Filtration Rates of Juvenile Purple Clam, *Saxidomus purpuratus* (Sowerby) Feeding on Red Tide Dinoflagellates

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ABSTRACT

The purpose of this study is to compare the clearance rate (CR) and intake rate (IR) of juvenile purple clam, *Saxidomus purpuratus* when feeding on different unialgal diet of red tide dinoflagellates (RTDs), and to know what is the most important cell characteristic of RTDs to cause the differences in feeding parameters. Experiments were performed to measure the CR and IR of juvenile *S. purpuratus* as a function of algal concentration when food was either the standard food, *Isochrysis galbana* or one of 9 RTDs.

Patterns of CR with increasing algal concentration were similar among different RTDs. The highest C_{max} was observed when *S. purpuratus* was feeding on *A. affine*, while the lowest on *C. polykrikoides*. The patterns of IR with increasing algal concentration were also similar among different RTDs. However, there were great differences in the maximum value of IR (I_{max}) among different RTDs. The highest I_{max} was observed when *S. purpuratus* was feeding on *A. carterae*, while the lowest on *G. catenatum*.

Some RTDs similar in size showed different C_{max}. Other RTDs different in size showed similar I_{max}. Life form of each RTD affected significantly the I_{max}, which was higher for single-celled RTDs than chain-forming RTDs. There were no significant differences in feeding parameters between toxic and nontoxic RTDs. Moreover, a toxic dinoflagellate, *A. carterae* recorded the highest I_{max} among RTDs. The most important characteristic of RTD as a factor affecting the feeding rate of *S. purpuratus* was life form, not size or toxicity of RTD species.

Key Words: *Saxidomus purpuratus*, Red Tide, Dinoflagellates, Clearance rate, Intake rate

INTRODUCTION

The purple clam, *Saxidomus purpuratus* (Class Bivalvia, Family Veneridae) is a suspension-feeding bivalve and one of the most important food resources for human. Its natural distribution is restricted to the coasts of China, Japan, and Korea. It inhabits the soft bottoms with silty sand from intertidal to subtidal zones to a depth of ca. 20 m (Choe *et al.*, 1999). Recently, commercial interest in this species has increased with strong demands and high prices. The

commercial yields from the traditional exploitation by divers have been declining due to over-harvesting. Moreover, the main catch fields of this species often suffer from severe harmful algal blooms. The severity of algal blooms and the damages to coastal ecosystem are fluctuating. Most of marine harmful algal blooms (red tide) are dominated by dinoflagellates. Massive blooms of dinoflagellates have often caused large-scale mortalities of shellfishes in aquafarms (e.g. ECOHAB, 1995). Thus, there have been many studies on the effects of red tide dinoflagellates (RTDs) on shellfish populations (Widdows *et al.*, 1979; Nielsen and Strømgren, 1991; Lesser and Shumway, 1993; Luckenbach *et al.*, 1993; Matsuyama *et al.*, 1997; Li *et al.*, 2001; Lee, 2003; Lee *et al.*, 2003). However, there are little studies on the interactions between dinoflagellates and commercially important bivalve

species in Korea. Here, the purpose of this study was established to know how the feeding activities are affected when *S. purpuratus* is feeding on various species of RTDs (*Akashiwo sanguinea*, *Alexandrium affine*, *Alexandrium catenella*, *Amphidinium carterae*, *Cochlodinium polykrikoides*, *Gymnodinium catenatum*, *Lingulodinium polyedrum*, *Prorocentrum minimum*, *Scrippsiella trochoidea*). From laboratory experiments, clearance rates and intake rates of juvenile *S. purpuratus* were measured as functions of algal concentrations when clams were fed on either unialgal prey of the RTDs or a standard food (*Isochrysis galbana*). From the functional responses, feeding parameters were estimated and compared among different RTD species, and the effects of cell characteristics (size, life form, and toxicity) of RTDs on feeding parameters were discussed. The results of this study will provide the basic information on the physiological change of bivalves during outbreak of red tides.

MATERIALS AND METHODS

1. Test Organisms

The juvenile *Saxidomus purpuratus* were obtained from a cohort reared at ambient seawater temperature in the Taean Marine Hatchery, National Fisheries Research and Development Institute of Korea. Three months old juveniles of *S. purpuratus* (4-6 mm in shell length) were used in feeding experiments. Clams were acclimated to the experimental temperature for 4 weeks: they were transferred into a 10-L aquarium with 5-μm filtered seawater (salinity: 30 psu), then the aquarium was placed in an incubator (temperature: 20℃) with 12 light: 12 dark cycle of 5 μE/m^2/sec provided by cool-white fluorescent lights. During acclimation, seawater was fully renewed everyday and clams were fed 1.0×10^6 cells/mL of *Isochrysis galbana*. Mortality was checked everyday and dead individuals were immediately removed when they were found. One day before the feeding experiments, clams were rinsed twice with freshly filtered seawater and depurated for 24 hr.

The red tide dinoflagellates (RTDs, Table 1) were grown at 20℃ in enriched f/2 seawater medium (Guillard and Ryther, 1962) without silicate, with continuous illumination of 100 μE/m^2/sec provided by cool-white fluorescent lights. Only cultures in exponential growth phase were used for experiments. Mean equivalent spherical diameter (ESD) of each alga was measured by a PAMAS-SVSS particle

Table 1. Size, carbon content, toxicity, life form, and the range of test concentration of the standard food (*Isochrysis galbana*) and the red tide dinoflagellates used in feeding experiments to measure clearance rate and intake rate of juvenile *Saxidomus purpuratus*. ESD: estimated spherical diameter. NT: nontoxic, T: toxic, S: single cell, C: chain form.

| Species	ESD (μm)	Carbon (ngC/cell)	Toxicity	Form	Test concentration (cells/mL)
Isochrysis galbana	4.5	0.02	NT	S	5.1×10^4 - 2.7×10^6
Akashiwo sanguinea	36.3	2.23	NT	S	7.1×10^1 - 2.9×10^3
Alexandrium affine	24.8	0.84	NT	C	7.4×10^1 - 6.7×10^3
Alexandrium catenella	24.5	0.83	T	C	6.7×10^1 - 7.4×10^3
Amphidinium carterae	16.2	0.27	T	S	2.2×10^3 - 1.3×10^5
Cochlodinium polykrikoides	23.2	0.70	NT	C	1.4×10^2 - 2.4×10^3
Gymnodinium catenatum	34.0	1.88	T	C	2.5×10^1 - 1.2×10^3
Lingulodinium polyedrum	37.9	2.50	NT	S	1.3×10^2 - 3.9×10^3
Prorocentrum minimum	12.9	0.15	NT	S	9.0×10^2 - 5.3×10^4
Scrippsiella trochoidea	25.1	0.85	NT	S	3.7×10^2 - 1.3×10^4
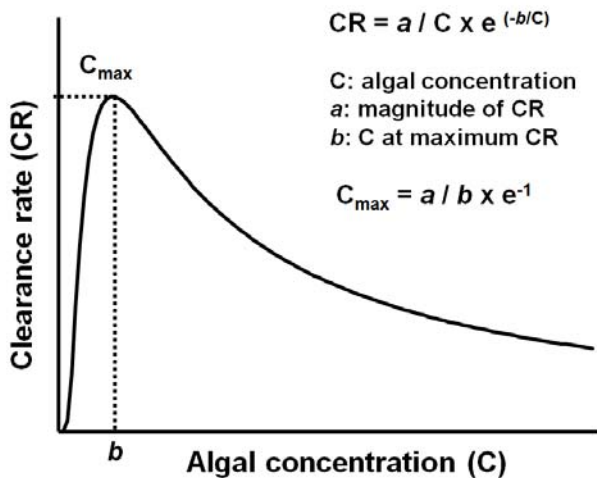
Fig. 1. The general relationship between algal concentration and clearance rate of bivalves expressed by an exponential equation (Riisgård, 1988)

counter. The number of measured cells was more than 2000. Cell volume (V) was calculated as: $V = 4/3 \pi (ESD/2)^3$. The carbon content was estimated from cell volume according to Strathmann (1967).

2. Feeding Experiments

Experiments were designed to determine the clearance rate (CR) and intake rate (IR) of *S. purpuratus* as a function of the algal concentration when clams were feeding on unialgal diet of either the standard food (*I. galbana*) or the RTD. The concentration range of each alga was determined from preliminary experiments so that the typical functional responses for both CR and IR could be obtained (Table 1). Three 100-mL polyethylene beakers for each concentration were used as experimental chambers. Algal suspensions with 6 different initial concentrations were prepared by diluting the dense cultures with filtered seawater to the target concentrations. Chambers were filled with 50 mL of algal suspensions, then, according to the concentration, 2 to 5 individuals of *S. purpuratus* were transferred into each chamber. Chambers were incubated in an undisturbed place at 20℃ under 5 μ E/m²/sec of cool white fluorescent lights for 1 to 2 hr. To determine the actual concentrations of algae at the beginning and the end of experiments, 5-mL aliquot

of algal suspension was sub-sampled from each bottle and fixed with 5% Lugol's solution, and all or more than 400 cells in triplicate 1-mL Sedgwick-Rafter chambers were counted. The algal concentration (in cells/mL) was converted to the carbon equivalent (in mgC/L) to facilitate inter-specific comparison of CR and IR among different algal species. The flesh dry weight (FDW) of *S. purpuratus* was determined by removing soft tissues from the shells, drying in an oven at 90℃ for 48 hr, and then weighing on an electronic microbalance (Sartørius Co.) to the nearest 0.01 mg.

3. Clearance rate and intake rate

The clearance rate (CR, L/g/hr) was calculated using the equation of Coughlan (1969) as:

$$CR = V \times \ln (C_0 / C_t) / (FDW \times t) \qquad (1)$$

where V is the volume of algal suspension (L), C_0 is the initial concentration (mgC/L), C_t is the final concentration (mgC/L), FDW is the flesh dry weight of *S. purpuratus* (g), and t is the incubation time (hr). To determine the functional response of the CR of *S. purpuratus* to the algal concentration, the data were fitted to an exponential equation (Fig. 1) (Riisgård, 1988) as:

$$CR = a / C^* \times e^{(-b / C^*)} \qquad (2)$$

where C^* is the mean algal concentration during incubation period (geometric mean of C_0 and C_t) and the constants a and b are parameters estimated from curve-fitting. Parameter a explains the magnitude of the CR and parameter b denotes the algal concentration at which the CR is maximal. The maximum CR (C_{max}) was calculated by substituting algal concentration with estimated b value to the above equation as:

$$C_{max} = a / b \times e^{-1} \qquad (3)$$

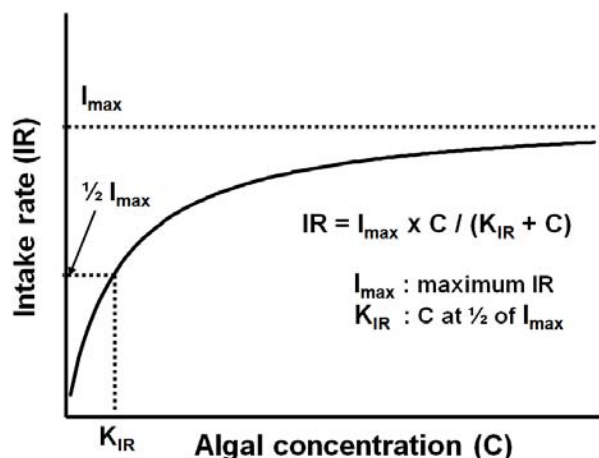Since we did not measure the rate of pseudofeaces production, the intake rate (IR, mgC/g/hr) was

Fig. 2. The general relationship between algal concentration and intake rate of bivalves expressed by the Michaelis-Menten equation (Båmstedt *et al.*, 2000)

calculated (Foster-Smith, 1975; Coutteau *et al.*, 1994) instead of the ingestion rate as:

$$IR = C^* \times CR \qquad (4)$$

To determine the functional response of the IR of *S. purpuratus* to the algal concentration, the data were fitted to the Michaelis-Menten equation (Fig. 2) (Crawley, 1975; Båmstedt *et al.*, 2000) as:

$$IR = I_{max} \times C^* / (KIR + C^*) \qquad (5)$$

where I_{max} is asymptotic maximum IR and K_{IR} is the half-saturation constant, i.e. the algal concentration where $IR = I_{max} / 2$.

4. Statistical analyses

The CR and the IR data among different algal concentrations of each RTD were compared by one-way analysis of variance (ANOVA) on SPSS program. Multiple comparisons were conducted using Tukey's HSD (Zar, 1984). Before the statistical analyses, the data were tested for normality and homogeneity of variance. If at least one of the above ANOVA requirements was not met, the data were log_{10} transformed, then ANOVA was repeated. For all ANOVA, a significance level of $\alpha = 0.05$ was used.

RESULTS AND DISCUSSION

1. Feeding rates on standard food

Clearance rate (CR, mean ± SD) of juvenile *Saxidomus purpuratus* when feeding on unialgal diet of the standard food (*Isochrysis galbana*) ranged from 1.7 ± 0.3 to 13.7 ± 1.1 L/g/hr (Fig. 3A). Algal concentration affected significantly the CR (F = 9.46, p = 0.001). As algal concentration increased from 1.0 to 3.5 mgC/L, the CR increased rapidly. But, after reaching the maximum, it decreased significantly as algal concentration increased from 3.5 to 15.9 mgC/L (p = 0.028). It was lowest when algal concentration was highest. Reduction in clearance rate with increasing algal concentration is known as a general phenomenon (Bayne *et al.*, 1976). Multiple comparison showed that there were no significant differences in CR when algal concentration was 15.6 to 54.6 mgC/L (p = 0.478). When CR data were fitted to the equation (2), the maximum CR (C_{max}) was estimated as 15.2 L/g/hr, which is in good accordance with Lee *et al.* (2002).

Intake rate (IR, mean ± SD) of juvenile *S. purpuratus* when feeding on unialgal diet of the standard food (*I. galbana*) ranged from 9.4 ± 2.2 to 98.5 ± 27.8 mgC/g/hr (Fig. 3B). IR was also affected significantly by the algal concentration (F = 14.88, p < 0.001). It increased rapidly with increasing algal concentration from 1.0 to 8.0 mgC/L (p = 0.003). As algal concentration increased further, the IR was saturated and fluctuated between 90.2 and 98.5 mgC/g/hr. There was no significant difference in IR when algal concentration was 8.0 to 54.6 mgC/L (p = 0.424). When IR data were fitted to the equation (5), the maximum IR (I_{max}) was estimated as 108.1 mgC/g/hr, which is also in good accordance with Lee *et al.* (2002).

2. Feeding rates on red tide dinoflagellates

In general, patterns of CR with increasing algal concentration for all of 9 RTDs were quite similar to that for the standard food (Fig. 4). CR increased rapidly at lower range of algal concentration, reached maximum, and then decreased gradually as algal
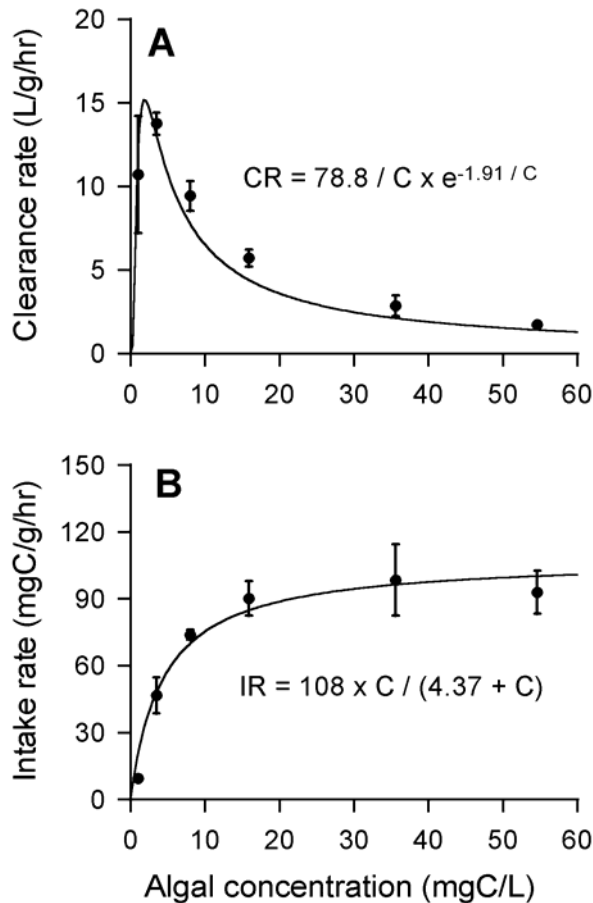
Fig. 3. Typical functional responses of juvenile *Saxidomus purpuratus* to algal concentration (C) when feeding on unialgal diet of standard food (*Isochrysis galbana*). **A**: clearance rate (CR), **B**: intake rate (IR). Symbol represents treatment mean ± SE. CR data were fitted to an exponential equation [eq. (2)], and IR data were fitted to the Michaelis-Menten equation [eq. (5)] using all treatments.

concentration increased further. Although the general patterns were similar among species, the magnitude of CR, algal concentration showing maximum CR, and the maximum CR value differed greatly.

The parameter a estimated from fitting equation (2) indicates the magnitude of CR for each food species. This value for RTDs ranged from 1.3 to 53.4 (Table 2), which was lower than that for the standard food (78.8). The highest a value among RTDs was found for *A. carterae*, which was 67% of *I. galbana*. But the lowest a value for *G. catenatum* was only 1.6% of *I. galbana*. Among RTDs, *A. carterae*, *L. polyedrum* and

S. trochoidea showed relatively high a value, while *G. catenatum*, *C. polykrikoides* and *A. affine* showed low a value.

The parameter b indicates the inflection point of algal concentration vs. clearance rate curve. When algal concentration is lower than b, CR is in increasing phase, while algal concentration is higher than b, CR is in decreasing phase. This value gives the information about the relationships between filtration activity of bivalve and quantity (or quality) of food. The parameter b for RTDs ranged from 0.07 to 1.10 mgC/L (Table 2), which was lower than that for the standard food (1.91 mgC/L). The highest b value among RTDs was found for *A. carterae*, which was 57% of *I. galbana*. But the lowest a value for *G. catenatum* was only 3% of *I. galbana*. Among RTDs, *A. carterae*, *L. polyedrum* and *S. trochoidea* showed relatively high b value, while *G. catenatum*, *A. affine*, *A. catenella* and *C. polykrikoides* showed low b value.

The parameter C_{max} indicates the maximum clearance rate of *S. purpuratus* when the algal concentration was b. There was ca. 4-fold difference in the C_{max} among RTDs. The highest C_{max} was observed when *S. purpuratus* was feeding on *A. affine*, followed by *A. carterae* and *A. catenella*. C_{max} for *A. affine* (18.7 L/g/hr) and *A. carterae* (17.9 L/g/hr) were slightly higher than that for the standard food (15.2 L/g/hr) (Table 2). On the other hand, C_{max} for chain-forming species, *G. catenatum* and *C. polykrikoides* were relatively lower than that for other species. The lowest C_{max} was found when *S. purpuratus* was feeding on *C. polykrikoides* (4.9 L/g/hr).

The general patterns of IR with increasing algal concentration for all of 9 RTDs were also similar to that for the standard food (Fig. 5). It increased rapidly at lower range of algal concentration, and then was saturated as algal concentration increased further. However, the intake rate among different RTDs was highly variable.

The parameter I_{max} estimated from fitting equation (5) indicates the theoretical maximum of intake rate for each food species. There was more than 40-fold difference in the I_{max} among RTDs ranging from 1.6
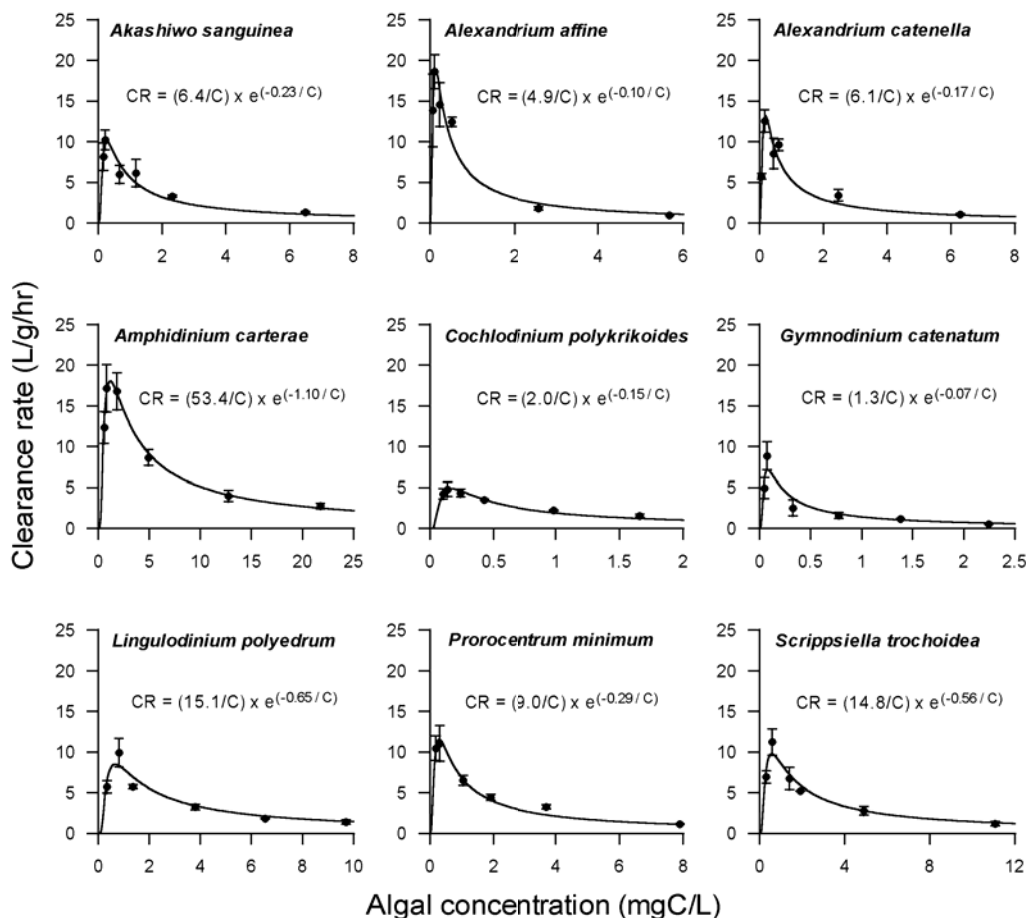
Fig. 4. Clearance rate (CR) of juvenile *Saxidomus purpuratus* as a function of algal concentration (C) when feeding on unialgal diet of each red tide dinoflagellate. Symbol represents treatment mean ± SE. Curves were fitted by an exponential equation [eq. (2)] using all treatments.

Table 2. Feeding parameters of juvenile *Saxidomus purpuratus* when feeding on unialgal diet of either the standard food (*Isochrysis galbana*) or one of the red tide dinoflagellate. Parameters are a (magnitude of overall clearance rate), b (algal concentration at C_{max}, mgC/L) C_{max} (maximum clearance rate, L/g/hr), I_{max} (maximum intake rate, mgC/g/hr), and K_{IR} (algal concentration when the intake rate is 1/2 of I_{max}, mgC/L).

| Species	a	b	C_{max}	I_{max}	K_{IR}
Isochrysis galbana	78.8	1.91	15.2	108.1	4.37
Akashiwo sanguinea	6.4	0.23	10.0	10.1	0.80
Alexandrium affine	4.9	0.10	18.7	5.9	0.16
Alexandrium catenella	6.1	0.17	13.1	8.4	0.42
Amphidinium carterae	53.4	1.10	17.9	64.8	2.75
Cochlodinium polykrikoides	2.0	0.15	4.9	3.5	0.59
Gymnodinium catenatum	1.3	0.07	7.1	1.6	0.20
Lingulodinium polyedrum	15.1	0.65	8.5	15.1	1.11
Prorocentrum minimum	9.0	0.29	11.6	11.7	0.72
Scrippsiella trochoidea	14.8	0.56	9.8	14.9	0.92
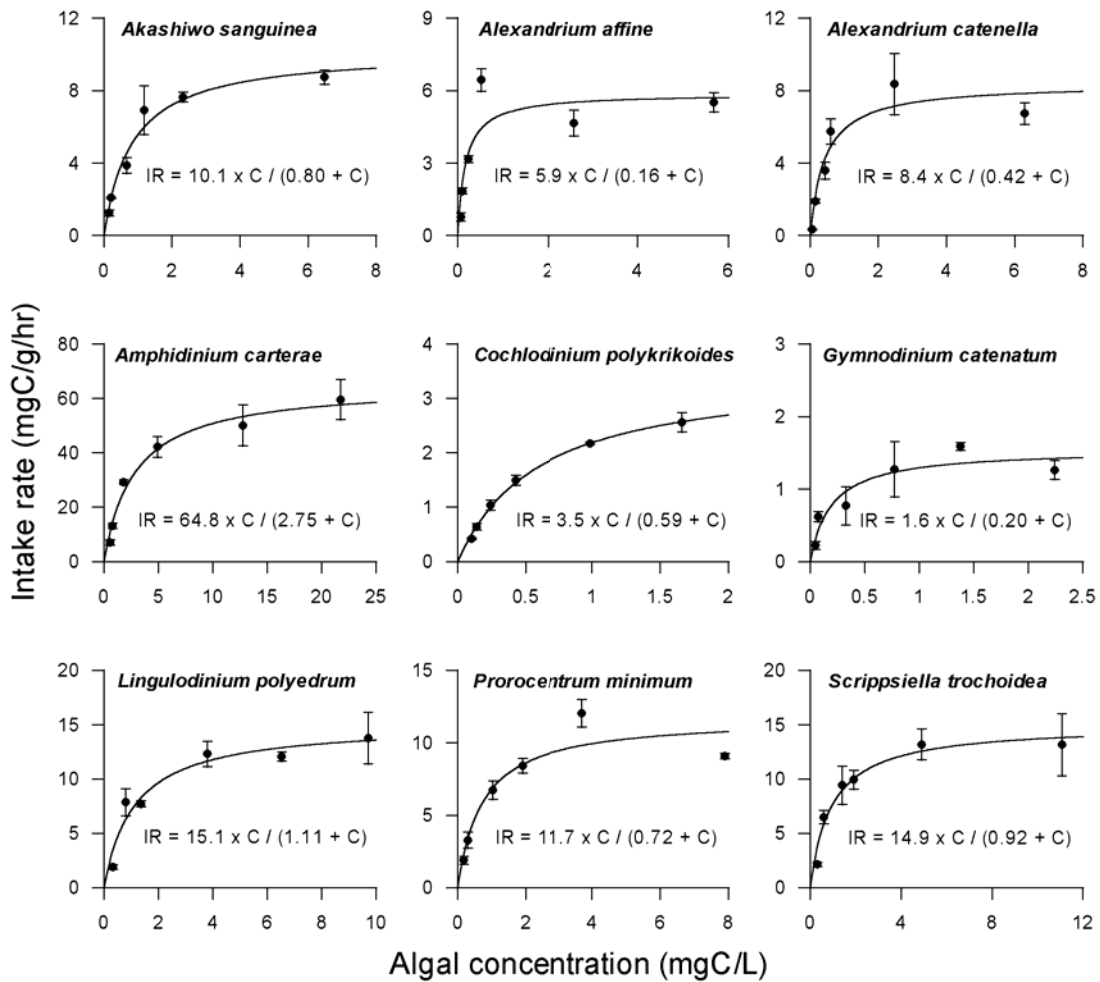
Fig. 5. Intake rate (IR) of juvenile *Saxidomus purpuratus* as a function of algal concentration (C) when feeding on unialgal diet of each red tide dinoflagellate. Symbol represents treatment mean ± SE. Curves were fitted by the Michaelis-Menten equation [eq. (5)] using all treatments.

to 64.8 mgC/g/hr (Table 2), which was lower than that for the standard food (108.1 mgC/g/hr). The highest I_{max} among RTDs was found for *A. carterae* (64.8 mgC/g/hr), which was 59% of *I. galbana*. But the lowest I_{max} for *G. catenatum* (1.6 mgC/g/hr) was only 1.5% of *I. galbana*. Among RTDs, *A. carterae*, *L. polyedrum* and *S. trochoidea* showed relatively high I_{max}, while *G. catenatum*, *C. polykrikoides* and *A. affine* showed low I_{max}. Except for *A. carterae*, the I_{max} value for other RTDs were less than 14% of *I. galbana*.

Since there were similarities among estimated parameters from fitting equations (2) and (5), correlation analyses were performed to know whether there are inter-relationships among feeding parameters of *S. purpuratus*. Among parameters from clearance rate function, there was a strong correlation between parameters a and b (r = 0.941, p < 0.01), while there was no correlation between these two parameters and C_{max} (r = 0.535, p < 0.01 and r = 0.336, p < 0.01 for a vs. C_{max}, and b vs. C_{max}, respectively) (Table 3). From intake rate function, there was a strong correlation between I_{max} and K_{IR} (r = 0.971, p < 0.01). Moreover, parameters from different functions also showed strong correlations (a vs. I_{max}, b vs. I_{max}, a vs. K_{IR}, b vs. K_{IR}, p < 0.01 for all cases). This indicates that parameter a, b, I_{max}, K_{IR} are inter-related, so that one of these four parameters

Table 3. Pearson's correlation coefficients among feeding parameters of juvenile *Saxidomus purpuratus* when feeding on unialgal diet of red tide dinoflagellates. Values with asterisks indicate that correlation is significant (p < 0.01).

|	a	b	C_{max}	I_{max}	K_{IR}
a	1.000				
b	0.941[**]	1.000			
C_{max}	0.525	0.336	1.000		
I_{max}	0.995[**]	0.911[**]	0.540	1.000	
K_{IR}	0.972[**]	0.951[**]	0.358	0.971[**]	1.000

can sufficiently represent and explain the trends of other parameters. In this study, I_{max} was selected as a representative parameter for further discussion, because it has the physiological information on maximum potential of intake rate of *S. purpuratus* for a given food species. Meanwhile C_{max} showed no correlation with other parameters, so it can be treated as an independent parameter.

Sprung and Ross (1988) suggested the ratio between maximum intake rate and maximum clearance rate as the "incipient limiting concentration (ILC)" around which the major change in functional responses occur. The ILC also provides the information on how much a bivalve can tolerate with increasing food concentration. In our data, the ILC concentration for RTDs lied between 0.23 and 3.62 mgC/L which is ca. 3.2-51% of that for *I. galbana*

(7.11 mgC/L). It is regarded that better food has higher ILC. The ILC for RTDs in this study can be arranged as (in descending order); *A. carterae > L. polyedrum > S. trochoidea > A. sanguinea > P. minimum > C. polykrikoides > A. catenella > A. affine > G. catenatum*. Generally, single celled RTDs showed higher ILC, while chain-forming RTDs showed lower ILC.

3. Factors affecting feeding parameters

Fig. 6 shows the relationships between cell size (carbon content) of RTDs and feeding paramaters (C_{max} and I_{max}) of *S. purpuratus*. Since there was a strong correlation between the diameter and carbon content of RTDs (r = 0.976, p < 0.01), we used the carbon content as a index of cell size. Although C_{max} and I_{max} apparently seem to decrease with increasing carbon content (r = -0.439 for C_{max} and -0.347 for I_{max}), there were no statistical significances in both cases (p = 0.239 and 0.360, respectively). *A. affine, A. catenella, S. trochoidea*, and *C. polykrikoides* were quite similar in cell size (23 - 25 μm in ESD), but C_{max} differed greatly (Fig. 6A). There was a 3.8 fold difference between *A. affine* and *C. polykrikoides*. This pattern was also found in I_{max}. *A. carterae* and *P. minimum* were similar in cell size (13 - 16 μm in ESD), but there was a 5.5 fold difference in I_{max} between two species (Fig. 6B). On the other hand, we could find RTDs with different cell size showing similar I_{max}. *L. polyedrum* (37.9 μm) and *S. trochoidea* (25.1 μm) were 2- and 3-times larger than *P. minimum* (12.9 μm), but differences in I_{max} of
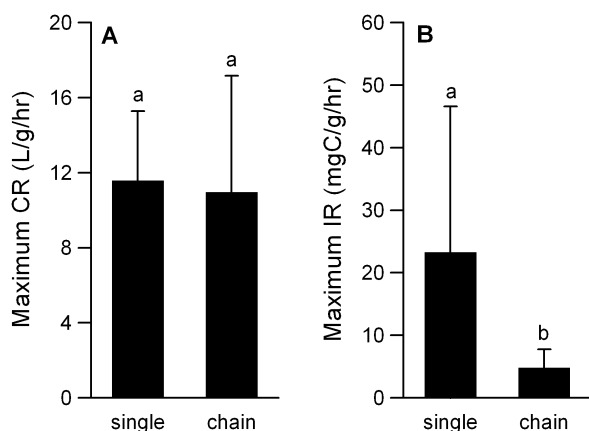
Fig. 6. Comparison of mean of maximum CR and maximum IR of *Saxidomus purpuratus* between single-celled and chain-forming red-tide dinoflagellates as food species.
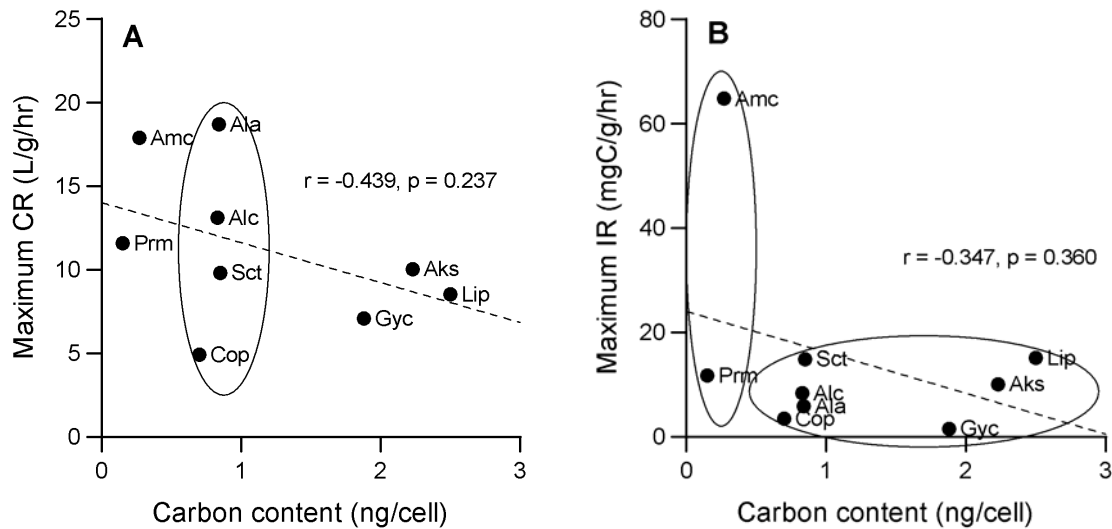
Fig. 7. Relationships between the size (carbon content) of red-tide dinoflagellates and the feeding parameters of *Saxidomus purpuratus* (A: maximum CR, B: maximum IR, Ala: *Alexandrium affine*, Amc: *Amphidinium carterae*, Alc: *Alexandrium catenella*, Prm: *Prorocentrum minimum*, Aks: *Akashiwo sanguinea*, Sct: *Scrippsiella trochoidea*, Lip: *Lingulodinium polyedrum*, Gyc: *Gymnodinium catenatum*, Cop: *Cochlodinium polykrikoides*).

these three species were less than 1.3 fold (Fig 6B).

Sprung and Rose (1988) reported the relationship between the size of food particle and the clearance rate of bivalve. They observed that the clearance rate of *Dreissena polymorpha* was nearly zero when food particle was less then 0.7 μm, increased as particle size increased within the range of 0.7 to 5 mm, and nearly constant when food particle was in the range of 5-35 μm. The size range of RTDs in this study is 13-38 μm, which is overlapping the last category of Sprung and Rose (1988), indicating that size effect on clearance rate is negligible. Shumway *et al*. (1997) measured the clearance rate of 3 juvenile scallops with different size of food particles, and reported that there was optimal range in the size of food particle and the range was different for different bivalve species. The size ranges of food particles showing the highest clearance rate of *Patinopecten yessoensis* and *Placopecten magellanicus* were 3-5 μm and 3-8 μm, respectively. They also reported that the clearance rate of *P. magellanicus* decreased when food particle was larger than 8 μm. According to them, all the RTDs in this study were much larger than the threshold cell size so that the lower clearance rate than that for *I. galbana* (4.5 μm) could be explained.

Fig. 7 compares the mean of feeding parameters (C_{max} and I_{max}) between single celled RTDs and chain-forming RTDs. There was no significant difference in C_{max} between single-celled and chain-forming RTDs (p = 0.859). However, significant difference was found in I_{max} between two groups (p < 0.05). When we arrange the RTDs in ascending order of I_{max}, chain-forming 4 species lied from the first to fourth rank. Moreover, it seemed that the length of chain also affected the I_{max}. The lowest I_{max} was found in *G. catenatum* that forms 8 to 16-celled chains, the next *C. polykrikoides* that forms 4 to 8-celled chains, and then followed by *A. affine* and *A. catenella* those form 2-celled chains.

Lee *et al*. (2003) observed similar results from estimating the feeding parameters of *Glauconome chinensis* feeding on 3 kinds of RTDs. They reported that there was more than 10 fold difference in I_{max} of *G. chinensis* between single-celled RTD (*S. trochoidea*) and chain-forming RTD (*C. polykrikoides*). The results from this study for *S. purpuratus* are in good
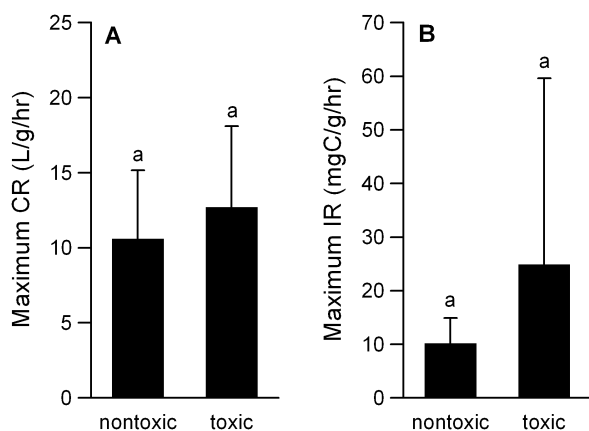
Fig. 8. Comparison of mean of maximum CR and maximum IR of *Saxidomus purpuratus* between nontoxic and toxic red-tide dinoflagellates as food species.

accordance with Lee *et al.* (2003).

Fig. 8 compares the mean of feeding parameters (C_{max} and I_{max}) between nontoxic RTDs and toxic RTDs. There were no significant differences in both C_{max} and I_{max} between nontoxic and toxic RTDs. Although not statistically significant, both parameters for toxic RTDs were numerically higher than nontoxic RTDs. Moreover, a toxic dinoflagellate, *A. carterae* recorded the highest I_{max} among RTDs (see Table 2). Higher mean C_{max} and I_{max} are mainly contributed by those of *A. carterae*. This indicates that the toxicity did not affect the feeding activity of *S. purpuratus*.

It is noticeable that the highest I_{max} was found in toxic *A. carterae*. This species is known to produce hemolytic compounds (Nayak *et al.*, 1997). Though not reported in Korean coastal waters, *A. carterae* is found in Japan, New Zealand, Australia, Canada, UK, and USA (Anderson, *et al.*, 1995). Red tides dominated by *A. carterae* killed fishes (Yasumoto, 1990). The toxicity was reported as 1 MU/1.3 × 10^8 cells (Jeong *et al.*, 2001). Nevertheless this species turned out to be the most favorable food among RTDs in this study. Lee (2003) studied the effects of RTDs on the survival and growth of larvae of *Mytilus galloprovincialis* and found no lethal effect of *A. carterae*, although it showed significant inhibition on growth. Jeong *et al.* (2001) also reported that the heterotrophic dinoflagellate *Oxyrrhis marina* was able to grow well on *A. carterae*. Therefore, toxicity of

RTDs on vertebrates maybe did not act as the same on invertebrates.

Whether a bivalve has preference between nontoxic and toxic algal food is not generalized so far. Matsuyama *et al.* (1997) reported that the clearance rate of *Mytilus galloprovincialis* fed on toxic dinoflagellate (*Heterocapsa circularisquama*) was significantly lower than those on nontoxic dinoflagellates (*S. trochoidea* and *Heterocapsa triquetra*). However, there are other reports that clearance rate does not differ between toxic and nontoxic algal species. Li and Wang (2001) reported that *Perna viridis* and *Ruditapes philippinarum* showed no differences in clearance rates between toxic and nontoxic strains of *Alexandrium tamarense*. Li *et al.* (2001) also reported that *Clamys nobilis* and *R. philippinarum* could not distinguish between toxic dinoflagellate (*A. tamarense*) and nontoxic diatom (*Thalassiosira pseudonana*). Therefore, toxic dinoflagellates are not always recognized as poor food source by bivalves. Whether the feeding activity is affected by the presence or absence of toxicity of algae seems to be species-specific (of bivalve). *S. purpuratus* seems to belong to the group that has no preference between toxic and nontoxic RTDs. Therefore, the most important characteristic of RTD as a factor affecting the feeding rate of *S. purpuratus* is life form, not size or toxicity of RTD species.

ACKNOWLEDGEMENTS

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