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Occurrence and Distribution of Cellular Slime Molds in South Korea

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ABSTRACT: An investigation of occurrence and distribution of dictyostelid cellular slime molds in South Korea were carried out. Thirty-one dictyostelid cellular slime molds were isolated from soils of 256 sample sites of 41 area within mountain forests, riversides, streamsides and coastal area in South Korea. The average number of species isolated at a given study area was 6.85. Based on the distribution value calculated from average frequency and site presence, four dictyostelid species distributed widely in South Korea; *Polyspondylium pallidum*, *P. violaceum*, *Dictyostelium mucoroides* and *D. minutum*. Especially, *P. pallidum*. were found in 30 area and the highest site presence. Eight dictyostelid species was described firstly in this study: *D. areum* var. *luteolum*, *D. delicatum*, *D. deminutivum*, *D. implicatum*, *D. microsporum*, *D. mucoroides* var. *stoloniferum*, *D. septentrionalis*, and *P. candidum*.

Key words: Cellular Slime Molds, Occurrence, Distribution, South Korea, *Polysphondylium pallidum*

INTRODUCTION

Previous studies of dictyostelid cellular slime molds have shown that these organisms distributed widely in the world (Benson and Mahoney 1977, Cavender 1976, 1989, Hagiwara 1989, 1993, Hong and Chang 1990, 1991, 1992a, 1992b, Raper 1984, Shim and Chang 1996a, 1998a, 1998b, 1998c, Shim *et al.* 1998b, Vadell *et al.* 1995). Cellular slime molds are usually abundant in humus and fermentation layers in rich organic matter. However cellular slime mold are not always in decaying plant material. More dictyostelid cellular slime molds than sixty species were found in the world, which occurred in the fermentation or humus layers of forest soil, cultivated field, dung of animals, coastal area, streamside and littoral zone(Cavender 1972, 1973, 1980, Raper 1984, Hagiwara 1989, 1990, 1991b, 1992a, 1992b, 1993, Hong and Chang 1990, 1991, Kwon and Chang 1996, Shim and Chang 1996b, 1997, 1998a, 1998c, Shim *et al.*, 1998a, 1998b, Stephenson 1988, Vadell *et al.* 1995). In addition, dictyosteilds were found in the alpine zone, the tundra area, desert and on the branches of tree in the humid area(Choi and Chang 1996, Hagiwara 1989, 1990, 1991a, Kanda 1982, Raper 1984, Stephenson *et al.* 1991).

Studies of cellular slime molds which have micro-distribution in the forest soil represent the facts that these organisms are influenced by the factors related to vegetation, climate, soil quality, interaction among species(Cavender 1980, Cavender and Hopka 1986, Chang *et al.* 1996a, 1996b, Landolt 1990, Shim and Chang 1996b). Stephenson(1988) studied on the distribution and ecology of Myxomycetes in temperate forests and mainly the effect of moisture-complex gradient to the forest communities. The distribution of them is varied in the elevation and topography(Cavender 1980, Hong *et al.* 1992, Shim and Chang 1998a, 1998c, Shim *et al.* 1998a). Several studies in Korea showed the relationship between the occurrence and distribution of cellular slime molds and soil quality(Chang *et al.* 1996a, 1996b, Hong and Chang 1991, Hong *et al.* 1992, Shim and Chang 1998a, 1998c). In addition, they represent the difference of the distribution and occurrence of cellular slime mold between deciduous forest and conifers, and between broad-leaved evergreen forest and conifer evergreen forest.

The present study was undertaken to examine the distribution and occurrence of dictyostelid cellular slime molds that occurred in South Korea. To investigate the distribution and occurrence of dictyostelids, soil samples were collected from various forest types. Cellular slime molds that are common and distribute widely in South Korea were investigated based on frequency and presence. Secondly, these organisms were characterized which haven t been undescribed with morphological and systematical

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characteristics in this study.

METHODS

Study area

It was studied that the occurrence of dictyostelid cellular slime molds from forty-one sites in South Korea(Fig. 1). Dictyostelids were isolated and identified from the soil samples of the sites. Table 1 showed the number and forest types of sample sites and area.

Collecting samples

Collection of soil samples and analysis of cellular slime mold were carried out according to Clonal Isolation Technique . Two to five soil samples were collected at each sites and mainly from the layers of forest soils with the rich organics. Soils were sampled in 14 × 12 cm vinyl bags and protected, then moved to the laboratory, and were placed at 4℃ in refrigerator.

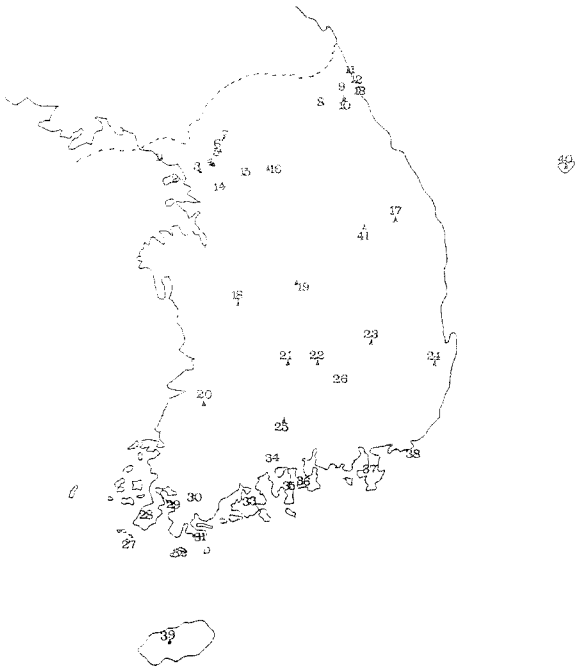

Fig. 1. Area of collecting soil samples in South Korea.
1. Kangwhado(Mani-san), 2. Incheon coastal area(Shindo, Jakyakdo, Yongjongdo, Chamjindo, Muuido, Yongyudo and Sammokdo), 3. Kwanak-san, 4. Nam-san, 5. Pukhan-san, 6. Gokneung streamside, 7. Surak-san, 8. Hangyeryong, 9. Chinburyong, 10. Seorak-san, 11. Geojin, 12. Ganseong, 13. Sokcho, 14. Anyang streamside, 15. Paldangho(littoral zone), 16. Yongmoon-san, 17. Taebaik-san, 18. Keryong-san, 19. Sokri-san, 20. Naejang-san, 21. Deokyu-san, 22. Kaya-san, 23. Palgong-san, 24. Toham-san, 25. Chiri-san, 26. Koryong(Nakdong riverside), 27. Kwanmaedo, 28. Chindo, 29. Haenam, 30. Kangjin, 31. Wando(Chudo), 32. Pogildo, 33. Koheung, 34. Kwangyang, 35. Yeosu(Odongdo), 36. Namhae, 37. Geojedo, 38. Dongbaekdo, 39. Halla-san, 40. Ulneungdo, 41. Sobaik-san.

Isolation and identification of dictyostelid cellular slime molds

Isolation procedure of species was involved in the use of hay infusion agar medium by leached mainly sedges dried with 1.5g KH_2PO_4, 0.96 g $Na_2HPO_4 \cdot 12H_2O$ and 20g agar. A final dilution of sample soils that seived through 2mm pore seive was 1: 50 by following procedure: 10g soils and 90ml sterile distilled water were given into 500ml erlenmyer flask, the flasks were placed on a shaker for 2 mins to disperse soil particles and spores and myxamoeba, the 5ml of suspension were mixed with the 7.5ml sterile water, then 0.5 ml above suspension with the 0.5ml of suitable pregrown *Escherichia coli* (10^7 ~ 10^8 cell/ml) solution was deposited to hay agar plates and spreaded by spreading bar. The agar plates were incubated for 5 ~ 7 days at 20 ~ 22℃, and then dictyostelids were isolated. The dictyostelids isolated were incubated at 20 ~ 22℃ on 0.1% Lactose-Peptone agar media supplemented with *E. coli*. 2 days the identification of dictyostelids was performed based on major key to acrosian previous reports (Hagiwara, 1989, Hong and Chang 1992a, 1992b, Raper 1984, Shim and Chang 1996b, Traub *et al.* 1981). They were observed and identified by their morphological characteristics(sorocarps, basal types, sorophores, aggregation and migration, color of sorophores and sori, spore size, and branch type) during life cycle.

Occurrence and distribution of dictyostelid species

The study to investigate the occurrence and distribution of dictyostelid cellular slime molds were performed on basis of presence and frequency of sites. Average frequency, site presence and distribution value are following equations. Rank of occurrence and distribution is determined by the distribution value.

$$Frequency(\%) = \frac{number\ of\ samples\ that\ a\ species\ occurred\ at\ a\ site}{total\ number\ of\ samples\ at\ a\ site} \times 100$$

$$Average\ Frequency(AF,\ \%) = \frac{sum\ of\ each\ frequency\ of\ species}{total\ number\ of\ site\ areas} \times 100$$

$$Site\ Presence(SP,\ \%) = \frac{number\ of\ site\ areas\ that\ a\ species\ occurred}{total\ number\ of\ the\ site\ areas} \times 100$$

$$Distribution\ Value(DV,\ \%) = \frac{Average\ Frequency + Site\ Presence}{2}$$

RESULTS AND DISCUSSION

Ocurrence and distribution of cellular slime molds

Thirty-one dictyostelid cellular slime molds occurred in South

Table 1. Vegetation of sample sites and area in South Korea

Study area	No. of sites	Forest type(genus)
1. Kangwhado(Mani-san)	7	*Quercus, Pinus*
2. Incheon coastal area (seven islands)	16	*Quercus, Pinus, Carpinus, Robinia, Carex, Oenothera, Erigeron, Calystegia, Artemisia*
3. Kwanak-san	5	*Quercus, Pinus. Zoysia japonica*
4. Nam-san	4	*Quercus, Pinus*
5. Pukhan-san	4	*Quercus, Pinus*
6. Gokneung streamside	12	*Persicaria, Humulus, Artemisia, Rumex, Eriochola*
7. Surak-san	5	*Quercus, Pinus*
8. Hangyeryong	6	*Pinus, Quercus, Acer*
9. Chinburyong	4	*Tilia, Juglans, Acer, Phrgmites, Miscanthus*
10. Seorak-san	6	*Qercus, Pinus, Abies*
11. Geojin	2	*Pigitaria, Chenopodium, Robinia* in beach
12. Ganseong	2	*Pinus*
13. Sokcho	4	*Pinus*
14. Anyang streamside	7	*Persicaria. Humulus, Artemisia, near factroys*
15. Paldangho(littoral zone)	3	*Typha, Salix, Arthraxon*
16. Yongmoon-san	2	*Quercus, Pinus*
17. Taebaik-san	11	*Quercus, Pinus, Taxus, Sasa, Rhododendron*
18. Keryong-san	6	*Quercus*
19. Sokri-san	6	*Pinus,Quercus*
20. Naejang-san	4	*Quercus, Pinus, Torreya*
21. Deokyu-san	5	*Quercus, Sasa. Betula, Taxus*
22. Kaya-san	4	*Pinus, Zelkova,* Evergreen broadleaved(mixed)
23. Palgong-san	4	*Quercus, Pinus*
24. Toham-san	5	*Quercus, Pinus, Persicaria, Forsyinthia*
25. Chiri-san	13	*Quercus, Pinus, Larix, Carpinus, Sasa, Abies*
26. Koryong(Nakdong riverside)	5	*Quercus. Persicaria, Oryza*
27. Kwanmaedo	4	*Machilus*
28. Chindo	4	Evergreen broadleaved, *Machilus*
29. Haenam	4	*Torreya*
30. Kangjin	4	*Camellia*
31. Wando(Chudo)	4	*Castanopsis*
32. Pogildo	4	Evergreen broadleaved(mixed)
33. Koheung	4	*Torreya*
34. Kwangyang	4	*Camellia*
35. Yeosu(Odongdo)	4	*Camellia*
36. Namhae	4	*Machilus*
37. Geojedo	4	*Camellia. Machilus*
38. Dongbaekdo	4	*Camellia*
39. Halla-san	32	*Torreya, Camellia, Carex, Quercus, Elaeocarpus, Dactylis, Spodiopogon, Carpinus, Abies, Pinus*
40. Ulneungdo	17	*Alnus, Fagus, Pinus, Acer Magnolia. Pinus*
41. Sobaik-san	7	*Quercus. Taxus*
Total	256	

Korea. Twenty-seven *Dictyostelium* and four *Polysphondylium* species were isolated from the soil samples of collected in forty-one site areas(Table 2). Compared with that eighteen dictyistelid species were found in Germany, and twelve species were isolated in Taiwan(Cavender *et al.* 1995, Hagiwara *et al.* 1992), in South Korea, richness of dictyostelid cellular slime molds was

Table 2. Dictyostelid cellular slime molds occurred in South Korea

Kingdom Plantae
Kingdom Mycetae
 Division Eumycota(true fungi; molds and mushrooms)
 Division Myxomycota(mycetozoa or slime fungi)
  Class Protosteliomycetes(protostelids)
  Class Myxomycetes(acellular or plasmodium-forming slime molds)
  Class Acrasiomycetes(cellular slime molds)
   Subclass Acrasidae(ascrasids)
   Subclass Dictyostelidae(dictyostelids)
    Family Acytosteliaceae
     Genus *Acytostelium*
    Family Dictyosteliaceae
     Genus *Coenonia*
     Genus *Dictyostelium*(구슬팡이 속)
        areum var.(新稱 거친노랑장대팡이)
        areum var. *luteolum*(거친장대팡이)
        aureo-stipes var.(노랑산호팡이)
        brefeldianum(가는구슬팡이)
        capitaum(털구슬팡이)
        caudabasis(꼬리구슬팡이)
        crassicaule(좀고사리팡이)
        delicatum(新稱 여린구슬팡이)
        deminutivum(新稱 왜구슬팡이)
        fasciculatum(흰꽃구슬팡이)
        firmibasis(장대팡이)
        flavidum(노랑장대팡이)
        floridum(꽃구슬팡이)
        giganteum(긴구슬팡이)
        implicatum(新稱 바늘구슬팡이)
        lacteum(좀털구슬팡이)
        macrocephalum(큰머리팡이)
        microsporum(新稱 좀머리팡이)
        minutum(좀구슬팡이)
        monochasiodes(좀꽃구슬팡이)
        mucoroides(구슬팡이)
        mucoroides var. *stoloniferum*(新稱 기는구슬팡이)
        polycephalum(포도송이구슬팡이)
        purpureum(자주구슬팡이)
        septentrionalis(新稱 큰구슬팡이)
        sphaerocephalum(왕구슬팡이)
        valenstemmum(장대구슬팡이)
     Genus *Polysphondylium*(돌려난가지팡이 속)
        candidum(新稱 좀돌려난가지팡이)
        pallidum(흰돌려난가지팡이)
        tenuissimum(긴돌려난가지팡이)
        violaceum(자주돌려난가지팡이)

very high. But, fifteen species of thirty-one dictyostelids have occurred in less than five sites, and it was suggested that some dictyostelids have habited in special area. The number of species isolated at a given site was 6.85. Whereas the number of species isolated was or so less than 7.0 of Japan, which is very high compared with 4.7 of India, and 4.3 of Switzerland (Kanda 1982, Traub *et al.* 1981).

In this study, *P. pallidum*, *P. violaceum*, *D. mucoroides*, and *D. minutum* of dictyostelid cellular slime molds were common and widely spread in South Korea(Table 3, Fig. 2). *D. mucoroides*, *D. sphaerocephalum*, *D. minutum*, *P. pallidum* were common in Germany (Cavender *et al.* 1995), *D. mucoroides*, *P. violaceum*, *P. violaceum* were distributed widely in Japan(Cavender and Kawabe 1989). For in Japan, *D. delicatum*, *D. firmibasis*, and *P. candidum* that had lower presence in South Korea were widespread. Average frequency and site presence of *P. pallidum*, the most common species, were 38%, 76% respectively. *P. violaceum* were isolated from twenty-nine areas, average frequency of it was 28%, site presence was 71%. It was concluded that *P. pallidum* and *P. violaceum* were relatively predominant species. *D. mucoroides* that have been reported to be ubiquitous species in previous studies (Cavender 1980, Chang *et al.* 1996a, 1996b, Hong and Chang 1991, Choi and Chang 1996, Kwon and Chang 1996) has the highest average frequency, but site presence of it was the third.

D. flavidum, *D. floridum*, *D. valenstemmum*, and *D. caudabasis* that were found firstly in South Korea distributed not widely. D. flavidum was proposed high mountain forests, occurred in evergreen conifers, but it never appeared in oak forest(Hong and Chang 1993, Chang *et al.* 1996a, 1996b, Shim and Chang 1996b). *D. floridum*, *D. valenstemmum*, and *D. caudabasis* were isolated from forest soils of some area, but was examined it as specialized species. *D. lavandulum* and *D. mizopodium* isolated from forest soils in Taiwan and Japan, and *D. discoideum* used for the important biological material were not found yet in this study.

Description of dictyostelid cellular slime molds

Eight dictyostelid species(*D. areum var. luteolum*, *D. delicatum*, *D. deminutivum*, *D. implicatum*, *D. microsporum*, *D. mucoroides* var. *stoloniferum*, *D. septentrionalis*, and *P. candidum*) were reported of the occuurence of them in previous studies(Kwon and Chang 1996, Park and Chang 1996, Shim *et al.* 1998a). But they haven't been undescribed with morphological and systematical characteristics. In this study, these organisms were characterized by morphologica and systematical properties during life cycle.

Dictyostelium areum var. *luteolum* (新稱 거친장대팡이)

This species is a variety of *D. areum* var. *areum*. *D. areum* var. *luteolum* is characterized by yellowish sori, and indented sorophores. Sori of it are larger than those of *D. areum* var. *areum*, spores are not eliptical, but almost oval. Aggregates are branch-type, and usually larger than those of *D. areum* var. *areum*.

Table 3. Occurrence of Dictyostelid Cellular Slime Molds in South Korea

Species	1[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	AF[1]	SP[2]	R[3]
D. aureo-stipes								33[b]		29	100		100	14	33						40				20	75	50			25	50					75	75		56	36		20	39	6
D. areum						42								14																								28			2	7	20
D. areum var.														14																												<1	2	27
D. brefeldianum						16						50						100		50	40	50		40	27	20	25	100	50		50	75						28	12	43	19	39	7
D. capitatum			33																			100			9		25	25	50		50	25			50		25	25	17			11	29	9
D. caudabasis								17	50																															4		2	7	21
D. crasscaule			33		50		20	17		15					33										14														17	4	14	5	24	13
D. delicatum																									5																		<1	2	31
D. deminutivum																						25																				14	1	2	23
D. fasciculatum																33	82																						39		71	5	8	19
D. firmibasis	10						20			15			25				55	25		50	40	100		60																	14	10	27	11
D. flavidum			33			16																	50		23	20												25		28			5	17	14
D. floridum																																								6			<1	2	29
D. giganteum						25								14	33										5														17	4		2	15	15
D. implicatum			33																			25		40	5																14	3	12	16
D. lacteum	4																				17																		25			1	7	22
D. macrocephalum						25				29	50			100	33	17									14	20														11	4		7	22	12
D. microsporum																							25																			<1	2	25
D. minutum	45	44				25		83	50			50	25	29		50	36	50	80	25	40	25		20	27		50	50			75	50			25	25		83		43	27	61	4
D. monochasiodes																																							6			<1	2	30
D. mucoroides	36	69	67	50	50	25								71		17	18	25	60	25	40	75		40	64	40	75		100	100	100	75		100		25	50	94	32	57	39	68	3
D. mucoroides var.						8																																			<1	2	28
D. polycephalum		6						17											10																					17			1	10	17
D. purpureum	10		67		50	16				15			25	14									25	40	14	40	25	25					75			25	25	22			13	43	5
D. septentriolnalis														29																											<1	2	24
D. sphaerocephalum			33			75								14		17								20	23	20				25					50	25		39	8		8	29	10
D. valenstemmum							20																																		<1	2	26
P. candidum										14							9							20																	14	1	10	18
P. pallidum	45	19	10	50	100	8	100	17					50	43		33	36	25	60	75		50		100	45	80	25	75		75		25	50	100		25	25	83	16	14	38	76	1
P. tenuissimum	10						20		50				25			17				25	60	25								25	25					25	25	6	16		9	34	8
P. violaceum		25	33			8				43	50		25	29	66	50	9		80	75	20		75	60	14	60	25		50	75	25		25	25	25	25	25	67	27	14	28	71	2

a. Sample sites, b. Frequency(%) = (number of samples that a species occurred at a site/total number of samples at a site) × 100

1. AF(Average Frequency, %) = (sum of each frequency of a species/ total number of sites) × 100

2. SP(Site Presence, %) = (number of sites that a species occurred/ total number of sites) × 100

3. R(Rank) is determined by the Distribution Value

Fig. 2. Occurrence and Distribution of *Polysphondylium pallidum*(P), *P. violaceum*(V), *Dictyostelium mucoroides*(M) and *D. minutum*(N) in South Korea.

Dictyostelium delicatum (新稱 여린구슬팡이)

D. delicatum has gregarious, sometimes solitary, and unbranched or sparsely branched sorocarps. Sometimes, it is phototrophic, and prostrated. Sorophores are tapering from base to apex, and 1~7mm in length. Tips are acuminate or compound clavate, a level 50㎛ below the top of tips is 2.5~15.0㎛. *D. delicatum* is characterized by white oval sori, oblong or eliptical spores. L/W(length/width) index of spores is 1.7~2.4, and the size of spores with polar granules is 5.1~7.5 × 2.7-3.5㎛.

Dictyostelium deminutivum (新稱 왜구슬팡이)

This species is characterized by solitary or clustered, unbranched or sparsely branched, and very small sorocarps (0.2~1.0mm), and colorless sori. Sorophores are colorless, tapering from base to apex, and almost unicellular. Basal areas are 5.0~8.5㎛ in diameter at the thickest part, a level 50㎛ below the top of the acuminate tips is 1.5~3.0㎛. Spores are capsule-like or reniform, with polar granules, and 3.5~5.0 × 1.2-2.0㎛ in size.

Dictyostelium implicatum (新稱 바늘구슬팡이)

This species is solitary, unbrached or sparsely irregularly branched, and phototophic. Sorophores are colorless, 0.5~5.9 mm in length, and tapering from base to apex. Conical bases are surrounded by basal disks, and 7.0~35.0㎛ in diameter at a level

100㎛ above the bottom, and 17.5~35.0㎛ in diameter at the thickest part. Tips are implicate, simple, and 2.5~10.0㎛ in diameter at a level 50㎛ below the top. D. implicatum has yellowish and oval sori, and eliptical spores. L/W index of spores is 1.6~2.1, without polar granules, and 6.6~9.5 × 3.7~5.0㎛ in size.

Dictyostelium microsporum (新稱 좀머리팡이)

This species is gregarious, unbranched or sparsely irregularly branched, not phototrophic, sometimes prostrated. Sorophores are colorless, 0.1~2.0mm in length, tapering from base to apex, unicellular except basal area. Clavate bases are 3.0~17.5㎛ in diameter at the thickest part, and obtuse or implicate, acuminate simple tips are 1.0~6.5 ㎛ in diameter at a level 50㎛ below the top. This dictyostelid has white oval sori, and eliptical spores with polar granules. There are two types of spores: L/W index 1.5~2.4, 3.3~5.3 × 1.7~2.8㎛ in size or L/W index 1.2~1.9, 4.4 ~5.8 × 2.8~4.3㎛.

Dictyostelium mucoroides var. *stoloniferum* (新稱 기는구슬팡이)

This species is a variety of *D. mucoroides*, and characterized by round bases, and phototrophic migration. As sori fall down in media, spores germinate immediately and after formation of pseudoplasmodium without regrowing they grow to several sorocarps within 6~8 hrs. Second sorocarps are small erect, and tapering, and don t respond to the light, but have an avoidance of the light during development stages.

Dictyostelium septentrionalis (新稱 큰구슬팡이)

This species is solitary, and unbranched, slight phototrophic, sometimes prostrated. Sorophores are colorless, multicellular, 1.5~8.2mm in length, tapering from base to apex with collar. Conical or round bases are surrounded by basal disk with 40~210 ㎛ in diameter. If this dictyostelid prostrate. A level 100㎛ above bottom is 16.0~75.0㎛ in thickness, capitate-compound tips is 5.0~35.0㎛ in diameter at a level 50㎛ below the top. Sori are white oval, spores is eliptical. Spores has L/W index 1.5~2.0, 7.6~10.4 × 4.3~6.0㎛ in size, without polar granules or with sometimes irregular granules.

Polysphondylium candidum Hagiwara(新稱 좀돌려난구슬팡이)

This species is usually solitary, sometimes clustered, not phototrophic, sometimes prostrated. It has 1~6 nodes, 2~10 whorl branches at a node. Terminal segment is very long, and 150 ~950㎛ in length. Internode segment is 300~1,130㎛ in length. The length of branches is 182~570㎛. Bases are round or clavate. The thickest part of branches is 10.0~36.5㎛ in diameter, the tips of branches are acuminate-simple. Sorophores are colorless, and thick, 0.3~7.0mm in length. Basal type is robust, usually round-like, sometimes obtuse. The thickest part of bases is 12.5~52.5㎛ in diameter. Tips are simple acuminate or obtuse. A level 50㎛ below top is 3.0~8.0㎛ in diameter, Sori are white oval, spores are eliptical, 1.8~2.6 L/W index, 8.0~11.4 × 3.7-5.5㎛ in size with polar granules.

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