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Geosmin Concentration and Its Relation to Environmental Factors in Daechung Reservoir, Korea

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The biological and physicochemical factors and geosmin concentration were monitored in the Daechung Reservoir for 25 weeks from April to October in 1999. Geosmin was detected 5 times within a range of 1.16～5.28 ng L^{-1}, mostly in the late summer. The highest geosmin concentration was recorded on August 31, which also overlapped with the peaks of phycocyanin concentration, cyanobacterial density, and *Anabaena spiroides* density. A correlation analysis indicated that geosmin production was closely related with a high water temperature, pH, total dissolved phosphorus (TDP), and *A. spiroides* density. A water temperature of 27°C, pH of 8.5, and TDP of 0.06 mg L^{-1} were identified as the prerequisite environmental conditions and threshold values for geosmin production. Accordingly, under such conditions, an *A. spiroides* density above 10,000 cells mL^{-1} indicates imminent geosmin occurrence.

Key words : *Anabaena spiroides*, Cyanobacteria, Daechung Reservoir, Geosmin, Odorous compound

INTRODUCTION

The eutrophication of lakes and reservoirs includes not only physicochemical and biological changes in the aquatic ecosystem but also an increase in the toxic compounds or dissolved organic compounds (DOC) in the water along with algal bloom. The production and consumption of DOC in an aquatic ecosystem is a very important ecological process, because it is directly and indirectly linked to primary productivity. From a public health standpoint, DOC is also critical as it can impair the potable and recreational use of water by imparting a bad taste and odor or forming disinfection byproducts during water treatment processes. The classes of such organic chemicals released include alkenes, aliphatic alcohols, aldehydes, ketones, esters, thioesters, and sulfides (Jüttner, 1983; Slater and Block, 1983).

In particular, the occurrence of geosmin (*trans*-1, 10-dimethyl-*trans*-9-decalol) and 2-methylisoborneol (1, 2, 7, 7-tetramethyl-exobicycloheptan-2-ol, MIB), which impart an earthy or musty odor to drinking water and fish is a worldwide problem. Many kinds of actinomycetes (Blevins *et al*., 1995; Dionigi, 1995) and cyanobacteria (Naes *et al*., 1989; Wu *et al*., 1991; Rosen *et al*., 1992; van der Ploeg *et al*., 1992) produce geosmin. Several kinds of protozoa (Hayes *et al*., 1991) and fungi (Mattheis and Roberts, 1992; Dionigi, 1995) are also known to produce geosmin. Therefore, geosmin is most prevalent in eutrophic lakes and reservoirs (Izaguirre *et al*.,

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1982; Yagi *et al.*, 1983; Wnorowski and Scott, 1992; Jones and Korth, 1995; Oh *et al.*, 1999). In addition, geosmin has an extremely low threshold level for producing a taste and odor, about 10 ng L^{-1} (Johnsen and Kuan, 1987). Geosmin is resistant to oxidation (Glaze *et al.*, 1990) and, therefore, difficult to be removed in conventional water treatment processes (Monteil, 1983; McGuire and Gaston, 1988).

It is known that geosmin production is affected by many environmental factors such as the type of nitrogen sources (Wu *et al.*, 1991), temperature (Blevins *et al.*, 1995), nutrient limitation (Naes and Post, 1988; Rashash *et al.*, 1995), growth phase (Rosen *et al.*, 1992), light intensity (Naes *et al.*, 1985; Naes and Post, 1988; Tsuchiya and Matsumoto, 1999), and interactions with bacteria (Aoyama *et al.*, 1995). However, the overall mechanism of geosmin synthesis is much variable on the environment.

In this study, biological and physicochemical factors and geosmin concentration were examined for 25 weeks from April to October in 1999, to identify the producers of geosmin in the Daechung Reservoir and determine the environmental factors related to the production of geosmin.

SAMPLING AND METHODS

Study area

The Daechung Reservoir is located on the upper reaches of the Geum River in the central region of South Korea (Fig. 1). The sampling site was located on the shore in the vicinity of the Daechung Dam. The depth of the sampling site was about 10 m.

Sampling

Water samples were collected every week from April 27 to October 12, 1999 from the surface (0～0.1 m) at one site nearby the Daechung Dam. The water samples were taken using 1-L polyethylene bottles and transported and stored at 4°C until analysis. The water samples for the algal biomass and cellular geosmin determination were concentrated about 1,000 times using a phytoplankton net (mesh size 10 μm). The data of precipitation and daily irradiance were obtained from the Korea Meteorological Administration.

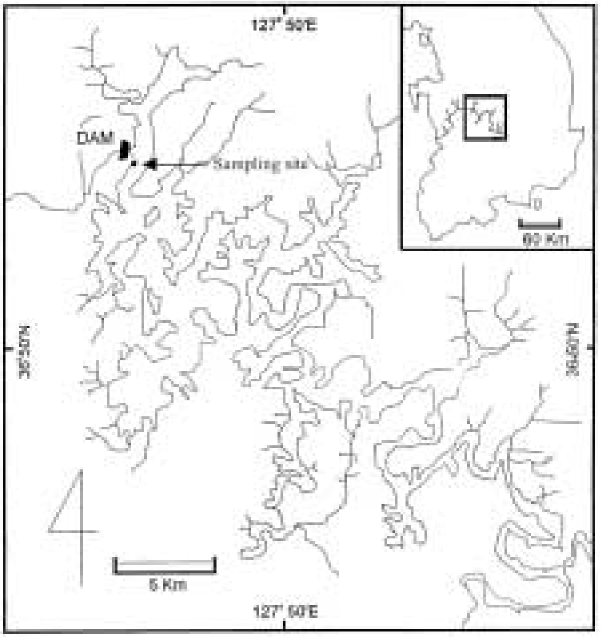

Fig. 1. Location of sampling site in Daechung Reservoir.

Physicochemical analysis of water samples

The water temperature and pH were measured using a pH meter (YSI 63) at the site. The total nitrogen (TN) and total phosphorus (TP) were determined after persulfate oxidation to nitrate (D'Elia *et al.*, 1977) and orthophosphate (Menzel and Corwin, 1965), respectively. The nitrate was determined using a Szechrome NB reagent (Wynne and Rhee, 1986) and the orthophosphate was determined by the phosphomolybdate method (APHA, 1995). The total dissolved nitrogen (TDN) and phosphorus (TDP) were determined after filtration of the water samples through a 0.45 μm cellulose filter (Millipore Type JH) and persulfate oxidation. The total particulate nitrogen (TPN) and phosphorus (TPP) were obtained by subtracting the dissolved form values from the total form values.

Biomass and phytoplankton analysis

The Chl-*a* was extracted with a chloroform-methanol mixture (2 : 1, vol/vol) and measured using a fluorometer (Turner 450) based on the method of Wood (1985). The phycocyanin was measured using a spectrophotometer (Shimadzu UV-160A) after extraction with acetone and sodium acetate (Myers *et al.*, 1978). Counting the algal cell numbers was performed with a haemacytometer (Marienfeld Fuchs–Rosenthal) under an optical microscope (Nikon Microphot FXA).

Geosmin analysis

The geosmin was analyzed using a gas chromatograph (GC) (Varian 3400 CX) equipped with a purge and trap concentrator (Tekmar 3000) (Stahl and Parkin, 1994; Park *et al*., 2000). A water sample of 25 mL was purged for 1 hour with nitrogen gas after filtration using a 0.45 μm membrane filter. The geosmin was desorbed at 245°C for 2 min and transferred directly to a chromatograph (transfer line 170°C) onto an XTI–5 fused silica column (Restek Co., 30 m × 320 μm i.d., 25 μm film thickness). The GC temperature program was set from 120°C (10 min) to 225°C (10 min) at a rate of 10°C min^{-1}. The geosmin in the water sample was identified based on a comparison with the retention time of the standard material (Sigma Co.) and then confirmed by spiking with the standard material. The concentration of geosmin in the water sample was calculated from the peak area using a standard curve.

For the analysis of geosmin in the particulate form, concentrated samples were centrifuged at 4,500 × g for 10 min in 4°C. Pellet was suspended in 10 mM potassium phosphate buffer (pH 7.0) containing 2–mercaptoethanol and disrupted by Mini–Beadbeater (Biospec product, 0.5 mm glass bead, 40 sec × 10 times). The disrupted cell suspension was centrifuged, filtered with 0.45 μm membrane filter and diluted with distilled water. All steps were performed under gas–tight condition.

Data analysis

Cell number was a mean value of seven measurements. Geosmin concentration and environmental factors were mean values of three measurements. Correlation coefficients between geosmin concentration and environmental factors were calculated using SigmaPlot 5.0 software (SPSS Inc., USA). *P* values less than 0.05 were considered statistically significant.

RESULTS

Physicochemical water quality

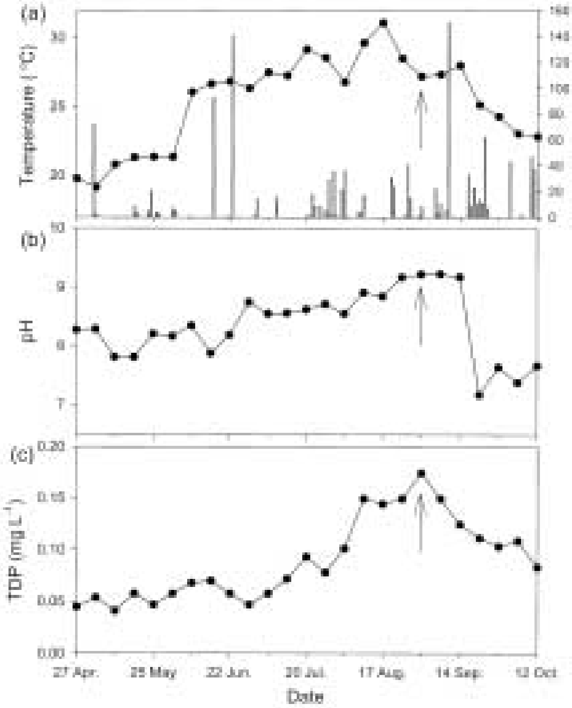

Fig. 2. Water temperature, precipitation (a), pH (b), and total dissolved phosphorus (c) in Daechung Reservoir in 1999. The arrows in the graphs indicate the time (August 31) of severe cyanobacterial bloom and geosmin production.

The Daechung Reservoir, a large branched–type, temperate, and dimictic lake with a storage capacity of 1.49 billion m^3, has been in a eutrophic state for years. The water temperature increased up to 31°C (August 17) in the summer and then decreased in September to below 25°C (Fig. 2a). Most precipitation was in the summer, particularly in late July and September, and seemed to be related to a decrease in the water temperature and pH (Fig. 2). The pH was usually above 8.0 during the investigation period, and this high pH value is a general characteristic of a eutrophic and productive lake (Fig. 2b). The pH increased above 9.0 in late August and then radically decreased to 7.7 in late September.

The TDP was highest at 0.17 mg L^{-1} on August 31 and thereafter decreased (Fig. 2c). As such, the water temperature, pH, and TDP all exhibited a similar trend, i.e. a continual increase until August, and subsequent decrease until October. As indicated by arrows in Fig. 2, these patterns closely resembled the cyanobacterial bloom, overlapping their peaks. The TP also exhibited the same pattern, yet with a slightly lower similarity. However, the TN, TDN, TPN and TPP

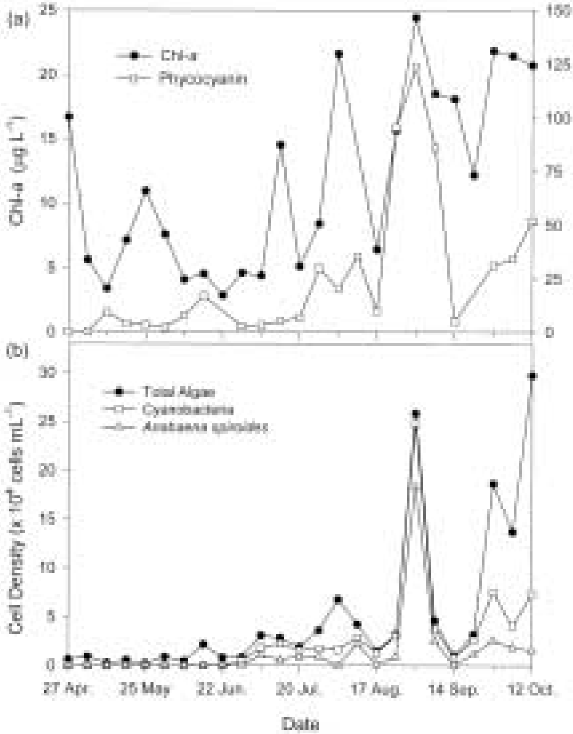

Fig. 3. Chlorophyll-*a* and phycocyanin concentrations (a). Cell densities of total algae, cyanobacteria, and *Anabaena spiroides* (b).

did not show any significant relationship with the cyanobacterial bloom (data not shown).

Cyanobacterial bloom

The Chl-*a* fluctuated significantly, although its peaks were concentrated in the summer (Fig. 3a). In contrast, the phycocyanin (cyanobacteria-specific pigment protein) showed one clear peak at 123.3 pM on August 31 (Fig. 3a). The algal blooms in the Daechung Reservoir could be attributed to the proliferation of cyanobacteria in summer, and the phycocyanin peaks were coincident with the cyanobacterial peaks (Fig. 3b). In addition, *Anabaena spiroides* made up most of the cyanobacteria throughout the sampling period. On average, *A. spiroides* made up about 40% of the cyanobacteria throughout the investigation period, yet at the time of the geosmin peak it made up 74%. Diatoms, such as *Aulacoseira granulata*, *Fragilaria crotonensis*, and *Asterionella formosa*, caused a large increase in the cell number of total algae in October.

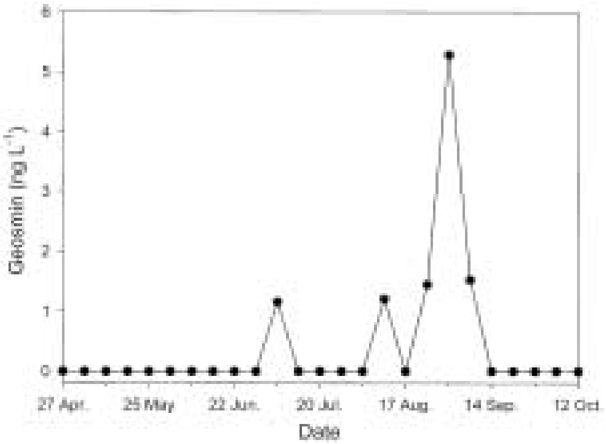

Fig. 4. Geosmin concentration in Daechung Reservoir.

Geosmin production

During the sampling period, the concentration of geosmin ranged from 1.16～5.28 ng L^{-1} and was only detected in 5 samples out of 25 (Fig. 4). A geosmin concentration below 1 ng L^{-1} could not be measured with the method used in the current study. Accordingly, geosmin at low concentrations below 1 ng L^{-1} may have been present, however, they could not be detected. Therefore, the episodes of geosmin occurrence may have been more than 5 times in reality. The analysis of geosmin was performed using two types of samples, particulate and dissolved forms. Geosmin was only detected in particulate form, thereby indicating that none or only a small amount of geosmin was released into the water from cells.

Correlation between geosmin and environmental factors

Table 1 shows that the cyanobacterial density, particularly the *A. spiroides* density, was highly correlated with the geosmin concentration ($r = 0.925$, $P < 0.001$). In addition, phycocyanin exhibited a similar high correlation ($r = 0.803$, $P < 0.001$). Therefore, any phenomena occurring along with the cyanobacterial bloom had a close relationship with *A. spiroides*. Plus biological factors showed higher correlation with the geosmin concentration than physicochemical factors (Table 1), because the geosmin production was directly related with the *A. spiroides* biomass. This indicates that biological factors can be used more

Table 1. Correlation coefficients between geosmin concentration and biological or physicochemical factors (n = 25).

Factors affecting geosmin concentration		Correlation coefficient
Biological	Cyanobacterial percentage	0.477*
	Cyanobacterial density	0.859***
	A. spiroides density	0.925***
	Phycocyanin	0.803***
Physicochemical	Total dissolved phosphorus	0.612**
	pH	0.498*
	Water temperature	0.266

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.001$

confidently for the estimation of geosmin production. In contrast, physicochemical factors can be used as earlier indicators of cyanobacterial bloom that produces geosmin.

Geosmin was detected when the cyanobacterial density exceeded about 20,000 cells mL^{-1} and the *A. spiroides* density about 10,000 cells mL^{-1} (Figs. 3, 4 and 5). The TDP concentration and pH were also apparently related with geosmin production (Fig. 5). Geosmin was detected when the TDP was above 0.15 mg L^{-1}, except on July 6 (0.058 mg L^{-1}). A pH of 8.5 was also a critical value for geosmin detection. However, these parameters did not show a linear relationship with the geosmin concentration. For the detection of geosmin, it would seem that the *A. spiroides* density, TDP, and pH all need to exceed their respective threshold values. Below these values, geosmin was not detected above 1 ng L^{-1}, yet when such parameters were above their threshold values, the geosmin concentration showed a steep increase, indicated as a circle size in Fig. 5.

DISCUSSION

The occurrence of geosmin in the Daechung Reservoir exhibited a high correlation with the phycocyanin concentration, cyanobacterial density, and *A. spiroides* density. This quantitative correlation of the occurrence of geosmin in the Daechung Reservoir was related to the cyanobacterial bloom, and showed a consistency with the result of Oh *et al.* (1999) who reported that *Anabaena* is a potent producer of geosmin. *Anabaena* is a cyanobacterial species that is most famous as a geosmin producer and frequently cited

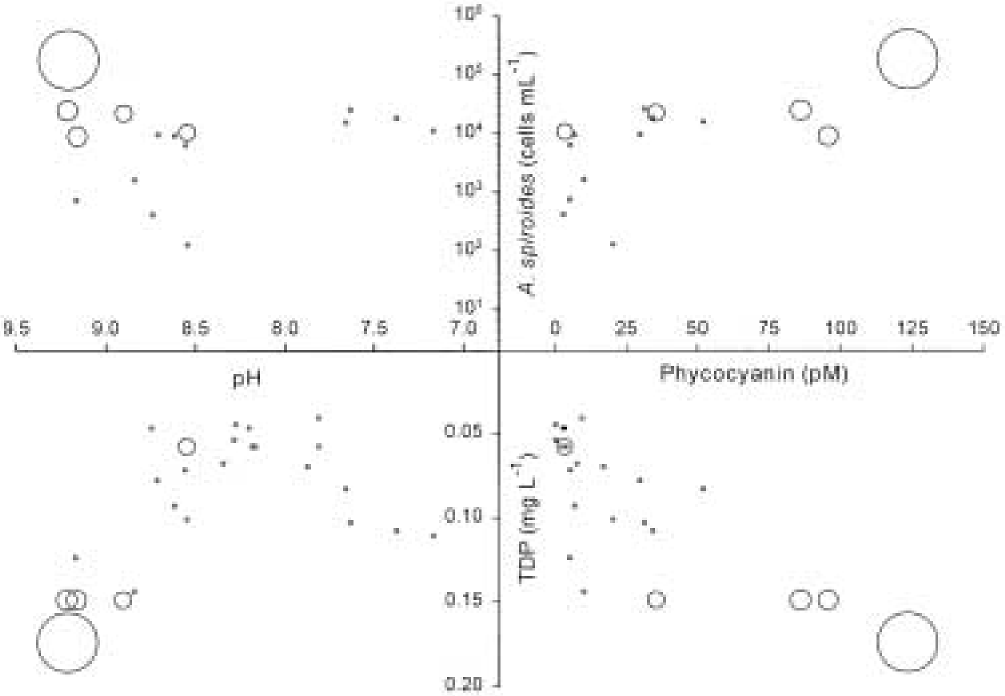

Fig. 5. Correlations between *Anabaena spiroides* density, phycocyanin, total dissolved phosphorus, pH, and geosmin concentration. The diameter of the circle is proportional to the concentration of geosmin.

globally (Wu *et al*., 1991; Bowmer *et al*., 1992; Rosen *et al*., 1992; Aoyama *et al*., 1995; Blevins *et al*., 1995; Jones and Korth, 1995). Other cyanobacterial species less frequently reported on include *Phormidium* (Izaguirre, 1992; Sugiura *et al*., 1998; Park *et al*., 2000), *Oscillatoria* (Tsuchiya and Matsumoto, 1999), *Fischerella* (Wu and Jüttner, 1988), and *Lyngbya* (Sugiura *et al*., 1998). In the current study, the average percentage of *Anabaena* in the cyanobacteria was over 40%, plus the cell density of *A. spiroides* made up over 94% of the total *Anabaena* cells during the sampling period. Accordingly, it seemed that *A. spiroides* was the primary producer of geosmin in the Daechung Reservoir.

The levels of geosmin in the Daechung Reservoir were relatively low compared with those from other countries. In 1981, Lake Biwa in Japan was reported to have 0.4 μg L^{-1} of geosmin (Yagi *et al*., 1983) and several reservoirs in South Africa during 1989～1990 showed geosmin concentrations ranging from 0.15～3.17 μg L^{-1} (Wnorowski and Scott, 1992). In the ponds of Auburn and Mississippi in the USA, geosmin was detected with a range of 0.05～8.9 μg L^{-1} (van der Ploeg *et al*., 1992). In contrast, the concentration of geosmin in the Daechung Reservoir during the investigation period was detected to be 1.16～5.28 ng L^{-1}, which was significantly lower than those in other countries. Jones and Korth (1995) reported that the average production of geosmin in *Anabaena* is 10 fg $cell^{-1}$. As such, it was possible to predict the occurrence of odor problems due to geosmin at *Anabaena* densities of >1,000～2,000 cells mL^{-1} in temperate Australian waters. In the Daechung Reservoir, the geosmin contents in the *A. spiroides* were within a range of 0.03～0.16 fg $cell^{-1}$, about 2 orders lower than those in Australia. This difference was attributed to a variation in the geosmin productivity, because the *Anabaena* densities were within a similar range. Consequently, the *Anabaena* in the Daechung Reservoir would seem to be a poor producer of geosmin.

The production of geosmin has been understood as a physiological mechanism through which cells adapt themselves to an environment (Wood and van Valen, 1990). In the Daechung Reservoir, the peak times for geosmin, phycocyanin, cyanobacteria, and *A. spiroides* all coincided, thereby implying *A. spiroides* produced geosmin. However, geosmin was not detected from September 21 to October 12, even though relatively high densities of *A. spiroides* were maintained. One possibility is that the geosmin concentrations were below the detection limit. A high density of *Anabaena* does not always ensure a high concentration of geosmin because the geosmin content per unit cell decreases as cells reach the stationary phase (Rosen *et al*., 1992). Another reason why geosmin may not have been produced was unfavorable environmental conditions, such as a low temperature and pH.

Decreases in the pH and temperature during that period would seem to be related to the non-detection of geosmin even with a high density of *A. spiroides*. The high pH value of 9.2 dropped drastically to 7.2 on September 21, and it is known that geosmin production decreases at a lower pH of about 6～7 (Park *et al*., 2000). The correlation coefficient ($r = 0.498$, $P < 0.05$) between the pH and the geosmin also indicated a significant relationship. Furthermore, the temperature decreased abruptly from 28°C to 25°C on September 21 and thereafter to 23°C on October 12. However, a lower production of geosmin with a decreased temperature is contradictory to a previous report (Blevins *et al*., 1995) where an increasing temperature was found to repress geosmin synthesis. Blevins *et al*. (1995) also showed that increasing the light intensity favors a greater geosmin synthesis. In the summer (from June to August) the daily irradiance at the Daechung Reservoir averaged 15.5 MJ m^{-2}, whereas in the autumn (from September to October) it decreased to 11.0 MJ m^{-2}. Therefore, the simultaneous decrease in the light and temperature in the autumn may have affected the geosmin production in opposite ways. The data obtained in the Daechung Reservoir would seem to indicate that the decrease in the light intensity had a more profound effect on the geosmin synthesis than the decrease in the temperature because no geosmin was detected after late September.

Park *et al*. (2000) reported that *Phormidium* sp. NIVA-CYA7 produces an increased level of geosmin per unit biomass when it is batch cultured in a low concentration of phosphorus. In addition, the unit content of microcystin, which is a cyanobacterial secondary metabolite, increases as the phosphorus concentration decreases in a P-limited chemostat (Oh *et al*., 2000). In this study, TDP and geosmin exhibited a high positive correlation ($r = 0.612$, $P < 0.01$). In contrast, the orthophosphate:TDP ratio showed a high negative correlation ($r = -0.623$, $P < 0.001$). Orthophosphate is the most readily utilizable phosphorus form for algae. The relatively increased P limitation and subsequent stimulation of geosmin production may have caused the negative correlation between the orthophosphate and the geosmin.

REFERENCES

American Public Health Association (APHA). 1995. Standard Methods for the Examination of Water and Wastewater, 19th ed. APHA, Washington, DC.

Aoyama, K., N. Kawamura, M. Saitoh, Y. Magara and Y. Ishibashi. 1995. Interactions between bacteria−free *Anabaena macrospora* clone and bacteria isolated from unialgal culture. *Water Sci. Technol.* **31**: 121−126.

Blevins, W.T., K.K. Schrader and I. Saadoun. 1995. Comparative physiology of geosmin production by *Streptomyces halstedii* and *Anabaena* sp. *Water Sci. Technol.* **31**: 127−133.

Bowmer, K.H., A. Padovan, R.L. Oliver, W. Korth and G.G. Ganf. 1992. Physiology of geosmin production by *Anabaena circinalis* isolated from the Murrumbidgee River, Australia. *Water Sci. Technol.* **25**: 259−267.

D'Elia, C. F., P.A. Steudler and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. *Limnol. Oceanogr.* **22**: 760−764.

Dionigi, C.P. 1995. The effects of copper sulfate on geosmin biosynthesis by *Streptomyces tendae, Streptomyces albidoflavus,* and *Penicillium expansum*. *Water Sci. Technol.* **31**: 135−138.

Glaze, W.H., R. Schep, W. Chauncey, E.C. Ruth, J.J. Zarnoch, E.M. Aieta, C.H. Tate and M.J. McGuire. 1990. Evaluating oxidants for the removal of model taste and odor compounds from a municipal water supply. *J. Am. Water Works Ass.* **5**: 79−84.

Hayes, S.J., K.P. Hayes and B.S. Robinson. 1991. Geosmin as an odorous metabolite in cultures of a free−living amoeba, *Vannella* species (Gymnamoebia, Vannellidae). *J. Protozool.* **38**: 44−47.

Izaguirre, G. 1992. A copper−tolerant species from Lake Mathews, California, that produces 2−methylisoborneol and geosmin. *Water Sci. Technol.* **25**: 217−223.

Izaguirre, G., C.J. Hwang, S.W. Krasner and M.J. McGuire. 1982. Geosmin and 2−methylisoborneol from cyanobacteria in three water supply systems. *Appl. Environ. Microbiol.* **43**: 708−714.

Johnsen, P.B. and J.C.W. Kuan. 1987. Simplified method to quantify geosmin and 2−methylisoborneol concentrations in water and microbiological cultures. *J. Chromatogra.* **409**: 337−342.

Jones, G.J. and W. Korth. 1995. *In situ* production of volatile odor compounds by river and reservoir phytoplankton populations in Australia. *Water Sci. Technol.* **31**: 145−153.

Jüttner, F. 1983. Volatile odorous excretion products of algae and their occurrence in the natural aquatic environment. *Water Sci. Technol.* **15**: 247−257.

Mattheis, J.P. and R.G. Roberts. 1992. Identification of geosmin as a volatile metabolite of *Penicillium expansum*. *Appl. Environ. Microbiol.* **58**: 3170−3172.

McGuire, M.J. and J.M. Gaston. 1988. Overview of technology for controlling off−flavors in drinking water. *Water Sci. Technol.* **20**: 215−228.

Menzel, D.W. and N. Corwin. 1965. The measurement of total phosphorus in seawater based on the liberation of organically bound fractions by persulfate oxidation. *Limnol. Oceanogr.* **10**: 280−282.

Monteil, A.J. 1983. Municipal drinking water treatment procedures for taste and odour abatement−A review. *Water Sci. Technol.* **15**: 279−289.

Myers, J., J.R. Graham and R.T. Wang. 1978. On spectral control of pigmentation in *Anacystis nidulans* (Cyanophyceae). *J. Phycol.* **14**: 513−518.

Naes, H., H. Aarnes, H.C. Utkilen, S. Nilsen and O.M. Skulberg. 1985. Effect of photon fluence rate and specific growth rate on geosmin production of the cyanobacterium *Oscillatoria brevis* (Kütz.) Gom. *Appl. Environ. Microbiol.* **49**: 1538−1540.

Naes, H. and A.F. Post. 1988. Transient states of geosmin, pigments, carbohydrates and proteins in continuous cultures of *Oscillatoria brevis* induced by changes in nitrogen supply. *Arch. Microbiol.* **150**: 333−337.

Naes, H., H.C. Utkilen and A.F. Post. 1989. Geosmin production in the cyanobacterium *Oscillatoria brevis. Arch. Microbiol.* **151**: 407−410.

Oh, H.−M., Y.−H. Ban, D.−K. Park, J.−W. Lee and J. Maeng. 1999. Production of odorous compounds by cyanobacteria in Daechung Reservoir. *Korean J. Limnol.* **32**: 181−188.

Oh, H.−M., S.J. Lee, M.−H. Jang and B.−D Yoon. 2000. Microcystin production by *Microcystis aeruginosa* in a phosphorus−limited chemostat. *Appl. Environ. Microbiol.* **66**: 176−179.

Park, D.−K., H.−M. Oh, C.−Y. Ahn and J. Maeng. 2000. Effect of selected environmental factors on the production of geosmin in *Phormidium* sp. *Korean J. Microbiol.* **36**: 52−57.

Rashash, D.M.C., A.M. Dietrich, R.C. Hoehn and B.C. Parker. 1995. The influence of growth conditions on odor−compound production by two chrysophytes and two cyanobacteria. *Water Sci. Technol.* **31**: 165−172.

Rosen, B.H., B.W. MacLeod and M.R. Simpson. 1992.

Accumulation and release of geosmin during the growth phases of *Anabaena circinalis* (Kütz.) Rabenhorst. *Water Sci. Technol.* **25**: 185-190.

Slater, G.P. and V.C. Block. 1983. Isolation and identification of compounds from a lake subject to cyanobacterial blooms. *Water Sci. Technol.* **15**: 229-240.

Stahl, P.D. and T.B. Parkin. 1994. Purge-and-trap extraction of geosmin and 2-methylisoborneol from soil. *Soil Sci. Soc. Am. J.* **58**: 1163-1167.

Sugiura, N., N. Iwami, Y. Inamori, O. Nishimura and R. Sudo. 1998. Significance of attached cyanobacteria relevant to the occurrence of musty odor in Lake Kasumigaura. *Water Res.* **32**: 3549-3554.

Tsuchiya, Y. and A. Matsumoto. 1999. Characterization of *Oscillatoria* f. *granulata* producing 2-methylisoborneol and geosmin. *Water Sci. Technol.* **40**: 245-250.

van der Ploeg, M., C.S. Tucker and C.E. Boyd. 1992. Geosmin and 2-methylisoborneol production by cyanobacteria in fish ponds in the southeastern United States. *Water Sci. Technol.* **25**: 283-290.

Wnorowski, A.U. and W.E. Scott. 1992. Incidence of off-flavors in South African surface waters. *Water Sci. Technol.* **25**: 225-232.

Wood, A.M. and L.M. van Valen. 1990. Paradox lost? On the release of energy-rich compounds by phytoplankton. *Mar. Microbial Food Webs* **4**: 103-116.

Wood, L.W. 1985. Chloroform-methanol extraction of chlorophyll-*a*. *Can. J. Fish. Aquat. Sci.* **42**: 38-43.

Wu, J.T. and F. Jüttner. 1988. Effect of environmental factors on geosmin production by *Fischerella muscicola*. *Water Sci. Technol.* **20**: 143-148.

Wu, J.T., P.I. Ma and T.L. Chou. 1991. Variation of geosmin content in *Anabaena* cells and its relation to nitrogen utilization. *Arch. Microbiol.* **157**: 66-69.

Wynne, D. and G-Y. Rhee. 1986. Effects of light intensity and quality on the relative N and P requirement (the optimum N : P ratio) of marine planktonic algae. *J. Plankton Res.* **8**: 91-103.

Yagi, M., M. Kajino, U. Matsuo, K. Ashitani, T. Kita and T. Nakamura. 1983. Odor problems in Lake Biwa. *Water Sci. Technol.* **15**: 311-321.

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<국문적요>

대청호의 geosmin 농도와 환경요인과의 관계

박대균[1] · 맹주선[1] · 안치용[2] · 정안식[2] · 이진환[3] · 오희목*

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대청호에서 1999년 4월부터 10월까지 25주간에 걸쳐 이화학적, 생물학적 수질과 geosmin 농도를 조사하였다. Geosmin은 대부분 늦은 여름에 1.16～5.28 ng L^{-1}의 농도로 총 5회 검출되었다. Geosmin의 가장 높은 농도는 8월 31일로 조사되었으며, phycocyanin 농도, cyanobacteria 세포수, *Anabaena spiroides* 세포수 등이 최고조에 달하는 시기와 일치하였다. Geosmin 농도와 환경요인과의 상관분석에 의하면 geosmin 생산은 수온, pH, 총용존인 그리고 *A. spiroides* 세포수에 의하여 크게 결정되는 것으로 보인다. Geosmin 생산은 수온 27°C, pH는 8.5, 총용존인은 0.06 mg L^{-1} 이상의 조건에서 나타났다. 이와 같은 조건에서 *A. spiroides* 세포수가 10,000 mL^{-1} 이상이면 geosmin이 검출된다고 볼 수 있다.