Article

A Taxonomic Study of Family Dinophysiaceae Stein (Dinophysiales, Dinophyta) in Korean Coastal Waters

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Abstract : A taxonomic survey of the dinoflagellate family Dinophysiaceae Stein was conducted on 17 locations off the coast of Korea. A total of twelve species have been identified and described, of which eight species, *Dinophysis dens* Pavillard, *D. infundibulus* Schiller, *D. irregulare* Lebour, *D. lapidistrigili-formis* Abé, *D. mitra* (Schütt) Abé vel Balech, *D. parvula* (Schütt) Jörgensen, *D. rapa* (Stein) Balech, *Phalacroma sphaeroideum* Schiller, are new records for Korea and six are potentially toxic.

Key words : dinoflagellate, *Dinophysis*, okadaic acid, diarrhetic shellfish poisoning, Korean coastal waters

1. Introduction

Several species of the family Dinophysiaceae Stein comprising thecate dinoflagellates are known to produce okadaic acid, dinophysistoxins (DTXs) and pectenotoxins (PTXs) (Lee *et al.* 1989) and are responsible for diarrhetic shellfish intoxications. Among ca. 200 species of Dinophysiaceae which are currently reported in the literature, 10 are acknowledged as toxic; *Dinophysis acuminata* Claparède et Lachmann (Andersen *et al.* 1996; Johansson *et al.* 1996), *D. acuta* Ehrenberg (Daiguji *et al.* 1998; James *et al.* 1999), *D. caudata* Saville-Kent (Fernández *et al.* 2002), *D. fortii* Pavillard (Yasumoto *et al.* 1980; Suzuki *et al.* 1997), *D. mitra* (Schütt) Abé vel Balech (Lee *et al.* 1989), *D. norvegica* Claparède et Lachmann (Lee *et al.* 1989), *D. rapa* (Stein) Balech (Lee *et al.* 1989), *D. rotundata* Claparède et Lachmann (Cembella 1989), *D. sacculus* Stein (Giacobbe *et al.* 2000) and *D. tripos* Gouret (Lee *et al.* 1989).

In Korea, there have been many studies on phytoplankton

distribution, species composition and taxonomy including *Dinophysis* and *Phalacroma*. After Yoo (1960, 1962) recorded *Dinophysis* sp. for the first time in Korea, many works have been done for several decades resulting in the reports on 6 species; *Dinophysis acuminata* (Han and Yoo 1983), *D. caudata* (Cho 1973; Shim *et al.* 1981), *D. fortii* (Shim and Lee 1983; Yoo 1984), *D. ovum* Schütt (Yang and Kim 1981; Choi 1983), *D. recurva* Kofoid et Skogsberg (Shim and Park 1984) and *D. rotundata* Claparède et Lachmann (Han and Yoo 1983). In spite of these intensive ecological and taxonomic works, and the great attention given to *Dinophysis* spp. associated with shellfish poisoning in the last decade, the geographic distributions and morphological characteristics within the family have not been fully described yet. In this paper, we attempt to elucidate local distribution of the toxic species and also to provide precise taxonomic descriptions of members of the family Dinophysiaceae observed in Korean coastal waters.

2. Material and methods

Phytoplankton samples were collected from 17 locations

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Fig. 1. Geographic location of the sampling sites off the coast of Korea.

St. 1 Donghae-si; St. 2 East Sea (In the middle of St.1 and St.3); St. 3 Ulleung-do; St. 4 Pohang; St. 5 Wolseong; St. 6 Korea Strait; St. 7 Masan; St. 8 Jinhae; St. 9 Samchunpo; St. 10 Mangyeong; St. 11 Taean; St. 12 Asan; St. 13 Sihwa; St. 14 Incheon; St. 15 Yeongjong-do; St. 16 Yeongheung-do; St. 17 Yellow Sea.

near coastal areas of Korea from 1990 to 2002. Samples were obtained using a 63 μm mesh plankton net (vertical and horizontal net-haul samples), and fixed with 4% formalin or Lugol's solution. All samples were preserved at the Marine Plankton Laboratory at Seoul National University, except for Lugol fixed samples collected from Jinhae and Masan Bay which were deposited at the Coastal Ecosystem Research Laboratory of the Korea Ocean Research and Development Institute (KORDI). The sampling locations are indicated in Fig. 1.

Identification of dinoflagellates in water samples was usually done by using differential interference contrast (DIC). The Zeiss Axioskop microscope was equipped with a Mc 80 microphotosystem. For scanning electron microscope (SEM), an aliquot of sample material was pipetted onto a Nucleopore filter (pore diameter 1 μm) and filtered gently. The filter paper was rinsed with 100 ml of distilled water to remove salts, air-dried, and affixed to an aluminum stub. The stubs were sputter-coated with gold and examined with a JEOL JSM-840A.

The authors consulted for species identification were Taylor (1976) for the genus, and Lebour (1925), Schiller (1933), Abé (1967), Drebes (1974), Balech (1976, 1988) and Dodge (1982) for species.

3. Results and discussion

A total of twelve species of the family Dinophysiaceae have been identified and described in this study. Six species, *Dinophysis acuminata*, *D. caudata*, *D. fortii*, *D. mitra*, *D. rapa*, *D. rotundata* are reported as being potentially toxic. Eight species are new records for Korea: *Dinophysis dens* Pavillard, *D. infundibulus* Schiller, *D. irregulare* Lebour, *D. lapidistrigiliformis* Abé, *D. mitra*, *D. parvula* (Schütt) Jörgensen, *D. rapa*, *Phalacroma sphaeroideum* Schiller. The distinction between the two genera considered and the morphological characteristics of each species are described as follows.

Family Dinophysiaceae Stein

Key to genera

- 1a. Epitheca not exceeding $0.35 \times$ body length, cingular list horizontally extended, sulcal list and sulcal ribs are developed-----*Dinophysis*
- 1b. Epitheca exceeding $0.35 \times$ body length, cingular list and sulcal list and sulcal ribs are lacking, just left trace of that-----*Phalacroma*

Genus *Dinophysis* Ehrenberg

Armored, laterally compressed cells with conspicuous cingular list. Anterior cingular list broadly funnel shaped extending beyond the epitheca which is relatively short, at times barely detectable. Hypotheca usually exceeds epitheca by at least 6 times. Cingulum distinctly premedian and, in rare case, of even width. Sulcal lists prominent, often resembling wings, supported by ribs, with or without simple posterior "sails". Plate formula: 5 epithecal plates, 4 cingular plates, 4 sulcal plates and 4 hypothecal plates.

Dinophysis acuminata Claparède et Lachmann

Pl. 1, a-c

Abé 1967, p. 43, fig. 7; Balech 1988, lam 5, fig. 5-10.

Syn.: *Dinophysis borealis* Paulsen; *Dinophysis lachmannii* Paulsen; *Dinophysis boehmii* Paulsen.

Considerably variable in size and shape. Cell oval, strongly compressed, rounded posteriorly with three or four small protrusion. Left longitudinal list narrow. Theca with fine poroids and pores arranged as in *D. acuta*. Yellow chloroplasts. Anterior cingular list towards the epitheca with a funnel shape. Epitheca is very small

Plate 1. a-c. *Dinophysis acuminata*; d-e. *Dinophysis caudata*. Scale bar ($\approx 20 \mu\text{m}$) in frame a applies to all frames.

underneath the upper girdle list. Occasionally with small protrusions on the hypotheca. Angle of cingular and sulcal lists is almost 100 degrees. Both cingular lists are long and thin. The first rib (R1) and the second rib (R2) are parallel and the third rib (R3) is curved distally.

Size: 45-49 μm long, 33-35 μm deep.

Distribution: East Sea (Wolseong; st. 5), South Sea (Jinhae; st. 8).

Note: Producer of okadaic acid, toxic to human and other mammals (Johansson *et al.* 1996).

***Dinophysis caudata* Saville-Kent**

Pl. 1, d-e; Pl. 2, a, c-g

Lebour 1925, p. 82, fig.22; Schiller 1933, p. 159, fig. 146 a-g; Abé 1967, p. 56, fig. 14.

Syn.: *Dinophysis caudata* var. *tripos* Gouret; *Dinophysis*

caudata Joergensen.

Peculiar body shape with wide distribution. Epitheca almost absent, hidden in the deep funnel. Hypotheca long, narrowing behind into a drawn-out point which is often toothed. Left sulcal list broad and reticulated. An antapical process or horn often present. Theca strongly areolated. Three sulcal ribs are well developed; R1 curved anteriorly, R2 and R3 posteriorly.

Size: 75-103 μm long, greatest dorso-ventral depth 37-50 μm .

Distribution: East Sea (Wolseong; st. 5), South Sea (Jinhae; st. 8).

Note: Producer of okadaic acid (Fernández *et al.* 2002).

Dinophysis dens Pavillard

Pl. 3, a-c

Balech 1988, lam 8, fig. 4-5; Schiller 1933, p. 130, fig. 123.

Plate 2. a, c-g. *Dinophysis caudata*; b. *Dinophysis fortii*; h. *Dinophysis infundibulus*. Scale bars (=20 μm) in frame b and d applies to frame h and d-g, respectively. Scales in a, c = 10 μm .

Cell body is twice as long as deep, with an almost straight or slightly concave ventral section and a slightly convex dorsal section. Epitheca is very small and flat or slightly

rounded. Girdle lists well developed, inclined anteriorly. The upper girdle lists at least twice as long as the lower lists. Angle of cingular and sulcal list is about 130

Plate 3. *a-c. Dinophysis dens*; *d-g. Dinophysis infundibulus*; *h-i. Dinophysis fortii*. Scale bar ($\approx 20 \mu\text{m}$) in frame *a* applies to all frames.

degrees. Upper and lower cingular lists are supported with thin spines. The length of the sulcal list is about twice that of the cingular list.

Size: 50-59 μm long, maximum width of left sulcal list 6-10 μm , 52 μm deep.

Distribution: New to Korea. East Sea (Pohang; st. 4).

Plate 4. a-b. *Dinophysis fortii*; c-g. *Dinophysis irregulare*; h. *Dinophysis lapidistrigiliformis*. Scale bar (=20 μm) in frame a applies to all frames.

Dinophysis fortii Pavillard

Pl. 2, b; Pl. 3, h-i; Pl. 4, a-b
 Abé 1967, p. 54, fig. 13; Schiller 1933, p. 134, fig. 127 a-c.
 Syn. : *Dinophysis laevis* Pouchet; *Dinophysis ovum* Schütt
 sensu Martin.

This species is easily confused with *D. dens*. The difference of the species is that the ventral side of the hypotheca of *D. fortii* is almost straight. Sulcal list is slanting along the cingular plane keeping a constant angle of 110-120°C. Upper cingular list is curved anteriorly enough

Plate 5. a-c. *Dinophysis irregulare*; d-f. *Dinophysis lapidistrigiliformis*; g-h. *Dinophysis parvula*. Scale bar (=20 μ m) in frame a applies to all frames.

to cover epitheca. The widest depth (dorso-ventral depth) is near the R3 rib of the left sulcal list. Sulcal list slightly reticulated. Theca surface is covered with large pores. Size: 56-83 μm long, dorso-ventral depth 43-58 μm , 27-32 μm wide. Distribution: Korea Strait (st. 6), South Sea (Jinhae; st. 8). Note: Producer of dinophysistoxin-1 (DTX1) and pectenotoxin-2 (PTX2) toxins (Yasumoto *et al.* 1980).

***Dinophysis infundibulus* Schiller**

Pl. 2, h; Pl. 3, d-g

Abé 1967, p. 40, fig. 5.

Cell body is broadly ovate, strongly contracting anteriorly to form a distinctly convex shape. Epitheca not visible from a side view. The body is a little longer than it is broad. Three well developed sulcal list; R3 curved posteriorly, R2 and R1 anteriorly. Upper cingular list is directed anteriorly and lower cingular list laterally. In a dorsal view, both hypothecal plates are convex.

Size: 38-45 μm long, 36-40 μm deep.

Distribution: New to Korea. Korea Strait (st. 6).

***Dinophysis irregulare* Lebour**

Pl. 4, c-g; Pl. 5, a-c; Pl. 6, d-e

Abé 1967, p. 57, fig. 15; Lebour 1925, text-fig. 4 a-c; Schiller 1933, fig. 61 a-c.

This species is characterized by its almost circular lateral outline of the body, and broad and fairly evenly rounded small epitheca which may be flattened at the apex. In dorso-ventral view, the body is sometimes symmetrically biconvex, but usually dorsal side more convex than ventral side. Broadest point near the R2 rib. Girdle list narrow but directed slightly forward, sometimes finely striated. Left longitudinal list rather narrow, often widening posteriorly with conspicuous spines. This species is special in terms of the structure of cell content (Pl. 4, g; Pl. 5, c).

Size: 57 μm long, 55 μm deep.

Distribution: New to Korea. East Sea (Wolseong; st. 5).

***Dinophysis lapidistrigiliformis* Abé**

Pl. 4, h; Pl. 5, d-f; Pl. 6, f; Pl. 7, a

Abé 1967, p. 48, fig. 8.

Rather like *D. acuminata*, but without protuberances. In dorso-ventral view the body is laterally convex, but in lateral view it is somewhat elongated ovoid and narrowly truncated anteriorly. Epitheca is absent. The upper girdle list is relatively wide forming a funnel over it and expands anteriorly. The lower cingular list is narrower than the

upper cingular list. Both cingular lists are slightly higher dorsally. The left sulcal list is relatively wide and supported by evenly shaped ribs. R1 and R2 project anteriorly and R3 curves posteriorly. The right sulcal list is short as in Pl. 4, h.

Size: 47 μm long, 32 μm wide.

Distribution: New to Korea. East Sea (Wolseong; st. 5).

***Dinophysis mitra* Schütt**

Pl. 6, a-c

Abé 1967, p. 63, fig. 18.

Syn.: *Phalacroma mitra* Schütt; *Phalacroma dolichopterygium* Murray et Whitting

Because *D. mitra* and *D. rapa* are very similar, Jörgensen (1923) considered them identical. Upper cingular list is toward the side and is thick and strong. Lower cingular list is also toward the side, but is shorter and thinner than upper cingular list. Three ribs of left sulcal list are long and strong. Right sulcal list has one sulcal rib and several teeth taws.

Size: 63-72 μm long, greatest dorso-ventral depth 50-58 μm .

Distribution: New to Korea. East Sea (Wolseong; st. 5).

Note: Producer of dinophysistoxin-1 (DTX1) (Lee *et al.* 1989).

***Dinophysis parvula* (Schütt) Joergensen**

Pl. 5, g-h

Schiller 1933, p. 64, fig. 57 a-d.

Epitheca fairly big. Length of epitheca is longer than the girdle width. Posterior part of cell body is round and theca surface is covered with small pores. Both girdle lists are directed laterally. List is not well developed. Girdle list is broader than it is long. Broadest in one third of the hypotheca, and dorso-ventral view ovoid. This species has a wide left sulcal list especially from R2 to R3. Length of R2 is short and that of R3 long. R1 and R2 are curved anteriorly and R3 posteriorly. Hallegraeff and Lucas (1988) suggested that *Dinophysis* genus evolved from the simplest species like *Dinophysis parvula*, which has only a small girdle and sulcal list.

Size: 45 μm long, 40 μm wide.

Distribution: New to Korea. Yellow Sea (Yeongjong-Do; st. 15).

***Dinophysis rapa* (Stein) Abé**

Pl. 6, g-h; Pl. 7, b, d-g; Pl. 8, a; Pl. 9, a-c

Abé 1967, p. 66, fig. 19.

Syn.: *Phalacroma rapa* Stein

The left sulcal list is more strongly developed than the right sulcal list, and this left list is strongly slanting to

Plate 6. a-c. *Dinophysis mitra*; d-e. *Dinophysis irregulare*; f. *Dinophysis lapidistrigiliformis*; g-h. *Dinophysis rapa*. Scale bars ($\approx 20 \mu\text{m}$) in frame a and d apply to frame b, h and e-g, respectively.

make an angle between it and cingular plane. In addition, the lateral outline of the ventral side of the hypotheca shows a distinct concavity just posterior to the rear end of the sulcus. This species is easily confused with *D. mitra*. Girdle list is well developed as shown in Pl. 7, b

and Pl. 8, a.

Size: $80 \mu\text{m}$ long, the greatest dorso-ventral depth $70 \mu\text{m}$.

Distribution: New to Korea. Yellow Sea (Yeongjong-Do; st. 15).

Note: Producer of okadaic acid (Lee *et al.* 1989).

Dinophysis rotundata Claparède et Lachmann

Pl. 7, c; Pl. 8, b-d; Pl. 9, d-e, g
Abé 1967, p. 57, fig. 15; Drebes 1974, p. 116, fig. 94 d;

Balech 1976, p. 91, fig. 4 O-T; Dodge 1982, p. 55, fig. 4 l.

Syn.: *Phalacroma rotundatum* (Claparède et Lachmann)
Kofoid et Michener

Plate 7. a. *Dinophysis lapidistrigiliformis*; b. *Dinophysis rapa* (apical view of epitheca); c. *Dinophysis rotundata*; d-g. *Dinophysis rapa*. Scale bar (=20 μ m) in frame a applies to all frames.

This species is characterized by its almost circular lateral body outline, a broad and fairly evenly rounded small epitheca which may be flattened at the apex. In dorso-

ventral view, the body is symmetrically biconvex. Broadest near the R2 rib. Girdle list narrow but directed slightly forwards, sometimes finely striated. Left

Plate 8. a. *Dinophysis rapa* (apical view of megacytic cell); b-d. *Dinophysis rotundata*; e-g. *Phalacroma sphaeroideum*. Scale bar (=20 μ m) in frame a applies to all frames.

longitudinal list rather narrow, often widening posteriorly with conspicuous spines. This species displays several varieties in terms of form.

Size: 48-50 μm long, 42-43 μm deep

Distribution: East Sea (Wolseong; st. 5), South Sea (Jinhae; st. 8).

Note: Producer of DTX-1 demonstrated in Japan, North American strains apparently non-toxic (Cembella 1989).

Genus *Phalacroma* Stein

Medium to large cells. Similar to *Dinophysis* Ehrenberg but cingular list, and left and right sulcal lists are not developed as in the case of *Dinophysis*, only leaving trace of list. According to Hallegraeff and Lucas (1988), the genus *Dinophysis* might have evolved from the simplest form like *Phalacroma parvulum* (= *Dinophysis parvula*),

Plate 9. a-c. *Dinophysis rapa*; d-e, g. *Dinophysis rotundata*; f, h-i. *Phalacroma sphaeroideum*. Scale bars (=20 μm) in frame a and e apply to frame b-d, g and f, h-i, respectively.

which has only small girdle and sulcal lists. It has evolved in three different ways; first, the cell body is developed and sulcal and girdle list also is developed and second, there is the excessive development of sulcal lists and girdle lists, and third, only the cell body is becoming larger. The fact that *Phalacroma sphaeroideum* does not have sulcal and girdle lists implies that this species might be more primitive than *Dinophysis parvula*.

Phalacroma sphaeroideum Schiller

Pl. 8, e-g; Pl. 9, f, h-i

Schiller 1933, p. 82, fig. 74 a-c.

Both girdle list and two sulcal lists are short (Pl. 8, e-g). There is no sulcal rib. Length of epitheca is twice as large as the girdle width. Suture of epitheca appears saw-toothed. Large and distinctive species easily confused with *P. apicata*. This illustrated species is lacking the sulcal ribs of the left sulcal list. Upper and lower girdle lists are not developed making a small boundary (Pl. 8, e, g; Pl. 9, h).

Size: 40-43 μm long, 32-43 μm wide, 37 μm deep.

Distribution: New to Korea, East Sea (Wolseong; st. 5).

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