Streptomyces capillispiralis sp. nov.

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A *Streptomyces* isolate that produces a cephalosporin C-4 carboxymethyl esterase is proposed as a new species, *Streptomyces capillispiralis*. The key characteristics of this species are gray spore mass color, spiral spore chains, and hairy spores. When simultaneous laboratory comparisons were made with cultures of similar *Streptomyces* species, the new isolate differed from them significantly. The type strain of *S. capillispiralis* is A49492 (= NRRL 12279). A separate paper dealing with the carboxymethyl esterase of this organism will be published in the future.

Strain A49492 was isolated in the course of a culture isolation program from a soil sample collected in Sweden. The organism differs significantly enough from other related species to warrant designation as a new species of the genus *Streptomyces*. Morphological and physiological data are reported to support recognition of a new species. A description of this organism and a discussion of its taxonomic position are also presented.

MATERIALS AND METHODS

Bacterial strains. Strain A49492 was isolated from a soil sample collected in Sweden. For comparative purposes, the following strains were also studied: *S. flaveolus* ATCC 3319 and "*S. flavoviridis*" ATCC 19903, which are strains from the Lilly culture collection; and *S. calvus* ATCC 13382, "*S. heimi*" ATCC 25460, "*S. malachitofuscus*" ATCC 25471, and *S. pilosus* ATCC 19797, which were obtained directly from the American Type Culture Collection (ATCC), Rockville, Md. (names in quotation marks are not on the Approved Lists of Bacterial Names [11] and have not been validly published as of 1 January 1980). These strains are the type strains of these species, as indicated in the Approved Lists (11) and the ATCC catalog 14th ed., except for that of "*S. flavoviridis*," which is stated in the ATCC catalog to be the neotype.

Cell wall analyses. Cell wall analyses were performed on cultures grown in yeast-malt extract broth (ISP no. 2) (10) for 24 h at 30°C. The mycelia were collected by centrifugation and were washed three times with distilled water. The washed cells were then freeze-dried. The cell wall sugars were determined by a modification of the procedure of Lechevalier (8). Diaminopimelic acid isomers were determined by the method of Becker et al. (1).

ISP methods. The methods and media recommended by the International *Streptomyces* project (ISP) for the characterization of *Streptomyces* species were followed (10), along with certain supplementary tests.

Additional methods. The pH range for growth was measured with the following buffers at 0.05 M in yeast-malt extract agar plates (ISP no. 2): citric acid, pH 3, 4, and 5; 2[N-morpholino]ethane sulfonic acid (MES), pH 6 (Sigma Chemical Co.); 3[N-morpholino]-propane sulfonic acid (MOPS), pH 7 (Aldrich Chemical Co.);

N-tris-(hydroxymethyl) methyl glycine (Tricine), pH 8 (Calbiochem); 2-(cyclohexylamino)ethanesulfonic acid (CHES), pH 8.5, 9.0, and 9.5 (P-L Biochemicals, Inc.); and 3-cyclohexylamino-1,1-propane sulfonic acid (CAPS), pH 10.0 and 10.5. The pH values of the agar plates were measured with a flat-surface electrode before inoculation.

Carbon utilization was determined on ISP no. 9 basal medium to which filter-sterilized carbon sources were added to achieve a final concentration of 1.0%. Plates were incubated at 30°C and read after 14 days.

Melanoid pigment production was determined in ISP no. 1 (tryptone-yeast extract broth), ISP no. 6 (peptone-yeast extract-iron agar), ISP no. 7 (tyrosine agar), and modified ISP no. 7 (lacking tyrosine).

Starch hydrolysis was determined by testing for the presence of starch with iodine on ISP no. 4 (inorganic salts-starch agar) plates (3).

Lysozyme resistance and decomposition of casein, esculin, hypoxanthine, tyrosine, and xanthine were measured by the procedure of Berd (2).

NaCl and sucrose tolerance were measured with ISP no. 2 agar. Antibiotic susceptibility was determined with susceptibility disks placed onto the surface of ISP no. 2 agar plates seeded with 2% vegetative inoculum.

The methods of Blazevic and Ederer (3) were followed for the catalase, phosphatase, and urease assays.

The Inter-science Color Council-National Bureau of Standards (ISCC-NBS) Centroid color charts, standard sample no. 2106 (13), were used to assign color names to the pigments produced.

Similarity coefficients were calculated from the equation (6) $S = [Ns^+ + Ns^-] / [Ns^+ + Ns^- + Nd] \times 100$, where Ns^+ is the number of positive similarities, Ns^- is the number of negative similarities, and Nd is the number of dissimilarities (differences).

RESULTS

Morphological characteristics. Strain A49492 produced well-developed, coiled, aerial mycelia, and it was therefore placed in the *Spirales* (S) section of the classification of Pridham et al. (9). This morphology was readily observed on all media which support formation of aerial mycelia. Oatmeal agar (ISP no. 3), ISP no. 7, tomato

FIG. 1. Spore-bearing aerial hyphae of strain A49492: composite of two photographs exhibiting spiral morphology. The organism was viewed with an optical microscope at $\times 400$. The figure shows an undisturbed habitat on ISP no. 3 (incubated for 14 days at 30°C).

FIG. 2. Spiral morphology of strain A49492 on tomato paste oatmeal agar, seen with a scanning electron microscope at $\times 10,000$. The organism was incubated for 14 days at 30°C . Bar, $1.0\text{ }\mu\text{m}$.

paste oatmeal agar, and tap-water agar provided excellent observation of spiral morphology (Figs. 1 and 2). The spirals were simple, open, loose coils of two to three turns. The sporophores bore chains of 10 to 50 spores. Scanning electron micrographs indicated that the spore shape was oval to globose (Fig. 3). The spore size ranged from 0.96 to $1.19\text{ }\mu\text{m}$ by 0.54 to $0.71\text{ }\mu\text{m}$. The average size was 1.05 by $0.62\text{ }\mu\text{m}$. The spore surface ornamentation was hairy (Fig. 4). Coremia were observed on yeast-malt extract agar (ISP no. 2).

Cultural characteristics. The aerial mycelium was in the gray (GY) color series of Tresner and Backus (12, 13); light brownish-gray was the predominant shade. Strain A49492 produced a nonfragmenting substrate or primary mycelium which varied from yellow-brown to brownish-black, depending on the medium. A brown, water-soluble pigment was occasionally produced. The strain did not produce melanoid pigments.

Physiological characteristics. The physiological characteristics of strain A49492 are as follows. Catalase, phosphatase, and urease were positive; casein, hypoxanthine, tyrosine, and xanthine were decomposed. Liquefaction of gelatin, hydrolysis of starch, reduction of nitrate, peptonization of milk, resistance to lysozyme, and decomposition of esculin were negative.

Acetate, D-arabinose, melibiose, raffinose, salicin, and sucrose were not utilized. Growth of A49492 occurred within a temperature range of 10 to 45°C , with an optimum of 30°C . A49492 tolerated a pH range of 6 to 9.5 , levels of NaCl up to 6% , and sucrose concentrations up to 35% .

Analysis of cell wall hydrolysates by paper chromatography demonstrated the presence of LL-diaminopimelic acid. No *meso* isomer was detected. Sugar determinations indicated that only glucose and ribose were present. This information indicates a type I cell wall and a type C sugar pattern (4). The morphological and chemical characteristics of strain A49492 permit a clear assignment of the organism to the genus *Streptomyces*.

A comparison of the characteristics of strain A49492 with the published descriptions of the currently recognized *Streptomyces* species indicated which species are most closely related (Table 1).

The six *Streptomyces* species listed in Table 1 were reported as belonging in the (GY) color series (13), with spiral (S) (9) sporophore morphology, hairy spore surface ornamentation, and a carbon utilization pattern similar to that of A49492. These reference strains were grown simultaneously with culture A49492 to obtain laboratory comparisons.

The similarity coefficients for each of the

FIG. 3. Spore shape of strain A49492 on ISP no. 7 (tyrosine agar), seen with a scanning electron microscope at $\times 2,000$. The organism was incubated for 14 days at 30°C . Bar, $10.0\text{ }\mu\text{m}$.

FIG. 4. Hairy spore surface ornamentation of strain A49492 on ISP no. 7 (tyrosine agar), seen with a scanning electron microscope at $\times 30,000$. The organism was incubated for 14 days at 30°C . Bar, $0.1\text{ }\mu\text{m}$.

TABLE 1. Strain A49492 and six *Streptomyces* reference strains used in this study

Strain ^a	ATCC no.	Coefficient of similarity
A49492		100
<i>S. calvus</i>	13382	67
<i>S. flaveolus</i>	3319	67
" <i>S. flavoviridis</i> "	19903	69
" <i>S. heimi</i> "	25460	67
" <i>S. malachitofuscus</i> "	25471	71
<i>S. pilosus</i>	19797	67

^a Names in quotation marks were not on the Approved Lists of Bacterial Names (11) and have not been validly published since 1 January 1980.

reference strains when compared with strain A49492 are given in Table 1. Ns^+ is the number of positive similarities, Ns^- is the number of negative similarities, and Nd is the number of dissimilarities. The total units of measurement ($Ns^+ + Ns^- + Nd$) were 152. This figure was composed of morphological and physiological characters. When only morphological characters were used, "*S. flavoviridis*" ATCC 19903 had the highest coefficient of similarity, but when both morphological and physiological characters were used, "*S. malachitofuscus*" ATCC 25471 had the greater number of common characters of similarity to A49492, as is shown in Table 1.

Table 2 lists in brief the similarities and differences among strain A49492, "*S. flavoviridis*" ATCC 19903, and "*S. malochitofuscus*" ATCC 25471.

The growth characteristics and pigmentation

of all of the strains studied are presented in Table 3. The color notations are from the ISCC-NBS Centroid color charts (13).

Strain A49492 was also compared with six *Streptomyces* species with respect to carbohydrate utilization patterns and antibiotic susceptibility. The data for carbohydrate utilization are presented in Table 4, and the antibiotic susceptibilities of these strains are given in Table 5.

Further comparisons were made with a number of other tests. Table 6 gives a summary of the results from these additional studies.

DISCUSSION

Streptomyces has been the most extensively studied and exploited genus of the *Actinomyce-tales*. This is due to its medical and industrial utility. Consequently, many new species have been suggested for this genus. Differences between strains are not hard to find; indeed, the more characters determined, the greater the number of differences observed (5). Therefore, the temptation to erect new species must be resisted. A conservative approach that is not based on occasional differences is preferable.

Strain A49492 exhibited considerable differences in relation to six *Streptomyces* species with which it was compared. These differences are not just occasional but, as Table 3 indicates, significant. Strain A49492 differs from "*S. flavoviridis*" ATCC 19903 and "*S. malochitofuscus*" ATCC 25471, the two organisms most similar, in growth, pigmentation, carbon utilization, NaCl and sucrose tolerance, pH range, urease production, and ability to decompose certain substrates.

TABLE 2. Differences and similarities among strain A49492, "*S. flavoviridis*" ATCC 19903, and "*S. malachitofuscus*" ATCC 25471^a

Similarity	Difference
Antibiotic susceptibility (see Table 5)	Carbon utilization (see Table 4)
Casein decomposition positive	Growth on various agar and liquid media
Catalase test positive	
Gelatin liquefaction negative	Melanoid pigment absent in A49492
Lysozyme susceptibility	NaCl toleration less for A49492
Morphology (spiral sporophores)	Soluble pigment produced by A49492
Nitrate reduction negative	Spore hair density greater in A49492
Optimal growth on Bennett agar	Sucrose tolerance less for A49492
Phosphatase test positive	Urease production by A49492
Skim milk, slight hydrolysis	Esculin decomposition ^b
Spore mass color, gray	Hypoxanthine decomposition ^b
Spore surface, hairy	Xanthine decomposition ^b
Starch hydrolysis negative	pH range ^b
Temperature range, 10–45°C ^b	
Tyrosine decomposition positive	

^a Names in quotation marks were not on the Approved Lists of Bacterial Names (11) and have not been validly published since 1 January 1980.

^b "*S. flavoviridis*" only.

TABLE 3. Comparison of strain A49492 with reference strains of six similar *Streptomyces* species"

Medium	Cultural characteristics						
	A49492	<i>S. flaveolus</i>	" <i>S. flavoviridis</i> "	<i>S. calvus</i>	" <i>S. heimi</i> "	" <i>S. malochitofuscus</i> "	<i>S. pilosus</i>
ISP no. 2	G	Good	Poor	Good	Fair	Abundant	Good
	R	77.m.yBr	80.Gy.yBr	74.S.yBr	94.l.OlBr	77.m.yBr	72.d.OY
	Am	Poor: 63.l.brGy	None	Fair: 79.l.gy.yBr	Fair: 93.yGy	Abun. 264.l.Gy	Good: 264.l.Gy
	Sp	None	None	None	Yellow	None	None
ISP no. 3	G	Fair	Good	Fair	Poor	Fair	Fair
	R	63.l.BrGy	93.yGr	79.l.Gy.yBr	90.Gy.Y	112.l.OlGy	112.l.OlGy
	Am	Good: 22.RGy	Fair: 264.l.Gy	Fair: 10.pKGy	Poor: 63.l.brGy	Good: 264.l.Gy	Good: 264.l.Gy
	Sp	None	None	None	Yellow	None	None
ISP no. 4	G	Good	Poor	Good	Abundant	Fair	Abundant
	R	91.d.Gy.Y	79.l.Gy.yBr	78.d.yBr	267.Bl	90.gy.Y	267.Bl
	Am	Good: 63.l.brGy	Good: Gy.yBr	Good: 63.l.brGy	Abun: 266.d.Gy	Good: 93.yGy	Abun: 264.l.Gy
	Sp	None	None	None	None	None	None
ISP no. 5	G	Abundant	Good	Good	Fair	Abundant	Good
	R	61.gyBr	90.gyY	77.m.yBr	112.l.OlGy	89.p.Y	77.m.yBr
	Am	Abun: 63.l.brGy	Trace	Good: 92.yW	None	Abun: 264.l.Gy	Good: 263.W
	Sp	Light gray	None	None	None	None	None
ISP no. 7	G	Abundant	Abundant	Abundant	Abundant	Abundant	Abundant
	R	59.d.Br	77.m.yBr	47.d.gy.rBr	65.brBlk	78.d.yBr	47.d.gy.rBr
	Am	Abun: 10.pkGy	Abun: 264.l.Gy	Abun: 109.lgyOl	Abun: 265.mGy	Abun: 264.l.Gy	Abun: 79.l.gy.Br
	Sp	Grayish Br	None	None	Gray	Gray	grBr
Bennett	G	Good	Good	Fair	Good	Good	Good
	R	72.d.OY	80.Gy.yBr	90.Gy.Y	90.Gy.Y	75.deep yBr	91.d.Gy.Y
	Am	None	Trace	None	None	Fair: 10.pKGy	None
	Sp	None	None	None	None	None	None

Calcium malate	G	Good	Good	Good	Fair	Fair	Good
	R	62.d.gyBr	90.Gy.Y	75.deep yBr	121.p.YGr	120.m.Ygr	75.deep yBr
	Am	Trace	Fair: 93.yGy	Fair: 92.yW	Trace	Trace	Good: 264.l.Gy
	Sp	Brown	None	None	None	None	None
Czapek	G	Abundant	Abundant	Abundant	Abundant	Abundant	Good
	R	47.d.Gy.rBr	91.d.Gy.Y	75.deep yBr	91.d.Gy.Y	95.m.OlBr	91.d.Gy.Y
	Am	Abun: 264.l.Gy	None	Abun: 112.l.OlGy	None	Poor: 263.W	Good: 264.l.Gy
	Sp	Brown	Y	None	None	None	None
Glucose asparagine	G	Good	Good	Fair	Fair	Fair	Fair
	R	95.m.OlBr	91.d.Gy.Y	88.d.Y	264.l.Gr	90.Gy.Y	90.Gy.Y
	Am	Trace	Good: 93.yGy	None	None	Fair: 264.l.Gy	Poor: 263.W
	G	None	None	None	None	None	None
TPO	G	Abundant	Abundant	Abundant	Poor	Abundant	Abundant
	R	65.brBl	62.d.Gy.Br	59.d.Br.	61.Gy.Br	125.m.Ol.G	59.d.Br
	Am	Abun: 63.l.brGy	Abun: 264.l.Gy	Abun: 112.l.Ol.Gy	Trace	Abun: 264.l.Gy	Abun: 264.l.Gy
	Sp	Dark brown	None	None	None	None	Brown
Tap-water agar	G	Poor	Poor	Fair	Poor	Fair	Fair
	R	Clear	Clear	Greenish Y	Clear	Clear	Clear
	Am	Poor	Fair	Fair	Poor	Good	Good
	Sp	None	None	None	None	None	None

^a G, Growth; R, reverse; Am, aerial mycelium; Sp, soluble pigment. The numbers represent colors (13). Characteristics (13) of the reverse and aerial mycelia, separated by periods, are as follows: Abun, abundant; m, moderate; l, light; d, dark; yBr, yellowish-brown; OlBr, olive-brown; OY, orange-yellow; s, strong; brGy, brownish-gray; Gy, gray; gyBr, grayish brown; rBr, reddish brown; R, red; brBl, brownish black; Bl, black; Gy, gray; gyY, grayish yellow; Y, yellow; yW, yellowish white; mGy, moderate gray, p, pale. Names in quotation marks are not on the Approved Lists of Bacterial Names (11) and have not been validly published since 1 January 1980.

TABLE 4. Carbon utilization by strain A49492 and six similar reference strains of *Streptomyces* species^a

Carbon source	A49492	ATCC no.					
		3319	19903	13382	25460	25471	19797
Control	—	—	—	—	—	—	—
Acetate	—	—	+	—	—	—	+
D-Arabinose	—	—	—	+	—	—	—
L-Arabinose	+	+	+	(+)	+	+	+
Cellobiose	+	+	+	+	+	+	+
Citrate	+	+	+	(+)	(+)	+	+
D-Fructose	+	+	+	+	+	+	+
D-Galactose	+	+	+	+	+	+	+
D-Glucose	+	+	+	+	+	+	+
<i>D</i> -Inositol	+	+	+	+	+	+	+
D-Maltose	+	+	+	+	+	+	+
D-Mannitol	+	+	+	+	+	+	+
Melibiose	—	—	—	(+)	—	—	—
Raffinose	—	+	—	+	—	—	—
Rhamnose	+	+	+	+	+	+	+
D-Ribose	+	+	+	+	+	+	+
Salicin	(+)	+	—	—	+	—	—
Sucrose	—	+	—	+	+	+	—
D-Xylose	+	+	+	+	+	+	+

^a Symbols: +, positive utilization (carbon source used); —, negative utilization (carbon source not used); (+), questionable utilization.

The coefficient of similarity between strain A49492 and the six compared species is low (Table 1). “*S. malochitofuscus*” ATCC 25471 was the most similar to A49492, with a coefficient of 71. However, this similarity is insufficient to consider A49492 to be a strain of “*S. malochitofuscus*.”

The coefficients of similarity when these six species were compared with one another rather than with strain A49492, were of the same general order as when they were compared with strain A49492. For instance, the coefficient of similarity when *S. pilosus* ATCC 19797 was compared with “*S. flavoviridis*” ATCC 19903 was 75. The other five reference strains of *Streptomyces* species, when compared with “*S.*

flavoviridis” ATCC 19903, had coefficients of similarity which were less than 75. Therefore, we suggest that strain A49492, which has a low similarity to the reference strains studied, be regarded as a member of a new species, for which the name *Streptomyces capillispiralis* sp. nov. is proposed (ca-pil-li-spi-ra' lis; L. n. *capillus* hair; L. adj. *spiralis* spiral or spiraled; M.L. adj. *capillispiralis* hairy-spiraled). The type strain is A49492 (7). A culture of this strain has been deposited at the Northern Regional Research Center, Peoria, Ill., under the accession number 12279.

The descriptions of the species and of the type strain are the same as that given above and in Tables 4 through 6 for strain A49492.

TABLE 5. Comparison of the antibiotic susceptibility of strain A49492 with those of the six similar reference strains of the *Streptomyces* species studied^a

Antibiotic (type)	Concn ^b	A49492	ATCC 3319	ATCC 19903	ATCC 13382	ATCC 25460	ATCC 25471	ATCC 19797
Erythromycin (macrolide)	15 µg	—	+	—	+	—	—	—
Cephalothin (β-lactam)	30 µg	—	—	—	—	—	—	—
Lincomycin (lincosaminide)	2 µg	—	—	—	—	—	—	—
Nystatin (polyene)	100 U	—	—	—	—	—	—	—
Polymyxin B (peptide)	300 U	—	—	—	—	—	—	—
Streptomycin (aminoglycoside)	10 µg	+	+	+	+	+	+	+
Tetracycline (perhydronaphthacene)	30 µg	+	+	+	+	+	+	+
Vancomycin (glycopeptide)	5 µg	+	+	+	+	+	+	+

^a Symbols: +, susceptible (zones of inhibition); —, resistant (no zones of inhibition).

^b Amount of antibiotic per disk.

TABLE 6. Comparison of strain A49492 with six similar reference strains of *Streptomyces* species^a

Test	A49492	ATCC 3319	ATCC 19903	ATCC 13382	ATCC 25460	ATCC 25471	ATCC 19797
Temperature range for growth (°C)	10–45	10–45	10–45	15–50	15–45	15–45	5–45
pH range for growth	6–9.5	6–9	6–9.7	6–9.5	6–9	6–9.5	6–9.7
NaCl tolerance (%)	6	8	8	6	6	10	6
Sucrose tolerance (%)	35	30	50	35	35	40	35
Catalase	+	+	+	+	+	+	+
Phosphatase	+	+	+	+	+	+	+
Urease	+	+	–	–	+	–	–
Nitrate reductase	–	–	–	–	–	–	–
Gelatin liquefaction	–	–	–	–	–	–	+
Melanoid pigments	–	–	+	–	–	+	+
Skim milk	(+)	(+)	(+)	+	–	(+)	(+)
Starch hydrolysis	–	–	–	–	–	–	–
Lysozyme resistance	–	(+)	–	(+)	(+)	–	–
Casein decomposition	+	+	+	+	+	+	+
Esculin decomposition	–	+	+	+	–	–	+
Hypoxanthine decomposition	+	+	–	+	+	+	–
Tyrosine decomposition	+	+	+	+	+	+	+
Xanthine decomposition	+	+	–	+	+	+	–
Morphology	S	S	S	S	S	S	S
Spore surface	H	H	H	H	H	H	H
Spore size (µm)	1.05 by 0.62	1.06 by 0.75	0.92 by 0.65	0.98 by 0.63	0.93 by 0.93	0.87 by 0.68	0.81 by 0.71

^a Symbols: +, positive reaction; –, negative reaction; (+), partial reaction (for lysozyme, symbol indicates equivocal results); S, spiral; H, hairy.

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REPRINT REQUESTS

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