Deinococcus yunweiensis sp. nov., a gamma- and UV-radiation-resistant bacterium from China

Yu-Qin Zhang,^{1,2†} Cheng-Hang Sun,^{1†} Wen-Jun Li,^{1,2} Li-Yan Yu,¹
Jian-Qin Zhou,¹ Yue-Qin Zhang,¹ Li-Hua Xu² and Cheng-Lin Jiang²

Correspondence

Wen-Jun Li
wjli@ynu.edu.cn

¹Institute of Medicinal Biotechnology, Chinese Academy of Medical Sciences & Peking Union Medical College, Beijing 100050, People's Republic of China

²Laboratory for Conservation and Utilization of Bio-Resources, Yunnan Institute of Microbiology, Yunnan University, Kunming, Yunnan, 650091, People's Republic of China

A Gram-negative, non-spore-forming, non-motile, rod-shaped, red-pigmented strain, designated YIM 007^T, was found as a contaminant on an agar plate in the laboratory of Yunnan Institute of Microbiology, China. The optimum growth pH and temperature for the isolate were 7.0–7.5 and 30 °C, respectively. The predominant respiratory quinone was MK-8. The polar lipid profile consisted mainly of various unknown phosphoglycerolipids and glycolipids. The major cellular fatty acids were C_{16:1}ω7c, C_{16:0}, C_{17:0} and C_{17:1}ω8c. L-Ornithine was detected in its peptidoglycan. The DNA G + C content was 64.1 mol%. Phylogenetic analysis based on 16S rRNA gene sequences indicated that strain YIM 007^T showed 16S rRNA gene sequence similarity levels of 86.8–92.1 % to the other described *Deinococcus* species. Based on the high 16S rRNA gene sequence divergence and phenotypic differences, it is proposed that the unknown strain should be classified as a novel species in the genus *Deinococcus* with the name *Deinococcus yunweiensis* sp. nov. The type strain is YIM 007^T (=KCTC 3962^T=DSM 17005^T).

The members of the genus *Deinococcus* are non-spore-forming, non-motile, coccoid or rod-shaped cells that exhibit a remarkable capacity to resist the lethal effects of ionizing radiation (Minton, 1994; Moseley, 1983; Smith *et al.*, 1992). The colony colour of most members of this genus is bright red, orange or light pink and the surface of the colonies is usually dry with pleats. At the time of writing, the genus *Deinococcus* comprises 20 species with validly published names (Suresh *et al.*, 2004; Ferreira *et al.*, 1997; Rainey *et al.*, 1997; Brooks & Murray, 1981; de Groot *et al.*, 2005; Rainey *et al.*, 2005; Lai *et al.*, 2006), including 11 recently named species, *Deinococcus deserti*, *D. ficus*, *D. hohokamensis*, *D. navajonensis*, *D. hopiensis*, *D. apachensis*, *D. maricopensis*, *D. pimensis*, *D. yavapaiensis*, *D. papagoneensis* and *D. sonorensis* (de Groot *et al.*, 2005; Rainey *et al.*, 2005; Lai *et al.*, 2006). Of these 20 species, which were isolated from a wide range of environments, *Deinococcus radiodurans*, the type species of this genus, has been studied most extensively to elucidate the mechanisms of radiation-resistance, and it has been determined that the radio-resistance of this species is a direct result of its ability to repair efficiently the DNA damage generated during

irradiation (Smith *et al.*, 1992; Minton, 1994; Mattimore & Battista, 1996; Battista, 1997; Battista *et al.*, 1999). In this paper, we report the results of a polyphasic study of another hitherto-unknown gamma- and UV-radiation-resistant strain, designated YIM 007^T, which was found on a contaminated plate in our laboratory.

A red-pigmented contaminant was found on a yeast extract-malt extract agar plate [4.0 % yeast extract, 10.0 % malt extract, 4.0 % glucose, 2.0 % agar; ISP 2 medium (Shirling & Gottlieb, 1966)] with a bacterial culture at 28 °C for about 2 weeks. It was then picked and serially diluted on ISP 2 agar plates. The purified strain, designated YIM 007^T, was maintained on ISP 2 agar slants at 4 °C and as a 20 % (w/v) glycerol suspension at –20 °C. Biomass for chemical and molecular studies was obtained by cultivation using ISP 2 broth or trypticase soy broth (Difco) (30 °C, 5 days, 150 r.p.m.).

Morphology and motility of cells grown for 12–48 h on ISP 2 agar medium were examined by light microscopy (model BH 2; Olympus) and using a Hitachi H-800 transmission electron microscope (TEM). For TEM observation, cells were negatively stained with 1 % (w/v) phosphotungstic acid after air-drying. Motility and flagella observation was performed using semi-solid agar and the staining method of Leifson (1960). Gram staining was carried out using the standard Gram reaction (Gram, 1884). Growth at different temperatures and pH was investigated as described by Xu

†These authors contributed equally to this work.

The GenBank/EMBL/DDBJ accession number for the 16S rRNA gene sequence of strain YIM 007^T is DQ344634.

Fatty acid profiles of strain YIM 007^T and related strains are available as supplementary material in IJSEM Online.

et al. (2005), but using ISP 2 as the basic medium. Tolerance to NaCl (0.5, 1, 3, 7, 10, 13 and 15 %) was also tested using ISP 2 medium. Metabolic properties were determined using API ID 32 E and API 32 GN test kits (bioMérieux) according to the manufacturer's instructions. Other physiological and biochemical tests were performed as described previously (Li *et al.*, 2004).

To determine the tolerance of the isolate to UV radiation, the cultures were grown in the appropriate liquid medium to the exponential phase. The cells were recovered by centrifugation, washed with 0.067 M potassium phosphate buffer at pH 7.0 and then diluted serially, and 0.1 ml was spread on ISP 2 agar plates (with their lids open) and then exposed to UV light at a distance of 30 cm from a UV source for the required dose and were then incubated at 30 °C for 14 days. For the gamma-radiation-resistance determination, cells were prepared as above and then exposed at room temperature to gamma radiation from a cobalt-60 source at doses of 1 and 8 kGy h⁻¹. After exposure to 0.1, 3, 5, 9, 10 and 20 kGy, suspensions were diluted in triplicate on the appropriate solid medium. Growth after 15 days was scored as positive or negative in comparison to an unirradiated control. At the same time, *D. radiodurans* AS 1.633^T and *Escherichia coli* DH5 α (both from the China General Microbiological Culture Collection Center, Beijing) were tested as positive and negative controls. Relative survival was determined by comparing with unirradiated cultures.

Purified peptidoglycan was prepared and analysed by the method of Schleifer & Kandler (1972). The respiratory quinone was isolated using the methods of Minnikin *et al.* (1984) and separated by HPLC (Kroppenstedt, 1982). Analysis of the cellular fatty acid pattern followed described methods (Miller, 1982) using the MIDI system (Microbial ID, Inc.). Polar lipids were extracted and analysed by two-dimensional TLC according to Tindall (1990). The DNA base composition of strain YIM 007^T was determined by using the thermal denaturation method (Marmur & Doty, 1962).

Extraction and amplification of genomic DNA for 16S rRNA gene sequence analysis were carried out as described by Xu *et al.* (2003). Multiple alignments with sequences of a broad selection of related species and calculations of levels of sequence similarity were carried out using CLUSTAL X (Thompson *et al.*, 1997). A phylogenetic tree (Fig. 1) was reconstructed using the neighbour-joining method of Saitou & Nei (1987) from K_{nuc} values (Kimura, 1980, 1983). The topology of the phylogenetic tree was evaluated by the bootstrap resampling method of Felsenstein (1985) with 1000 replicates.

The cells of strain YIM 007^T were aerobic, non-spore-forming, non-motile rods. Cells of *Deinococcus grandis*, *Deinococcus indicus* and *D. deserti* are also rod-shaped (Suresh *et al.*, 2004; de Groot *et al.*, 2005), whereas those of all other members of the genus are spherical (Rainey *et al.*, 1997; Hirsch *et al.*, 2004). As with cells of *D. indicus*, *D.*

Fig. 1. Phylogenetic dendrogram obtained by distance-matrix analysis of 16S rRNA gene sequences, showing the position of strain YIM 007^T among its phylogenetic neighbours. Numbers on branch nodes are bootstrap values (percentages of 1000 resamplings; only values > 70 % are given). The sequence of *Thermus aquaticus* YT-1 (GenBank accession no. L09663) was used as the root (not shown). Bar, 2 % sequence divergence.

grandis and *D. deserti*, strain YIM 007^T stained Gram-negative, whereas those of other *Deinococcus* species stain Gram-positive (Suresh *et al.*, 2004; Hirsch *et al.*, 2004). Colonies of strain YIM 007^T were red, circular, shining and opaque on most agar media tested. The temperature range for growth was 10–50 °C, with optimum growth at 30 °C. The pH range for growth was 6.0–9.0, with optimum growth occurring between pH 7.0 and 7.5. The other physiological and biochemical properties of strain YIM 007^T are listed in Table 1 or in the species description.

The survival rate of cultures of strain YIM 007^T after exposure to increasing doses of gamma and UV radiation was analysed in comparison with *D. radiodurans* AS 1.633^T and *E. coli* DH5 α . There was no growth for *E. coli* DH5 α at a dose of 3.0 kGy gamma radiation, whereas almost no decrease in survival was observed for strains *D. radiodurans* AS 1.633^T and YIM 007^T. At 16.0 kGy gamma radiation, there was still growth for *D. radiodurans* AS 1.633^T and YIM 007^T. As for UV radiation tolerance, the lethal dose of UV radiation for *E. coli* DH5 α was 30 J m⁻², whereas strains YIM 007^T and *D. radiodurans* AS 1.633^T could grow at the highest dose of 624 J m⁻².

The peptidoglycan of strain YIM 007^T contained L-ornithine. The predominant respiratory quinone was detected as MK-8. The major fatty acids were monounsaturated and straight-chain saturated fatty acids, such as

Table 1. Properties of strain YIM 007^T useful for differentiation from selected species of the genus *Deinococcus*

Strains: 1, strain YIM 007^T (*D. yunweiensis* sp. nov.) (data from this study); 2, *D. sonorensis* KR-87^T (data from Rainey *et al.*, 2005); 3, *D. murrayi* ALT-1b^T; 4, *D. geothermalis* AG-3a^T (data in columns 3 and 4 from Ferreira *et al.*, 1997); 5, *D. apachensis* KR-36^T; 6, *D. hopiensis* KR-140^T; 7, *D. radiodurans* ATCC 13939^T (data in columns 5–7 from Rainey *et al.*, 2005). +, Positive; –, negative; ND, no data available.

Characteristic	1	2	3	4	5	6	7
Morphology	Rod	Spherical or short rod	Spherical	Spherical	Spherical	Spherical	Spherical
Gram stain	Negative	Positive	Positive	Positive	Positive	Positive	Positive
Motility	–	–	–	–	+	–	–
Temperature for growth (°C)							
Range	10–50	ND	30–52.5	30–55	ND	ND	ND
Optimum	30	30	47	47	30	30	30
pH for growth							
Range	6.0–9.0	ND	5.0–10.5	4.0–9.0	ND	ND	ND
Optimum	7.0–7.5	ND	8.0	6.5	ND	ND	ND
Carbon utilization							
Rhamnose	+	+	–	+	+	+	–
Ribose	–	+	–	ND	–	+	+
Trehalose	–	+	+	+	+	+	+
Mannitol	+	ND	–	+	ND	ND	ND
D-Melibiose	+	+	–	–	ND	ND	ND
Sorbitol	+	ND	–	+	ND	ND	ND
L-Arabinose	+	+	–	–	+	+	–
Major fatty acids (> 10%)	16:1 ω 7c (27.74 %); 16:0 (26.03 %); 17:0 (13.43 %)	15:1 ω 6c (12.7 %); 15:0 (10.3 %); 16:0 iso (12.5 %); 16:1 ω 7c (13.1 %)	17:1 ω 9c iso (19.9 %); 17:0 iso (11.6 %); 17:0 (10.4 %)	15:0 iso (24.8 %); 17:0 iso (35.3 %)	15:0 iso (11.2 %); 16:0 iso (10.5 %); 16:1 ω 7c (10.6 %); 17:0 iso (10.8 %)	16:1 ω 7c (51.1 %); 16:0 (13.6 %)	16:1 ω 7c (39.9 %); 16:0 (14.1 %); 17:1 ω 8c (11.8 %)
DNA G + C content (mol%)	64.1	70.3	69.9	65.9	68.5	66.2	67.0
Source	Contaminated plate	Desert soil	Hot spring	Hot spring	Desert soil	Desert soil	Ground pork and beef

$C_{16:1\omega7c}$, $C_{16:0}$, $C_{17:0}$ and $C_{17:1\omega8c}$, which were also predominant in most other *Deinococcus* species (see Supplementary Table S1 available in IJSEM Online). Specifically, for the new isolate YIM 007^T, relative amounts of some straight-chain saturated components, such as $C_{16:0}$, $C_{17:0}$, $C_{18:0}$, were higher than in any other described *Deinococcus* species (Supplementary Table S1).

The results of two-dimensional TLC analysis of polar lipids extracted from *D. radiodurans* AS 1.633^T and strain YIM 007^T are shown in Fig. 2. Based on their staining behaviour, the polar lipid profiles of the two strains consisted of various unknown phosphoglycolipids (three in total) and glycolipids (five in total), and an unknown phospholipid and an unknown aminophospholipid were also detected. Polar lipid profiles of both strains were dominated by phosphoglycolipids, which is consistent with previously reported

results for some *Deinococcus* species (Thompson *et al.*, 1980; Counsell & Murray, 1986; Embley *et al.*, 1987). *D. radiodurans* AS 1.633^T exhibited an unknown glycolipid component (GL5) and a relatively larger amount of unknown phosphoglycolipids PGL1 and PGL2, distinguishing it from YIM 007^T. Strain YIM 007^T showed an unknown phosphoglycolipid (PGL3) that was not detected in *D. radiodurans* AS 1.633^T. The chromatographic behaviour of the polar lipids GL1–GL4, PGL1, PGL2 and PGL3 of strain YIM 007^T was similar to the polar lipid spots GL1–GL4, PGL1, PGL2 and PGL4 reported for *D. ficus* (Lai *et al.*, 2006) and the polar lipids reported for *Deinococcus radiophilus* D16 and *Deinococcus radiopugnans* D17 (Embley *et al.*, 1987). The presence of these lipids in extracts of strain YIM 007^T confirms its assignment to the genus *Deinococcus*.

Comparison of the almost-complete 16S rRNA gene sequence (1459 bp) of strain YIM 007^T with homologous sequences of a wide range of related type strains revealed that strain YIM 007^T showed 16S rRNA gene sequence similarity levels of 86.8–92.1 % to the other described *Deinococcus* species. A distance matrix dendrogram is shown in Fig. 1. In the dendrogram, strain YIM 007^T is encompassed by the major branch of the genus *Deinococcus*. The DNA G+C content was determined to be 64.1 mol%.

The results of 16S rRNA gene sequence comparison together with chemotaxonomic data clearly demonstrate that strain YIM 007^T is a member of the genus *Deinococcus*. However, strain YIM 007^T forms a separate lineage within the genus (Fig. 1). Additionally, strain YIM 007^T differs from some other *Deinococcus* species with validly published names in some phenotypic characteristics (Table 1). Therefore, based on the above phenotypic and genotypic data, it is proposed that strain YIM 007^T represents a novel species of the genus *Deinococcus*, for which the name *Deinococcus yunweiensis* sp. nov. is proposed.

Description of *Deinococcus yunweiensis* sp. nov.

Deinococcus yunweiensis (yun.wei.en'sis. N.L. masc. adj. *yunweiensis* pertaining to Yunwei, an abbreviation of the Chinese name of Yunnan Institute of Microbiology, China, where the type strain was isolated).

Aerobic, Gram-negative, non-spore-forming, non-motile rods. The colony colour on most tested media is reddish. Colonies are circular, opaque and approximately 1.5–2.8 mm in diameter after incubation on ISP 2 medium for 24 h at 30 °C. The optimum growth pH, NaCl concentration and temperature are respectively pH 7.0–7.5, 0–1 % and 30 °C. Resistant to gamma (>16 kGy) and UV (>624 J m⁻²) irradiation. Catalase and oxidase reactions are positive. Casein is decomposed, while starch and Tween 80 are not decomposed. Positive for urease, lipase, α -maltosidase, β -glucuronidase, α -galactosidase, *N*-acetylglucosaminidase, β -glucosidase, lysine decarboxylase,

Fig. 2. Two-dimensional TLC of polar lipids of *D. radiodurans* AS 1.633^T (a) and isolate YIM 007^T (b). GL1–GL5, Unidentified glycolipids; PGL1–PGL3, unidentified phosphoglycolipids; PL, unidentified phospholipids; APL, unidentified aminophospholipid; PIG1 and PIG2, pigments.

gelatin liquefaction, methyl red test and Tween 20 esterase, while negative for ornithine decarboxylase, arginine dihydrolase and nitrate reduction. Glucose, rhamnose, sucrose, maltose, malonate, mannitol, salicin, D-melibiose, sorbitol, L-arabinose and galacturonate can be utilized as sole carbon sources. The peptidoglycan contains L-ornithine. The predominant respiratory quinone is MK-8. The polar lipid profile consists mainly of various unknown phosphoglycerolipids and glycolipids. The cellular fatty acids are C_{16:1}ω7c (27.7 %), C_{16:0} (26.0 %), C_{17:0} (13.4 %), C_{17:1}ω8c (9.4 %), C_{18:0} (5.0 %) and small amounts of i-C_{11:0} (0.5 %), C_{12:0} (0.6 %), i-C_{13:0} (1.0 %), C_{15:1}ω6c (0.4 %), C_{15:0} (1.8 %), C_{16:1}ω9c (0.8 %), i-C_{17:0} (1.4 %), C_{17:1}ω6c (1.4 %), i-C_{17:1}ω9c (1.4 %), C_{18:1}ω7c (2.8 %) and C_{18:1}ω9c (4.1 %). The DNA G+C content of the type strain is 64.1 mol%.

The type strain is strain YIM 007^T (= DSM 17005^T = KCTC 3962^T).

Acknowledgements

This research was supported by the National Basic Research Program of China (project no. 2004CB719601), the National Natural Science Foundation of China (project nos 30240005 and 3060001) and the Yunnan Provincial Natural Science Foundation (project no. 2004C0002Q); W.-J. L. was also supported by the Program for New Century Excellent Talent in University (NCET).

References

- Battista, J. R. (1997).** Against all odds: the survival strategies of *Deinococcus radiodurans*. *Annu Rev Microbiol* **51**, 203–224.
- Battista, J. R., Earl, A. M. & Park, M. J. (1999).** Why is *Deinococcus radiodurans* so resistant to ionizing radiation? *Trends Microbiol* **7**, 362–365.
- Brooks, B. W. & Murray, R. G. E. (1981).** Nomenclature for “*Micrococcus radiodurans*” and other radiation-resistant cocci: *Deinococcaceae* fam. nov. and *Deinococcus* gen. nov., including five species. *Int J Syst Bacteriol* **31**, 353–360.
- Counsell, T. J. & Murray, R. G. E. (1986).** Polar lipid profiles of the genus *Deinococcus*. *Int J Syst Bacteriol* **36**, 202–206.
- de Groot, A., Chapon, V., Servant, P., Christen, R., Fischer-Le Saux, M., Sommer, S. & Heulin, T. (2005).** *Deinococcus deserti* sp. nov., a gamma-radiation-tolerant bacterium isolated from the Sahara Desert. *Int J Syst Evol Microbiol* **55**, 2441–2446.
- Embley, T. M., O'Donnell, A. G., Watt, R. & Rostron, J. (1987).** Lipid and cell wall amino acid composition in the classification of members of the genus *Deinococcus*. *Syst Appl Microbiol* **10**, 20–27.
- Felsenstein, J. (1985).** Conference limits on phylogenies: an approach using the bootstrap. *Evolution* **39**, 783–789.
- Ferreira, A. C., Nobre, M. F., Rainey, F. A., Silva, M. T., Wait, R., Burghardt, J., Chung, A. P. & da Costa, M. S. (1997).** *Deinococcus geothermalis* sp. nov. and *Deinococcus murrayi* sp. nov., two extremely radiation-resistant and slightly thermophilic species from hot springs. *Int J Syst Bacteriol* **47**, 939–947.
- Gram, H. C. (1884).** Über die isolierte Färbung der Schizomyceten in Schnitt- und Trockenpräparaten. *Fortschr Med* **2**, 185–189 (in German).
- Hirsch, P., Gallikowski, C. A., Siebert, J., Peissl, K., Kroppenstedt, R. M., Schumann, P., Stackebrandt, E. & Anderson, R. (2004).** *Deinococcus frigens* sp. nov., *Deinococcus saxicola* sp. nov., and *Deinococcus marmoris* sp. nov., low temperature and draught-tolerating, UV-resistant bacteria from continental Antarctica. *Syst Appl Microbiol* **27**, 636–645.
- Kimura, M. (1980).** A simple method for estimating evolutionary rates of base substitutions through comparative studies of nucleotide sequence. *J Mol Evol* **16**, 111–120.
- Kimura, M. (1983).** *The Neutral Theory of Molecular Evolution*. Cambridge: Cambridge University Press.
- Kroppenstedt, R. M. (1982).** Separation of bacterial menaquinones by HPLC using reverse phase (RP 18) and a silver loaded ion exchanger as stationary phases. *J Liq Chromatogr* **5**, 2359–2387.
- Lai, W. A., Kämpfer, P., Arun, A. B., Shen, F. T., Huber, B., Rekha, P. D. & Young, C. C. (2006).** *Deinococcus ficus* sp. nov., isolated from the rhizosphere of *Ficus religiosa* L. *Int J Syst Evol Microbiol* **56**, 787–791.
- Leifson, E. (1960).** *Atlas of Bacterial Flagellation*. London: Academic Press.
- Li, W.-J., Zhang, Y.-Q., Park, D.-J., Li, C.-T., Xu, L.-H., Kim, C.-J. & Jiang, C.-L. (2004).** *Duganella violaceinigra* sp. nov., a novel mesophilic bacterium isolated from forest soil. *Int J Syst Evol Microbiol* **54**, 1811–1814.
- Marmur, J. & Doty, P. (1962).** Determination of the base composition of deoxyribonucleic acid from its thermal denaturation temperature. *J Mol Biol* **5**, 109–118.
- Mattimore, V. & Battista, J. R. (1996).** Radioresistance of *Deinococcus radiodurans*: functions necessary to survive ionizing radiation are also necessary to survive prolonged desiccation. *J Bacteriol* **178**, 633–637.
- Miller, L. T. (1982).** Single derivatization method for routine analysis of bacterial whole-cell, fatty acids methyl esters, including hydroxy acids. *J Clin Microbiol* **16**, 584–586.
- Minnikin, D. E., O'Donnell, A. G., Goodfellow, M., Alderson, G., Athalye, M., Schaal, A. & Parlett, J. H. (1984).** An integrated procedure for the extraction of isoprenoid quinones and polar lipids. *J Microbiol Methods* **2**, 233–241.
- Minton, K. W. (1994).** DNA repair in the extremely radioresistant bacterium *Deinococcus radiodurans*. *Mol Microbiol* **13**, 9–15.
- Moseley, B. E. B. (1983).** Photobiology and radiobiology of *Micrococcus* (*Deinococcus*) *radiodurans*. *Photochem Photobiol Rev* **7**, 223–275.
- Rainey, F. A., Nobre, M. F., Schumann, P., Stackebrandt, E. & da Costa, M. S. (1997).** Phylogenetic diversity of the deinococci as determined by 16S ribosomal DNA sequence comparison. *Int J Syst Bacteriol* **47**, 510–514.
- Rainey, F. A., Ray, K., Ferreira, M., Gatz, B. Z., Nobre, M. F., Bagaley, D., Rash, B. A., Park, M.-J., Earl, A. M. & other authors (2005).** Extensive diversity of ionizing-radiation-resistant bacteria recovered from a Sonoran Desert soil and the description of nine new species of the genus *Deinococcus* obtained from a single soil sample. *Appl Environ Microbiol* **71**, 5225–5235.
- Saitou, N. & Nei, M. (1987).** The neighbor-joining method: a new method for reconstructing phylogenetic tree. *Mol Biol Evol* **4**, 406–425.
- Schleifer, K. H. & Kandler, O. (1972).** Peptidoglycan types of bacterial cell walls and their taxonomic implications. *Bacteriol Rev* **36**, 407–477.
- Shirling, E. B. & Gottlieb, D. (1966).** Methods for characterization of *Streptomyces* species. *Int J Syst Bacteriol* **16**, 313–340.
- Smith, M. D., Masters, C. I., & Moseley, B. E. B. (1992).** Molecular biology of radiation resistant bacteria. In *Molecular Biology and*

Biotechnology of Extremophiles, pp. 258–280. Edited by R. A. Herbert & R. J. Sharp. New York: Chapman & Hall.

Suresh, K., Reddy, G. S. N., Sengupta, S. & Shivaji, S. (2004). *Deinococcus indicus* sp. nov., an arsenic-resistant bacterium from an aquifer in West Bengal, India. *Int J Syst Evol Microbiol* **54**, 457–461.

Thompson, B. G., Anderson, R. & Murray, R. G. (1980). Unusual polar lipids of *Micrococcus radiodurans* strain Sark. *Can J Microbiol* **26**, 1408–1411.

Thompson, J. D., Gibson, T. J., Plewniak, F., Jeanmougin, F. & Higgins, D. G. (1997). The CLUSTAL X windows interface: flexible

strategies for multiple sequence alignment aided by quality analysis tools. *Nucleic Acids Res* **25**, 4876–4882.

Tindall, B. J. (1990). Lipid composition of *Halobacterium lacusprofundi*. *FEMS Microbiol Lett* **66**, 199–202.

Xu, P., Li, W. J., Xu, L. H. & Jiang, C. L. (2003). A microwave-based method for genomic DNA extraction from actinomycetes. *Microbiology (Beijing)* **30**, 82–84 (in Chinese).

Xu, P., Li, W.-J., Tang, S.-K., Zhang, Y.-Q., Chen, G.-Z., Chen, H.-H., Xu, L.-H. & Jiang, C.-L. (2005). *Naxibacter alkalitolerans* gen. nov., sp. nov., a novel member of the family ‘*Oxalobacteraceae*’ isolated from China. *Int J Syst Evol Microbiol* **55**, 1149–1153.