carbohydrates; 76.70% for content and 66.67% for level of glycogen) but the changes were less. This was followed by lipids (66.69% for content and 44.44% for level) in *Cerithidea cingulata*, whereas in *Cerithium coralium* proteins were utilized (54.30% for content and 34.48% for level) next to carbohydrates. The protein utilization in *Cerithidea cingulata* was found to be less (63.99% for content and 39.93% for level) when compared to carbohydrates and lipids. In *Cerithium coralium*, lipids played a minor role (51.18% for content and 25.89% for level).

The biochemical constituents of the foot are utilized next to those of the GDG complex in both species. In the foot also, the carbohydrates (68.33% for content and 53.95% for level in *Cerithidea cingulata* and 57.61% for content and 50.83% for level in *Cerithium coralium*) played the major role as a fuel for energy needs during starvation. The same trend of utilizing lipids (60.87% for content and

44.12% for level) next to carbohydrates was noticed in *Cerithidea cingulata*. *Cerithium coralium* utilized proteins (36.86% for content and 25.71% for level) next to carbohydrates. In *Cerithidea cingulata*, proteins were least utilized (53.30% for content and 32.88% for level) whereas lipid utilization was found to be less (43.42% for content and 22.50% for level) in *Cerithium coralium*.

The viscera of both animals play almost a minor role during starvation stress. The biochemical constituents were reduced on exposure to starvation but to a lesser extent. In this tissue also, the utilization of carbohydrates (57.70% for content and 43.54% for level in *Cerithidea cingulata* and 52.41% for content and 41.94% for level in *Cerithium coralium*) and glycogen (58.90% for content and 45.16% for level in *Cerithidea cingulata* and 51.36% for content and 40.70% for level in *Cerithium coralium*) was more when compared to proteins and lipids. Lipid utilization, which followed that of carbohydrates in *Cerithidea cingulata* was 57.24% for content and 42.85% for level. In *Cerithium coralium*, protein utilization was high (48.17% for content and 36.17% for level) when compared to lipids. The biochemical constituents that were least affected in *Cerithidea cingulata* and *Cerithium coralium* were proteins (56.35% for content and 41.67% for level) and lipids (43.56% for content and 31.07% for level) respectively.

The levels and contents of different body biochemical constituents suggest that total carbohydrates constitute the major fuel during starvation in both species and that, among all the body components, the GDG complex contributes

Table 5

Effect of starvation on the content of different biochemical constituents in the viscera of *Cerithidea cingulata* (a) and *Cerithium coralium* (b). All values are expressed as g/100 g dry weight of the tissue \pm SD except TNPS (m mol/100 g dry weight of the tissue \pm SD). F-test, * $P < 0.05$.

No. of days	Carbohydrates		Glycogen		Proteins		TNPS		Lipids	
	a	b	a	b	a	b	a	b	a	b
0	0.825 ± 0.028	0.582 ± 0.038	0.696 ± 0.039	0.403 ± 0.019	2.424 ± 0.084	1.993 ± 0.056	0.023 ± 0.007	0.021 ± 0.007	1.139 ± 0.045	1.313 ± 0.052
7	0.788 ± 0.022	0.538 ± 0.032	0.662 ± 0.011	0.377 ± 0.042	2.308 ± 0.071	1.840 ± 0.064	0.030* ± 0.008	0.026 ± 0.005	1.105 ± 0.049	1.435 ± 0.060
14	0.748 ± 0.021	0.495 ± 0.036	0.636 ± 0.032	0.354 ± 0.023	2.163 ± 0.059	1.684 ± 0.050	0.036* ± 0.007	0.030 ± 0.006	1.036 ± 0.043	1.294 ± 0.059
21	0.710 ± 0.016	0.443* ± 0.044	0.606 ± 0.031	0.323* ± 0.018	2.057* ± 0.052	1.546 ± 0.053	0.043* ± 0.008	0.035 ± 0.006	0.971* ± 0.052	1.081* ± 0.058
28	0.616* ± 0.026	0.385* ± 0.038	0.519 ± 0.036	0.284* ± 0.025	1.929* ± 0.076	1.342 ± 0.054	0.055* ± 0.007	0.040 ± 0.006	0.886* ± 0.046	0.961* ± 0.042
38	0.588* ± 0.020	0.277* ± 0.042	0.494* ± 0.040	0.196* ± 0.031	1.699* ± 0.059	1.033 ± 0.042	0.055* ± 0.005	0.043 ± 0.005	0.795* ± 0.049	0.741* ± 0.054
48	0.524* ± 0.019	0.443* ± 0.038			1.471* ± 0.062		0.059* ± 0.006		0.695* ± 0.057	
68	0.455* ± 0.023	0.382* ± 0.014			1.306* ± 0.064		0.058* ± 0.007		0.582* ± 0.059	
98	0.349* ± 0.038	0.286* ± 0.029			1.058* ± 0.042		0.055* ± 0.006		0.487* ± 0.046	

more to meeting energy demands. Thus it is clear from our results on both species that the decrease in the percentage of different biochemical constituents is more when calculated on the basis of content than on the level. Lipids are preferred after carbohydrates by *Cerithidea cingulata* while *Cerithium coralium* takes proteins after carbohydrates. Finally, proteins and lipids are least utilized by *Cerithidea cingulata* and *Cerithium coralium* in all three body components. Therefore, the metabolism of both the cerithiids is "carbohydrate-oriented" when exposed to starvation. Such a condition of carbohydrate-oriented metabolism was reported in the cerithiid *Clypeomorus clypeomorus* (MANMADHA RAO, 1977), and several other mollusks were also found to show "polysaccharide-oriented" metabolism. EMERSON (1967) suggested that certain terrestrial and freshwater mollusks show carbohydrate-oriented metabolism, whereas marine mollusks exhibit "lipid-oriented" metabolism. VON BRAND *et al.* (1957) reported appreciable utilization of polysaccharides in the freshwater snail *Australorbis glabratus*. *Mytilus edulis*, an estuarine and marine bivalve (BAYNE, 1973), also exhibited reduced levels of carbohydrates when exposed to starvation. RAMAMURTI & SUBRAHMANYAM (1976) noticed carbohydrate metabolism in the terrestrial snail *Cryptozona semirugata* during starvation. *Planorbis corneus*, a freshwater snail, also showed a carbohydrate-oriented metabolism when subjected to starvation (EMERSON, 1967). In some of marine snails—*Nucella lamellosa* (STICKLE & DUERR, 1970), *Thais lapillus* (BAYNE & SCULLARD, 1978), *Littorina keenae* (EMERSON

& DUERR, 1967), and *Morula granulata* (UMA DEVI *et al.*, 1986), lipid-oriented metabolism was reported. The importance of lipids and their utilization in invertebrates was discussed by GIESE (1966). Thus, there is a preferential utilization of a particular body reserve during starvation. The estuarine cerithiids of the present investigation belong to the category of carbohydrate-oriented metabolism, and thus tend to resemble freshwater rather than marine mollusks.

Earlier investigations (PRABHAKARA RAO & PRASADA RAO, 1983b) on these cerithiids revealed utilization of glycogen when exposed to oxygen-free seawater. During reproduction, when there is an energy demand for the production of sperm and ova, the cerithiid *Clypeomorus clypeomorus* (MANMADHA RAO, 1977) also depends on a carbohydrate reserve food material. Thus, the cerithiids show carbohydrate-oriented metabolism whenever energy is needed for the body. The differences in the utilization of carbohydrates in both species depend on the quantities stored inside the body. *Cerithidea cingulata* stored greater amounts of carbohydrates compared to *Cerithium coralium*. As long as carbohydrate reserves remain, the animals are able to survive. Death occurs due to insufficient amounts of carbohydrates, even though lipids and proteins can substitute to some extent. A similar observation was recorded in *Planorbis corneus* where death occurs due to complete exhaustion of carbohydrates during starvation exceeding 58 days (EMERSON, 1967). The preference of lipid utilization next to carbohydrates in *Cerithium coralium* may be

attributed to environmental differences. The storage of body biochemical reserves were found to be higher in *Cerithidea cingulata*, which normally faces this type of stress in the upper reaches of the estuary. As food material is readily available in the habitat of *Cerithium coralium*, storage inside the body of the animal is unnecessary.

The rates of oxygen consumption in both species decreased gradually with increasing periods of starvation. The weight-specific oxygen consumption was also observed to decrease during starvation in both species, but the decrease was not so rapid when compared to the decrease in the rates of oxygen consumption (Table 1). However, similar trends of decreases in the rates of oxygen consumption have been reported in several mollusks when exposed to starvation: *Ancylus fluviatilis* (BERG et al., 1958), *Lymnaea stagnalis* (DUERR, 1965), *Littorina keenae* (EMERSON & DUERR, 1967), *Potamopyrgus jenkinsi* (LUMBYE & LUMBYE, 1965), *Nerita albicilla* and *Nerita chemaeleon* (PRASADA RAO & JAYA SREE, 1983), *Thais lapillus* (STICKLE & BAYNE, 1982) and *Morula granulata* (UMA DEVI et al., 1986). The intercept values also showed a decreasing trend with starvation period in both cerithiid species but the decrease was greater in *Cerithidea cingulata* than *Cerithium coralium*. In *M. granulata*, a similar tendency of decreasing intercept values "a" when subjected to starvation was reported (UMA DEVI et al., 1986). However, STICKLE & BAYNE (1982) did not find any change in the intercept values of *Thais lapillus* during starvation, although according to BAYNE & SCULLARD (1978), the intercept values showed a decreasing tendency in *T. lapillus*. Our results of the weight-specific oxygen consumption in both species during starvation corroborates results on *M. granulata*. However, *Nucella lamellosa* exhibited an increased or constant weight-specific oxygen consumption (STICKLE & DUERR, 1970; STICKLE, 1971). The decreased rates observed in the present investigation may be an adaptation of the animals to conserve stored food.

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