Class

Actinobacteria

Subclass

Actinobacteridae

Order

Actinomycetales

Suborder

Streptomycineae

Family

Streptomycetaceae

Genus

Streptomyces

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The Genus Streptomyces

From the genus *Streptomyces* a high number of species have been described and the genus encludes the species of the former genera *Chainia, Elytrosporangium, Microellobosporium, Kitasatoa, Kitasatosporia* and *Streptoverticillium.*

Vegetative hyphae (0,5-2,0 µm in diameter) produce an extensively branched mycelium that rarely fragments. The aerial mycelium at maturity forms chains of three to many spores. One species with single spores has also been reported. A few species bear short chains of spores on the substrate mycelium. Sclerotia-,
pycnidial-, sporangia-, and synnemata-like structures may be formed by some species. Spores are nonmotile. Form discrete and lichenoid, leathery or butyrous colonies. Initially colonies are relatively smooth surfaced, but later they develop a weft of aerial mycelium that may appear floccose, granular, powdery or velvety. Produce a wide variety of pigments responsible for the color of the vegetative or aerial mycelia. Colored diffusible pigments may also be formed. Many strains produce one or more antibiotics or other secondary metabolites.

The cell wall peptidoglycan contains major amounts of L-diaminopimelic acid (L-DAP). The wall lack mycolic acids but contains major amounts of saturated, iso-, anteiso- fatty acids; possess either hexa- or octahydrogenated menaquinones with nine isoprene units as the predominant isoprenolog; and have complex polar lipid patterns that typically contains diphosphatidylglycerol, phosphatidylethanolamine, phosphatidylinositol, and phosphatidyinositol mannosides.

The temperature optimum is at 25-35℃; some species grow at temperatures within the psychrophilic and thermophilic range. Widely distributed and abundant in soil, including composts. A few species are pathogenic for animals and humans; others are phytopathogens.

Type species is Streptomyces albus.

Lit.: Waksman, S. A. and A. T. Henrici. 1943
The nomenclature and classification of the actinomycetes.
J. Bacteriol. 46: 337-341

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Genus Identity Card

Genus	***Streptomyces***
Wall chemotype	LL-DAP (type I)
Whole cell sugar pattern	
Fatty acid pattern	C 16:0, iso C 17:0, anteiso C 17:0
Major menaquinone (MK)	-9(H_6), 9(H_8)
Phospholipidtype	diphosphatidylglycerol, phosphatidylethanolamine, phosphatidylinositol, phosphatidylinositol-mannoside
Mol% G+C of DNA	69-78
Morphology	vegetative hyphae produce extensively branched mycelium that rarely fragments, aerial mycelium forms chains of spores; sclerotia-, pycnidial-, sporangia-, and synnemata-like structures may be formed
Type species	*Streptomyces albus*

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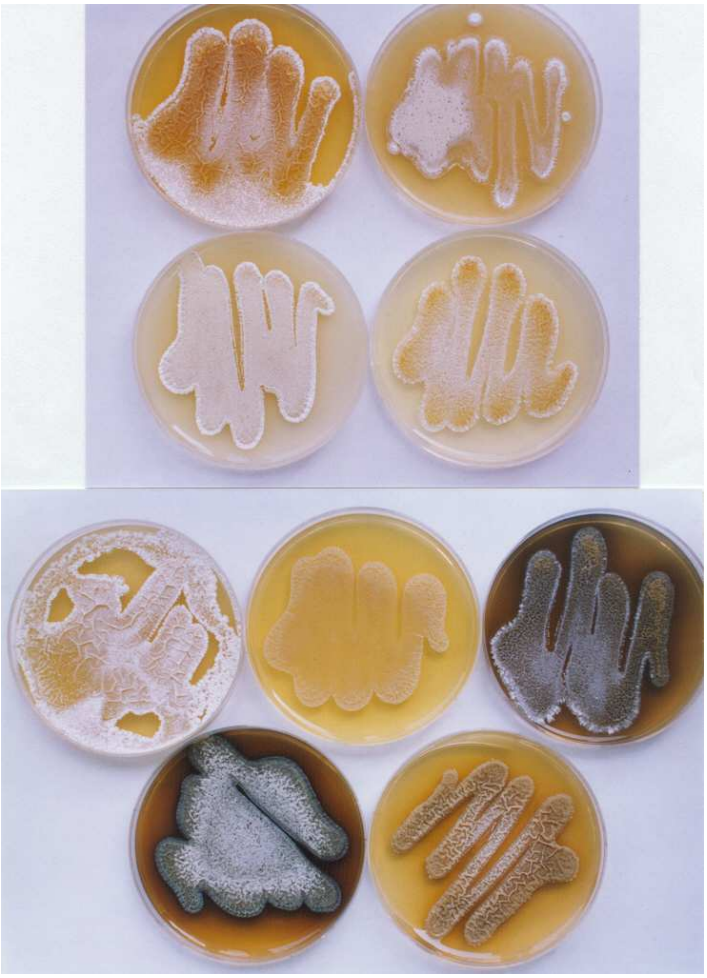
Streptomyces erumpens
(white series)



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Streptomyces echinatus
(grey series)

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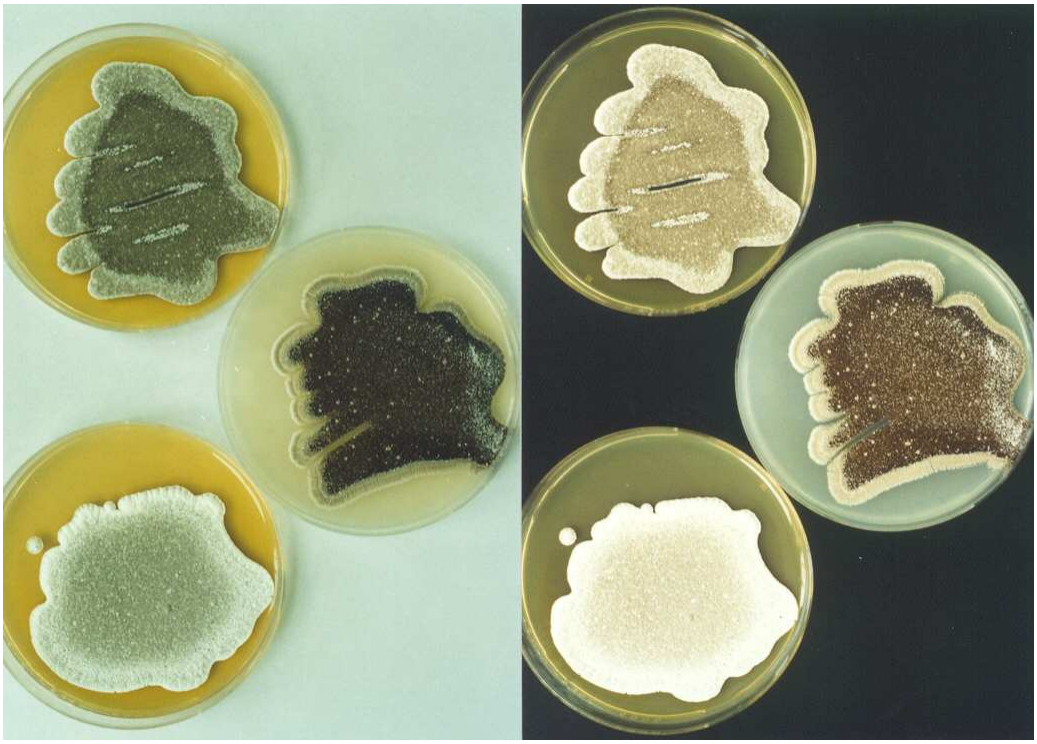
Streptomyces hygroscopicus
(grey series)



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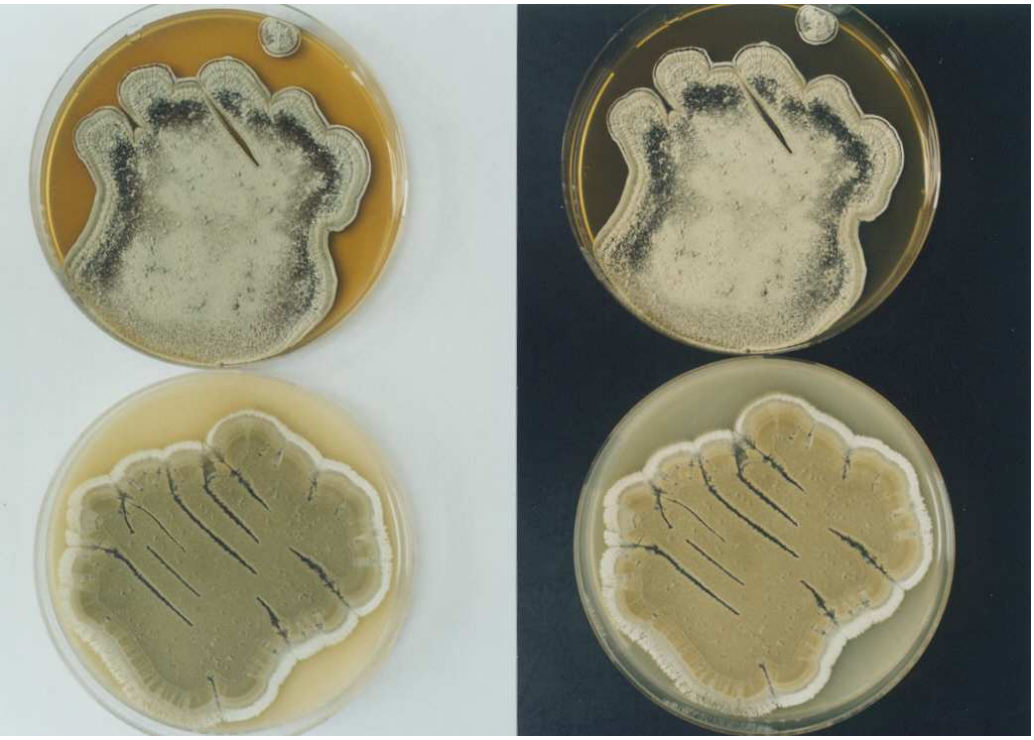
Streptomyces aureofaciens
(grey series)



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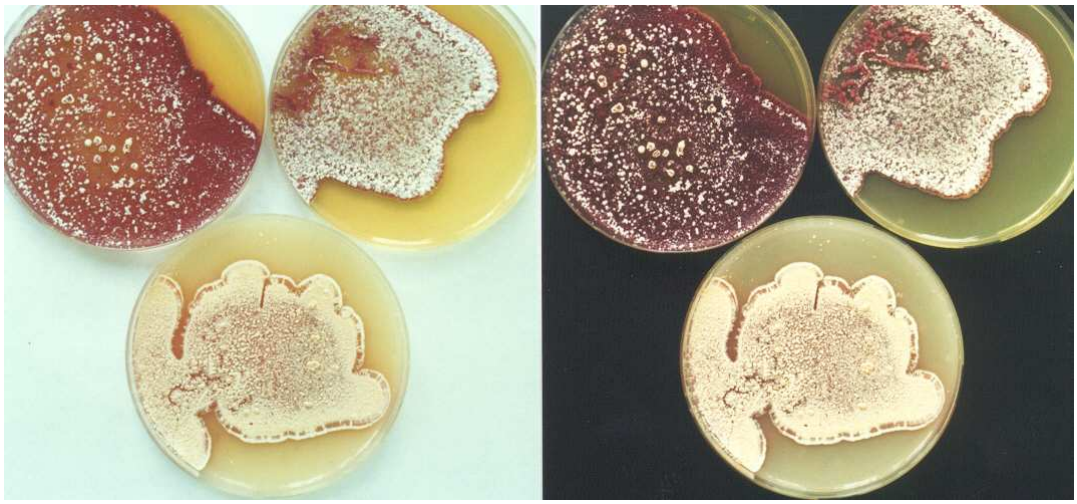
Streptomyces purpurascens
(red series)



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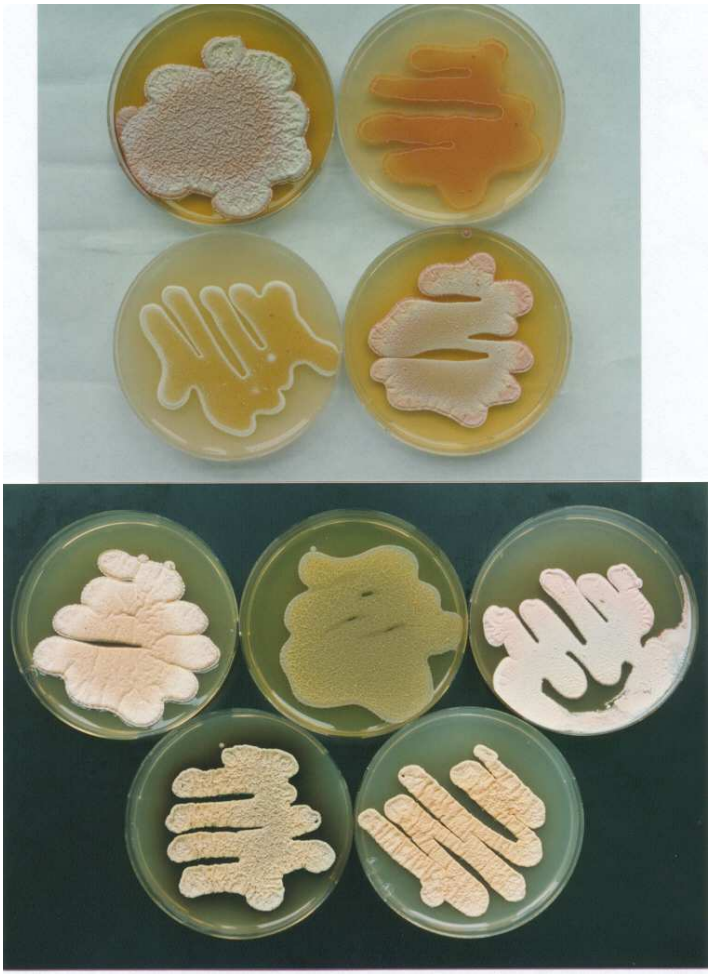
Streptomyces fulvissimus
(red series)



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Streptomyces viridochromogenes
(blue series)

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Streptomyces diastaticus
(Melanin)

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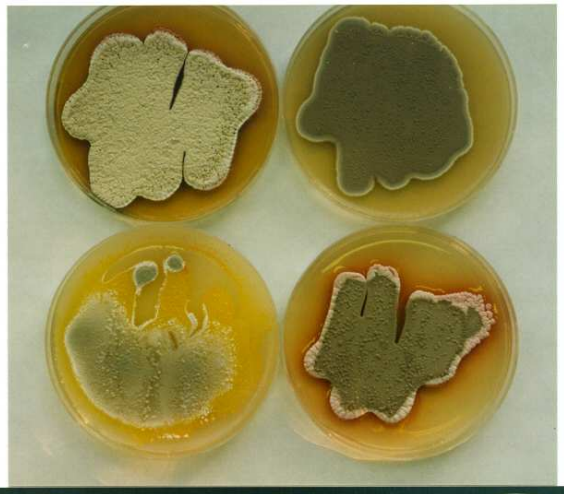
Streptomyces aurantiacus



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Streptomyces carpinensis
(*Elytrosporangium*)

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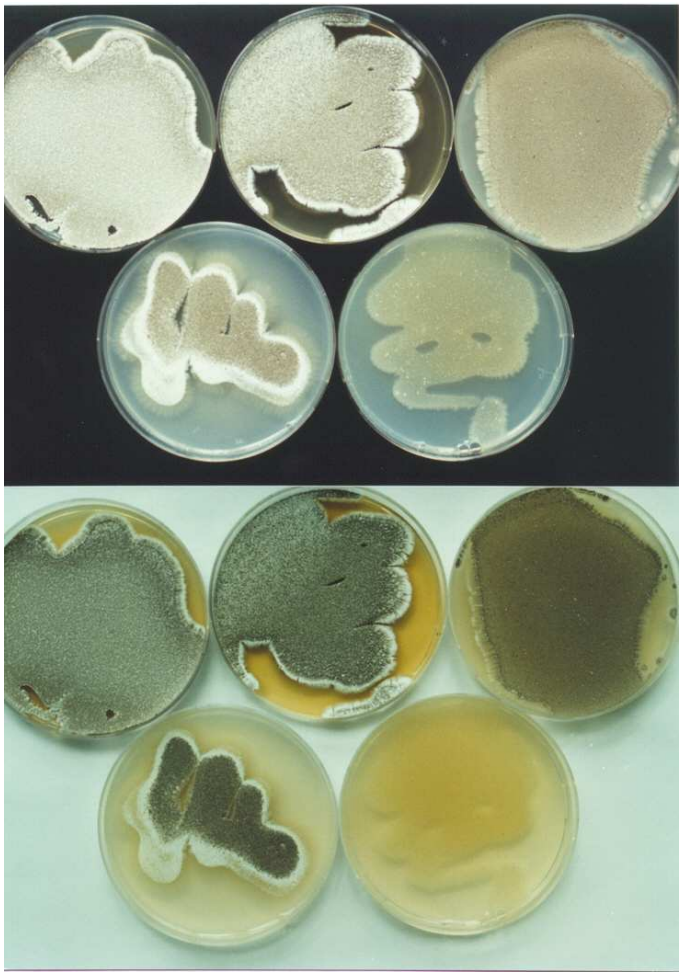
Streptomyces cystargineus
(Kitasatosporia)



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Streptomyces griseoverticillatus
(Streptoverticillium)

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Streptomyces salmonis
(Streptoverticillium)

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Streptomyces peucetius
(Anthracyclines)

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Streptomyces avermitilis
(Avermectin)

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Streptomyces bambergiensis
(Moenomycin))

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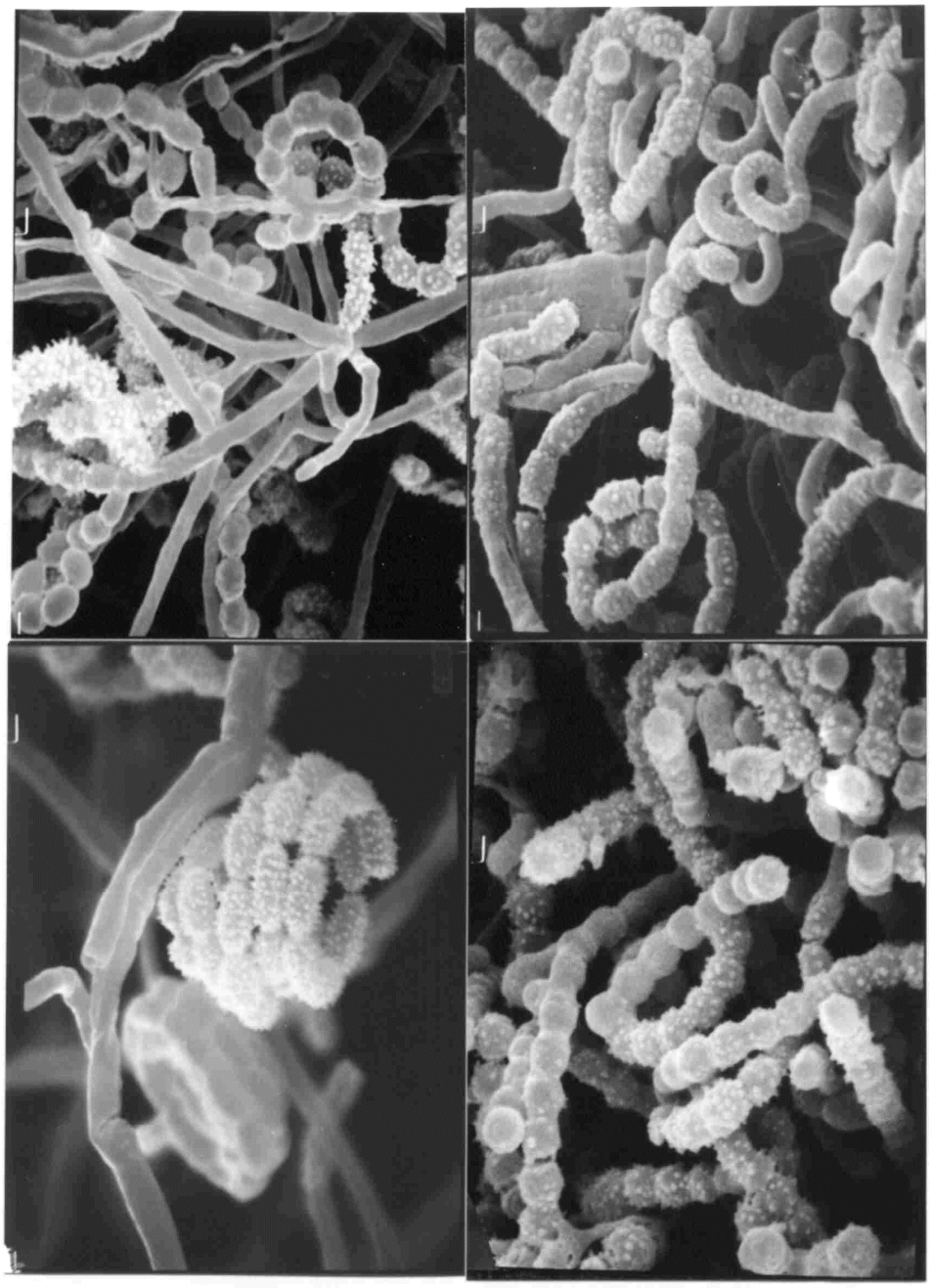

Spore chain morphology and spore surface in scanning electron microscopy

A – RA/spiny B – RA/warty
C – Spira/ spiny D – RF/warty

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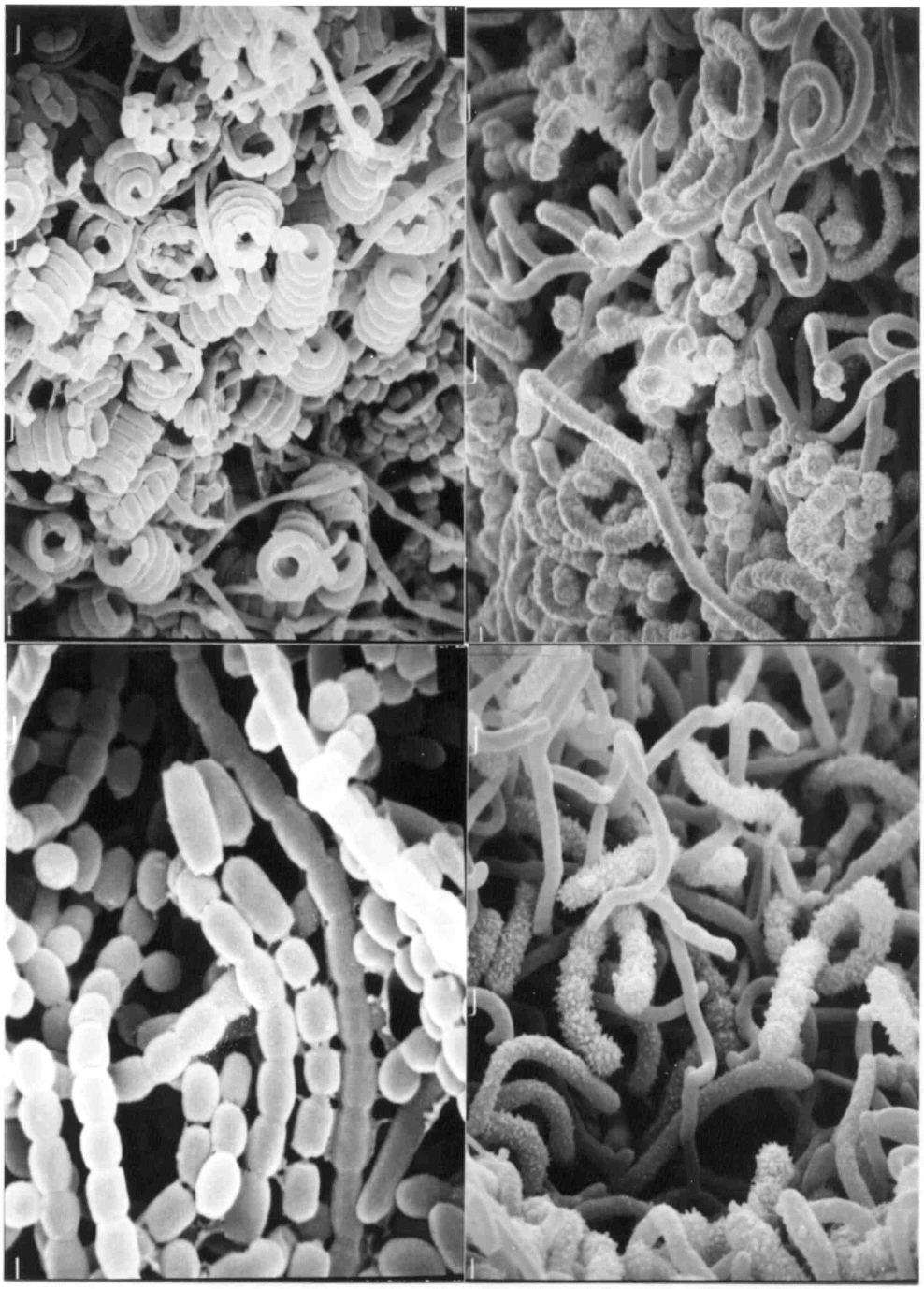

Spore chain morphology and spore surface in scanning electron microscopy

A – Spira/smooth B – RAa/warty
C – RF/ smooth D – RF/hairy

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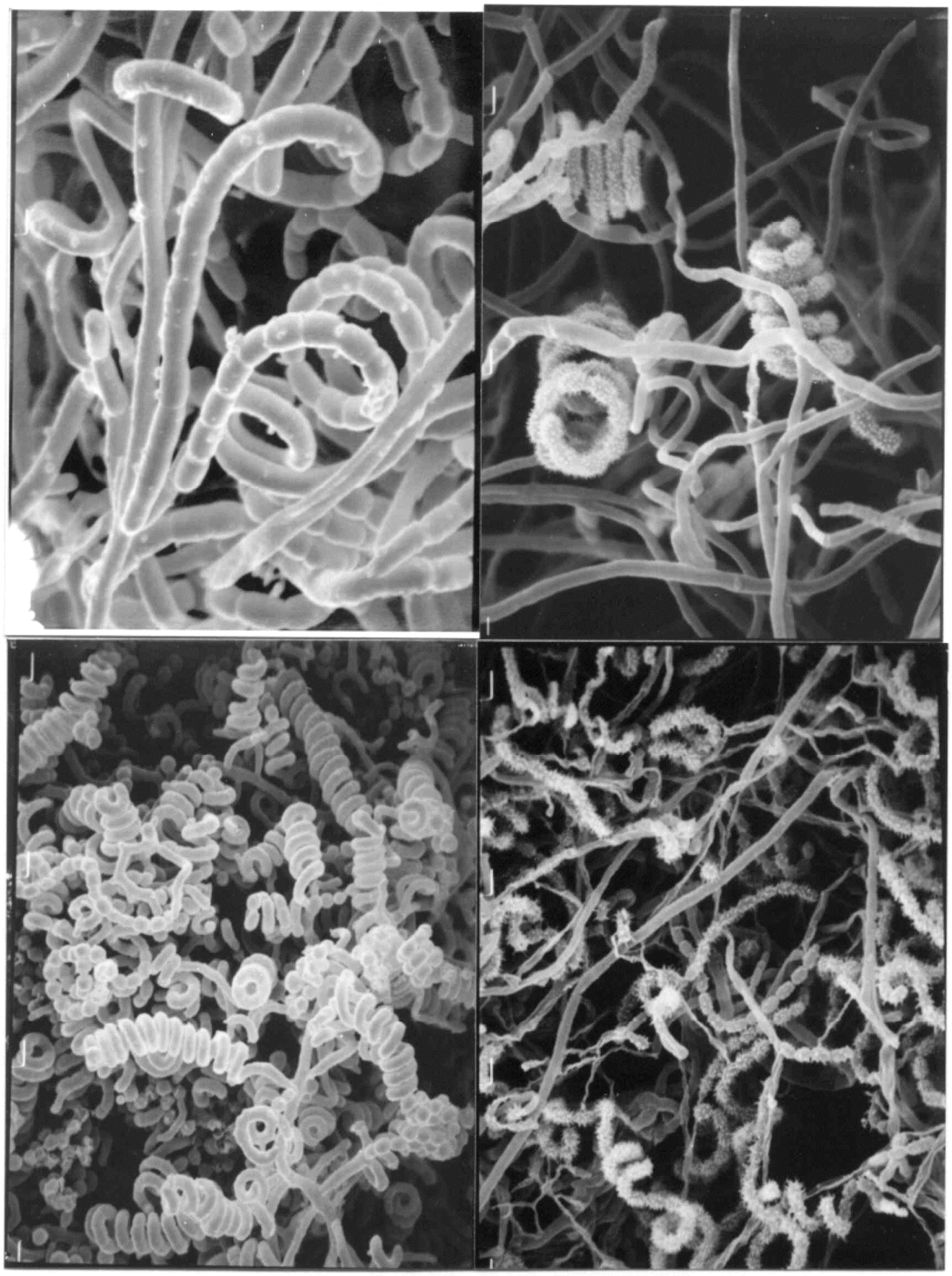

Spore chain morphology and spore surface in scanning electron microscopy

A – Verticillus/smooth B – Spira/hairy
C – Spira/ smooth D – RAb/hairy

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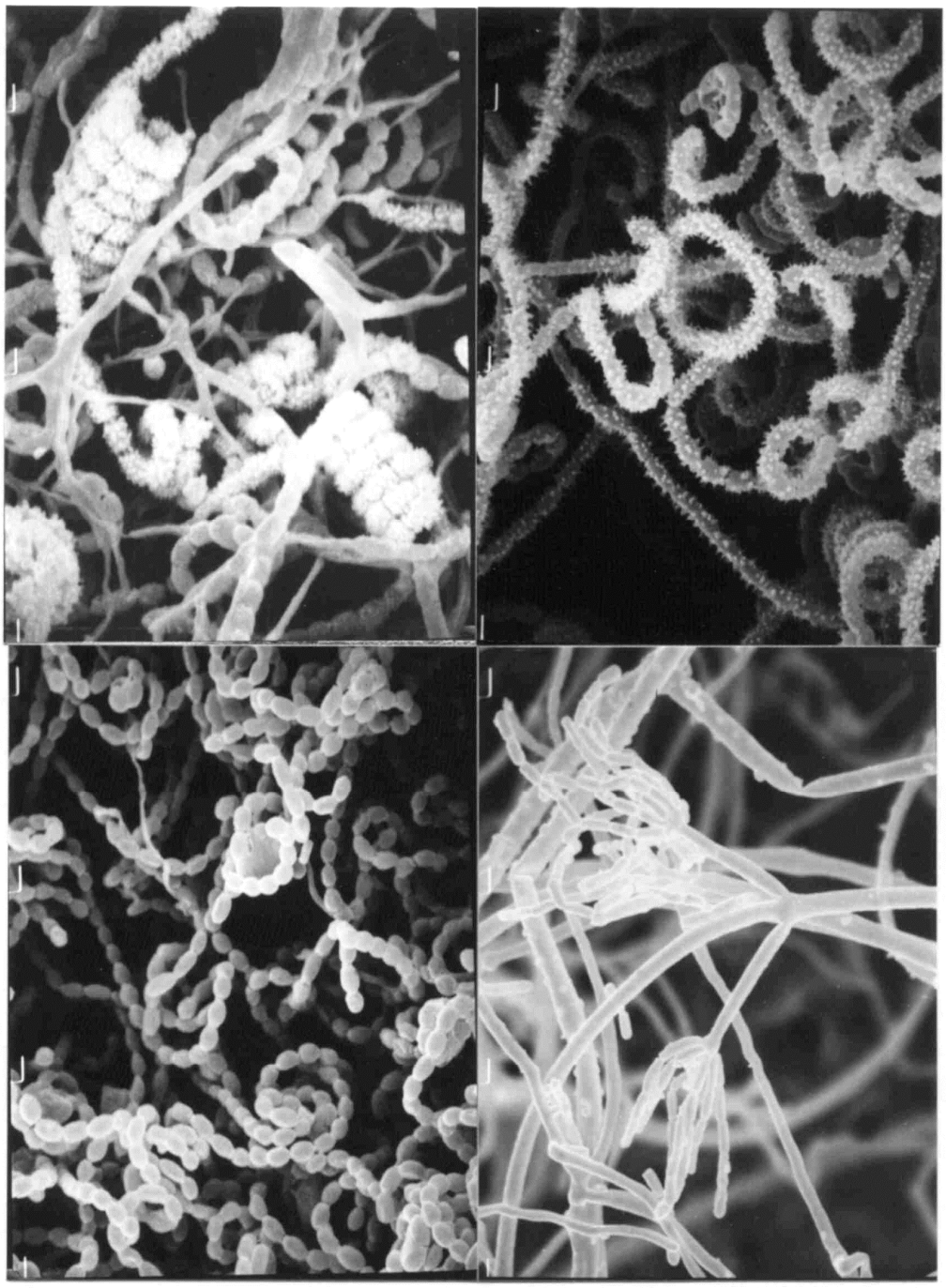

Spore chain morphology and spore surface in scanning electron microscopy

A – Spira/spiny B – RAb/hairy

C – RAb/ smooth D – Biverticillus/smooth

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Spore chain morphology of *Streptomyces* species I

(basing on Hütter 1967)

a. Rectus-Flexibilis (RF)
b. Retinaculum- Apertum (RA)
   (left and right RAa, middle RAb)
c. Spira type A

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Spore chain morphology of *Streptomyces* species II
(basing on Hütter 1967)

d. Spira type B
e. Verticillus-Rectus-Flexibilis (Ve)
f. Verticillus-Spira (Ve)

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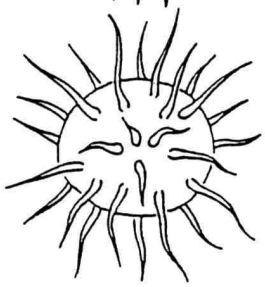
Types of spore surface in *Streptomyces* taxonomy

(basing on Vobis 1997)

1. Smooth

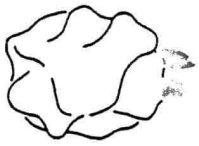
2. Spiny or spinous

3. Hairy

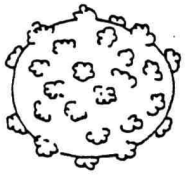


4. Warty

5. Rugose



6. Knobby



History of Taxonomy in the Streptomycetes

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Investigator	Criterion or Criteria Used	Number of MajorGroups Proposed
Krainsky (1914)	Size of single-spore colonies	2
Waksman and Curtis (1916)	Proteolysis and formation of soluble pigment	4
Drechsler (1919)	Morphology of sporophores	(No defined groups)
Waksman (1919)	Formation of soluble pigment	2
Millard and Burr (1926)	Growth characteristics in glycerine synthetic solution	5
Jensen (1930)	Formation of soluble Pigment	2
Duche´(1934)	Cultural characteristics	(Several keys and groups)
Waksman and Henrici (1948)	Ecology and temperature requirements	4
Krassilnikov (1941, 1949)	Morphology of sporo-phores	2
Baldacci et al. (1953)	Color of vegetative mycelium	2
Hesseltine et al. (1954)	Spore color and morphol-ogy of sporophores	8
Yamaguchi and Saburi (1955)	Morphology of sporophores	4
Gauze et al. (1957)	Color of aerial mycelium and color of vegetative mycelium	15
Shirling and Gottlieb (1966)	Criteria of International Streptomyces Project (ISP)	(only Streptomyces)
Locci (1989)	Numerical Classification	3
Stackebrandt (1997)	Phylogenic clustering of 16S rRNA/rDNA	1

Methods for Characterization of Streptomyces Species (Bergey´s Manual 1989) I

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(Williams et al. 1983)

Characters	Character state
1. Spore chain morphology	*Rectiflexibilis, Retinaculiaperti, or spirals*
2. Spore surface ornamentation	Smooth, warty. Hairy, or rugose
3. Other morphological features	Fragmentation of substrate mycelium, sclerotia formation, sporulation on substrate mycelium
4. Color of spore mass	Blue, gray, green, red, violet, white, or yellow
5. Pigmentation of substrate mycelium (colony reverse)	Yellow-brown (no distinctive pigment), blue, green, red-orange, or violet, pH sensitivity of pigments
6. Diffusible pigments	Yellow-brown, blue, green, red-orange, or violet, pH sensitivity of pigments
7. Melanin pigment production	On peptone-yeast extract-iron agar and tyrosine agar
8. Antimicrobial activity	Activity against *Aspergillus niger, Bacillus subtilis, Candida albicans, Escherichia coli, Micrococcus luteus, Pseudomonas fluorescens, Saccharomyces cerevisiae, and Streptomyces murinus*
9. Enzyme activity	Lectinase, lipolysis, and proteolysis (on egg-yolk medium), Hydrolysis of chitin, hippurate, and pectin. Nitrate reduction. Hydrogen sulfide production. β-Lactamases and β-lactamase inhibitor production.

Methods for Characterization of Streptomyces Species (Bergey´s Manual 1989) II

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(Williams et al. 1983)

Characters	Character state
10. Degradation activity	Adenine, allantoin, arbutin, casein, DNA, elastin, esculin, gelatin,, guanine, hypoxanthine, RNA, starch, testosterone, Tween 80, L-tyrosine, urea, xanthine, and xylan.
11. Resistance to antibiotics (µg/ml)	Cephalorodine (100), dimethylchlor-tatracycline (500), gentamicin (100), lincomycine (100), neomycine (50), oleandomycin (100), penicillin G (10 i.u.), rifampicin (50), streptomycin (100), tobramycin (50) and vancomycin (50).
12. Growth temperatures and pH	4°, 10°, 37° and 45° C. pH 4.3.
13. Growth in the presence of inhibitory compounds (% w/v)	Crystal violet (0,0001), phneol (0,1), phenylethanol (0,1, 0,3), potassium tellurite (0,001, 0,01), sodium azide (0,01, 0,02), sodium chloride (4,7,10,13), and thallous acetate (0,001, 0,01)
14. Use of nitrogen sources (0,1% w/v)	DL-α-amino-n-butyric acid, L-arginine, L-cysteine, L-histidine, L-hydroxyproline,L-methionine, potassium nitrate, L-phenylalanine, L-serine, L-threonin and L-valine.
15. Use of carbon sources (0,1 % w/v)	Adonitol, L-arabinose, cellobiose, dextran, D-fructose, D-galactose, meso-inositol, inulin, D-lactose, mannitol, D-rhamnose, salicin, sucrose, trehalose, xylitol and D-xylose. Sodium acetate, sodium citrate, sodium malonate, sodium propionate, and sodium pyruvate (these 5 compounds were used at 0,1% w/v).

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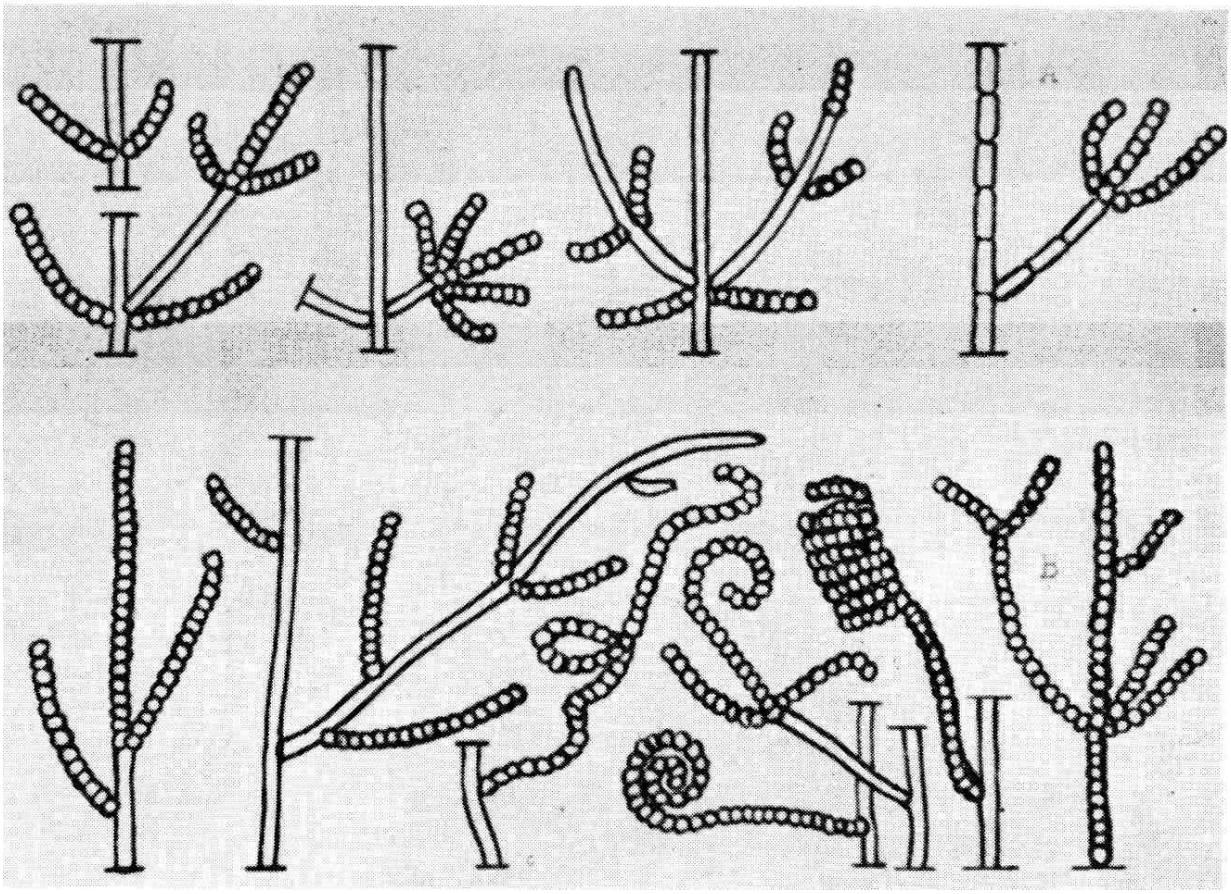
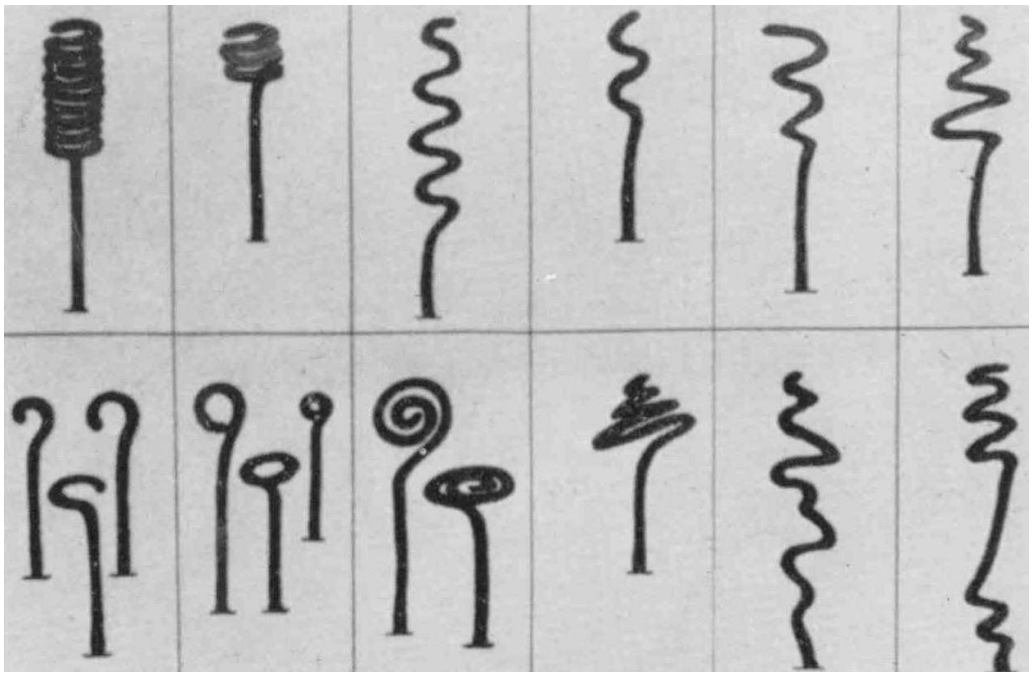


Spore formation in Streptomyces species (from Shinobu 1958)



Schematic representation of different types of spirals produced by various Streptomycves species; the spirals range from long to short, from compact to irregular (from Shinobu 1958)

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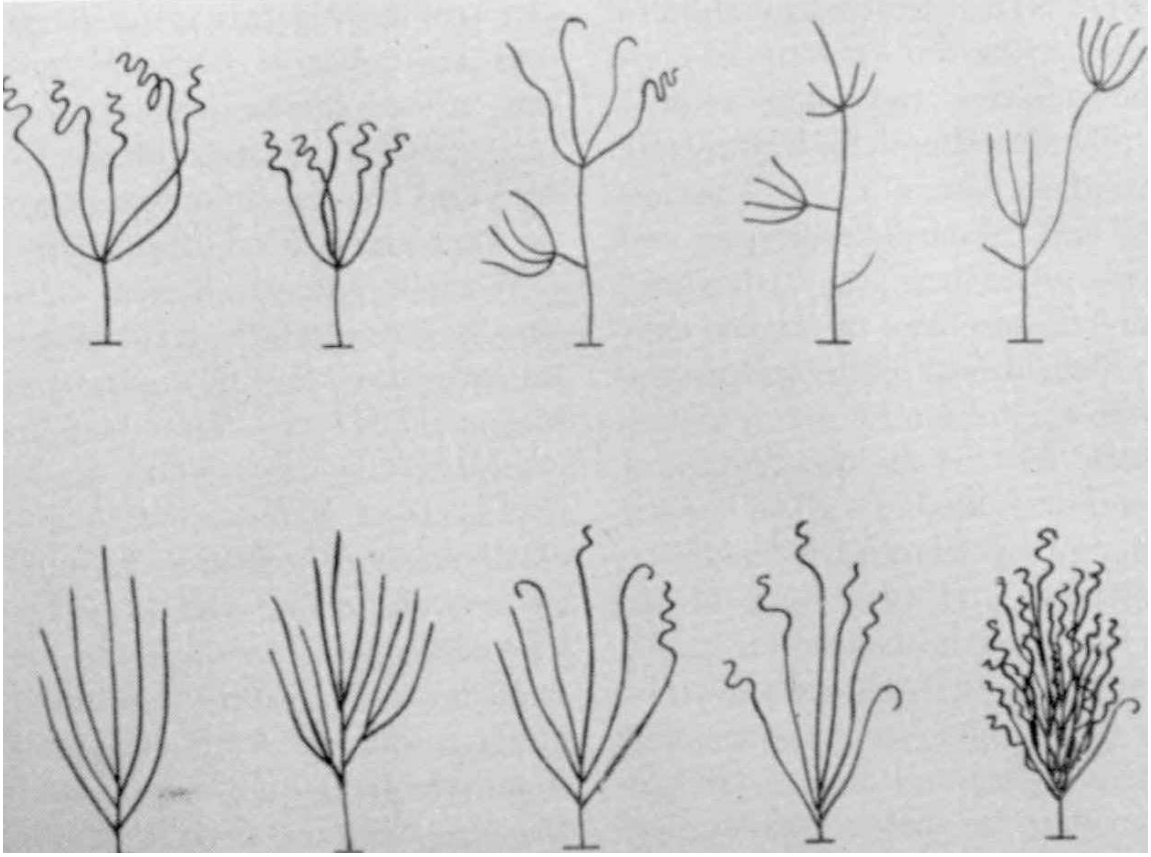
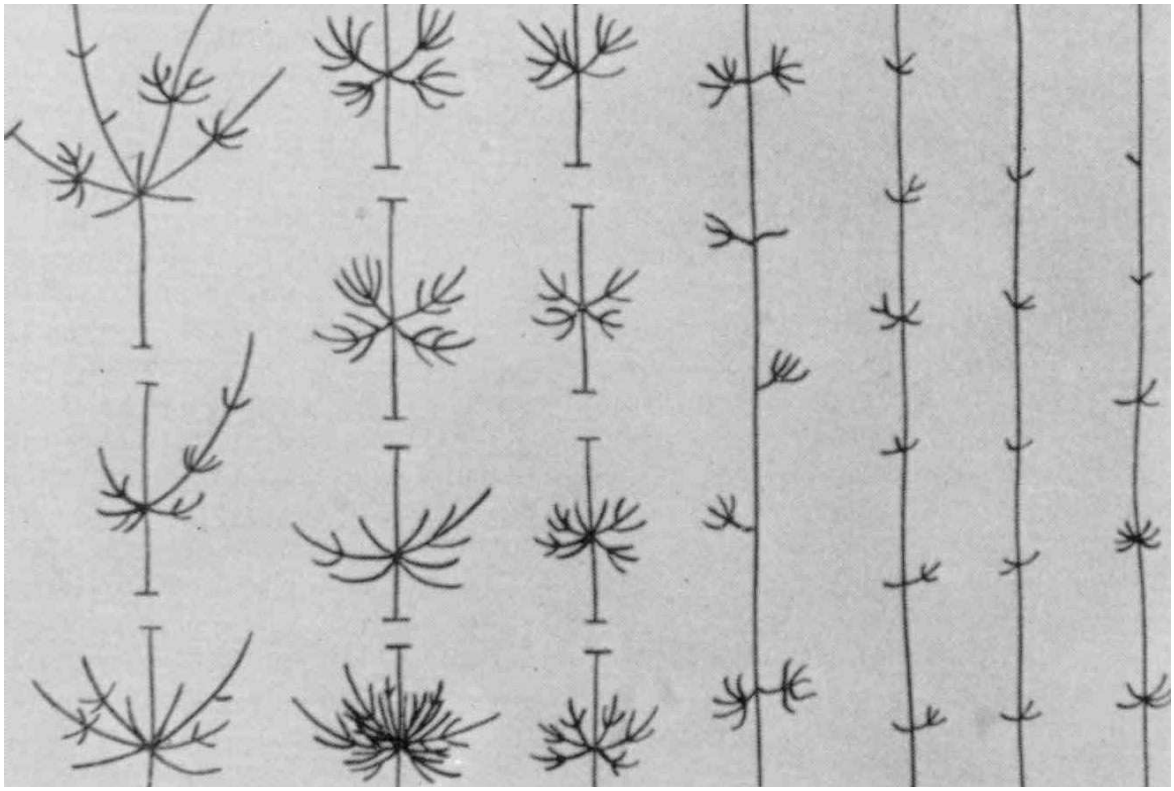


Schematic representation of tuft and cluster formation by certain Streptomyces species (from Shinobu 1958)



Verticill formation including both, primary and secondary verticals (from Shinobu 1958)

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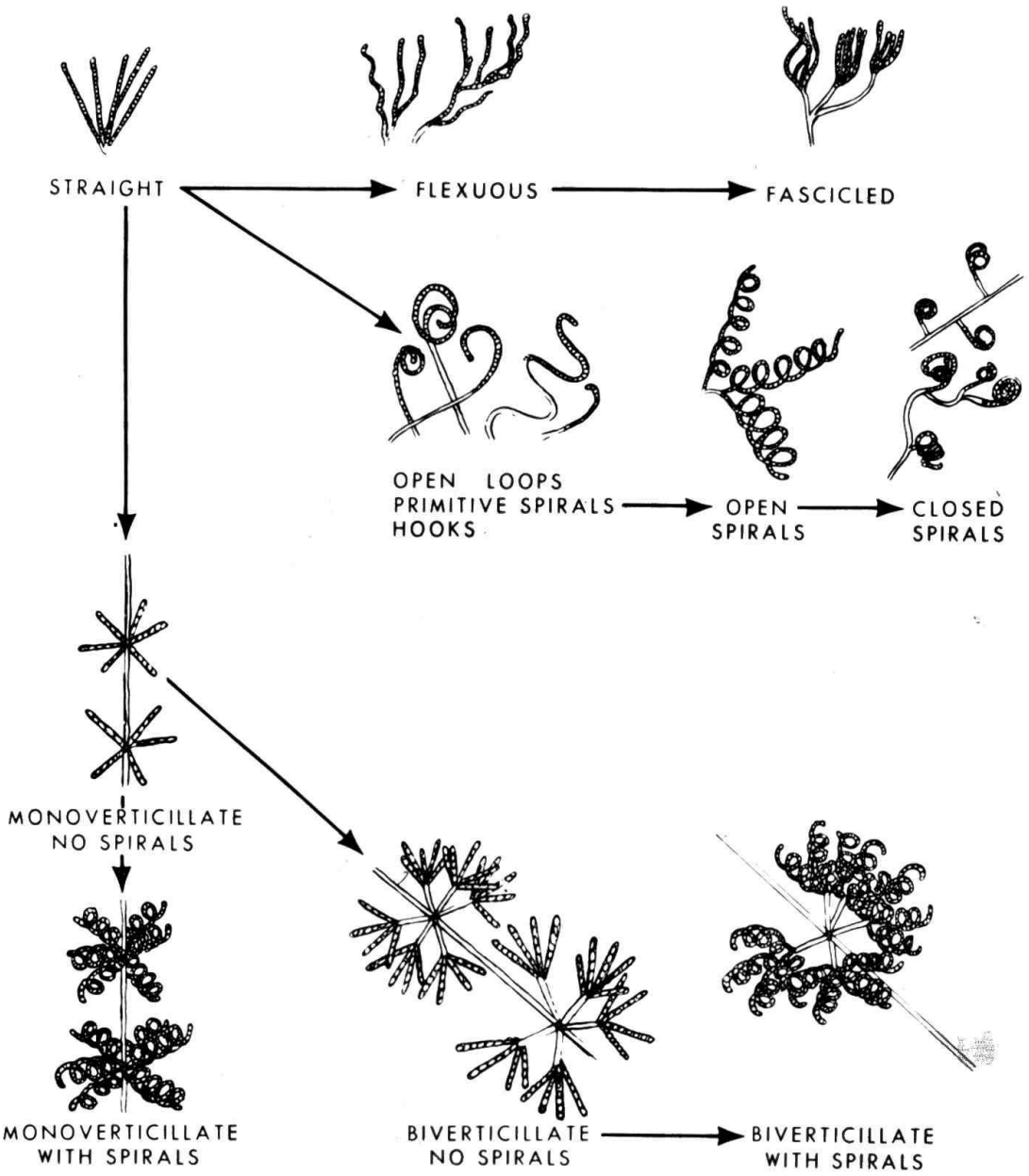

Suggested evolutionary development of sporophore structure in the genus Streptomyces (from Pridham et al. 1958)

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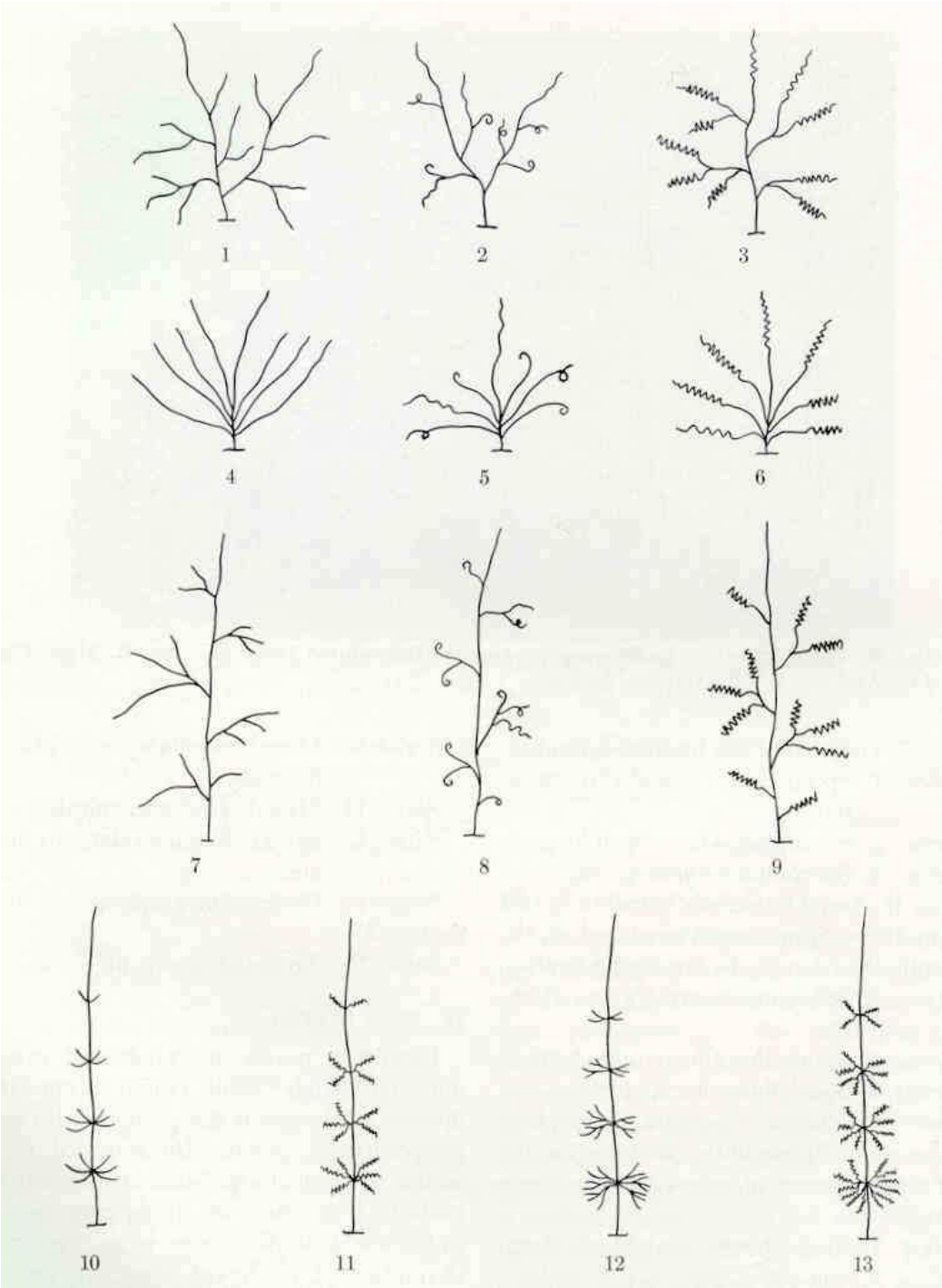

Morphological groups in the genus Streptomyces (Mayama 1959)
Section I irregulary branched
Section II branching in tufts
Section III long main stem-nonverticillate
Section IV long main stem-verticillate

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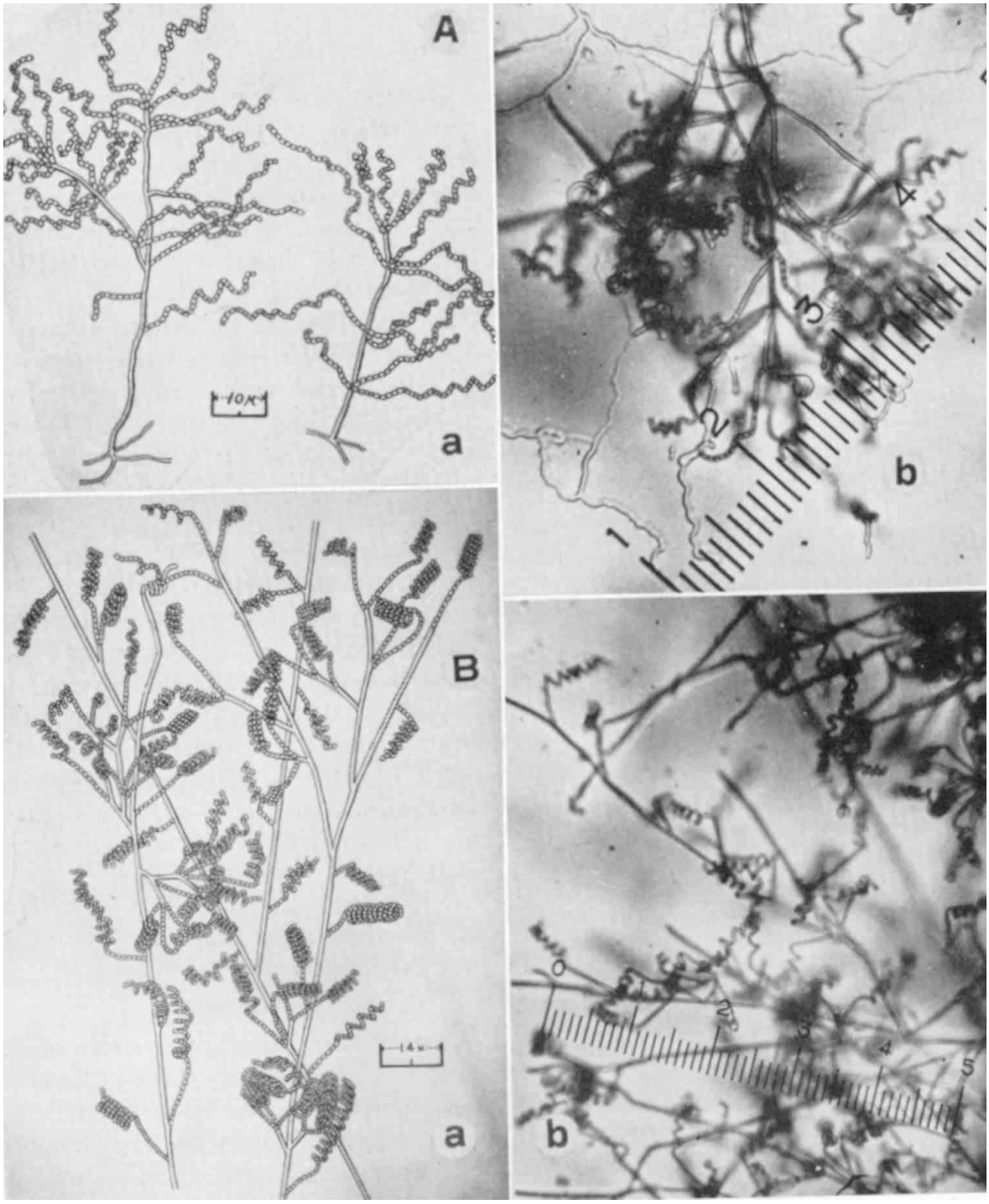

Moephological types of Streptomycetes according to Nomi (1959) I

A Aerial hyphae flexous or strainght, spirals extenden to compact
B Aerial hyphae straight, spirals on side branches

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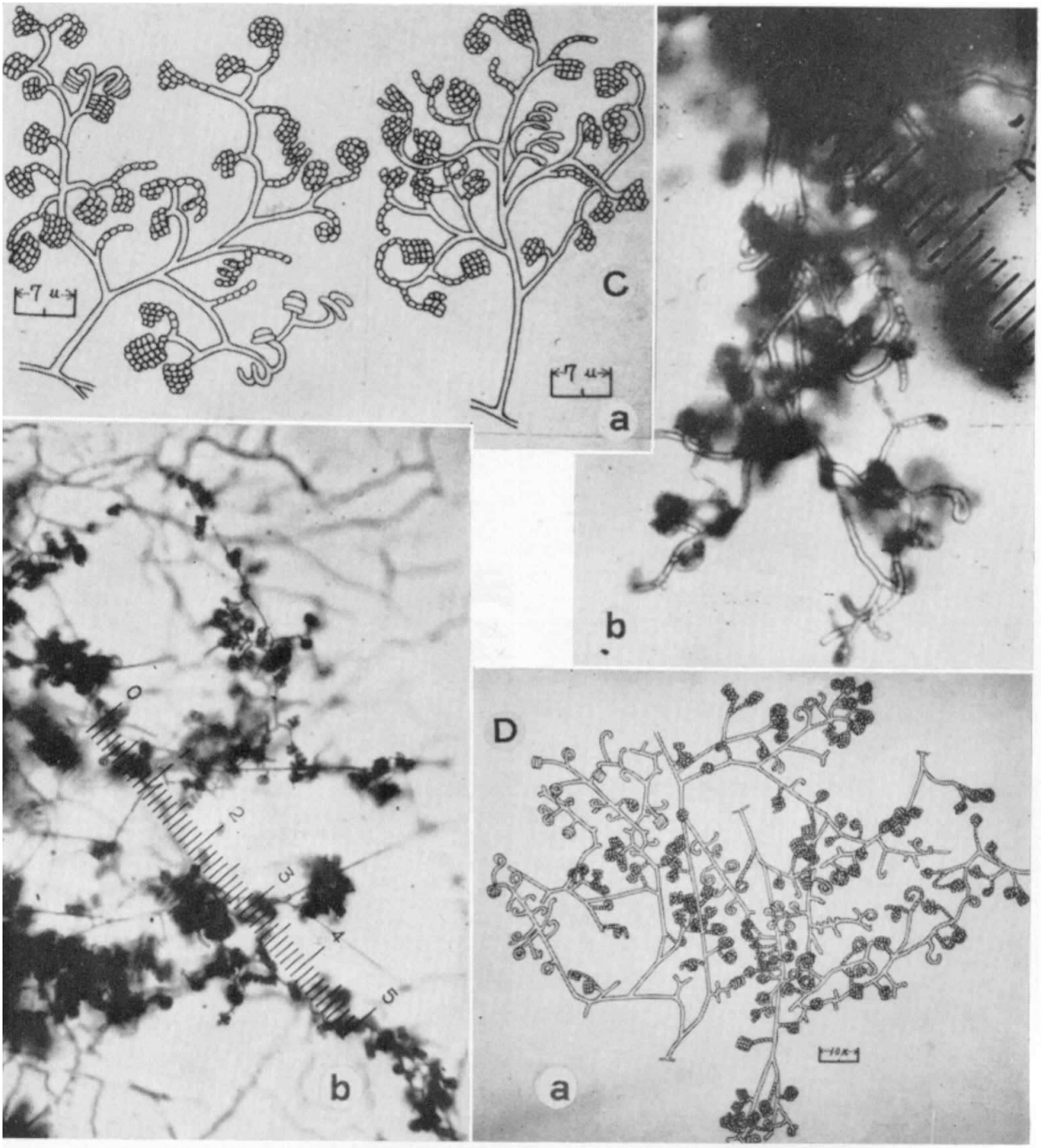

Moephological types of Streptomycetes according to Nomi (1959) II

C Aerial hyphae wavy, spirals on terminal filaments
D Aerial hyphae long, sporophores as side branches

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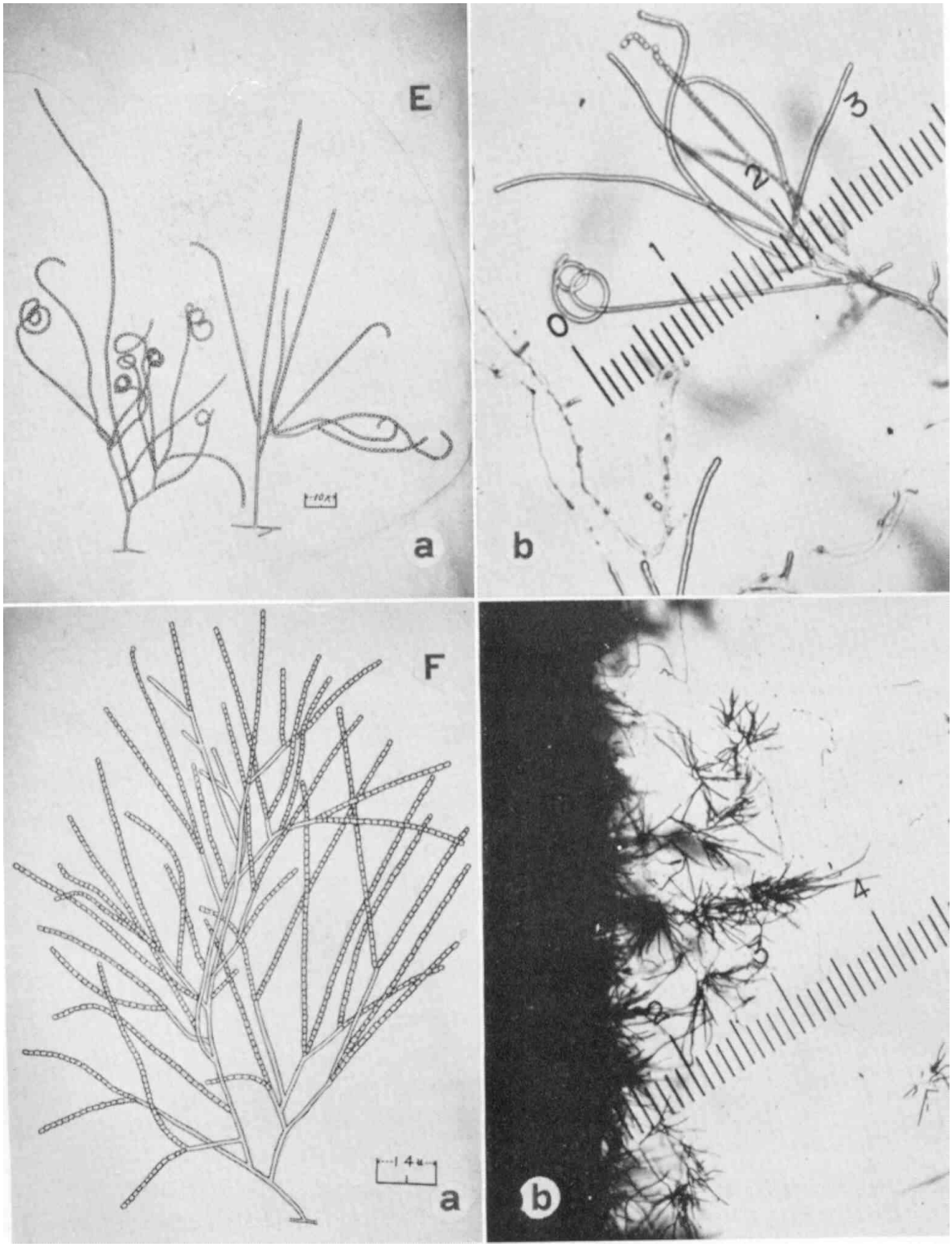

Moephological types of Streptomycetes according to Nomi (1959) III

E Aerial hyphae in clusters, both spiral- and nonspiral forming
F Aerial hyphae in clusters, no spirals or loops

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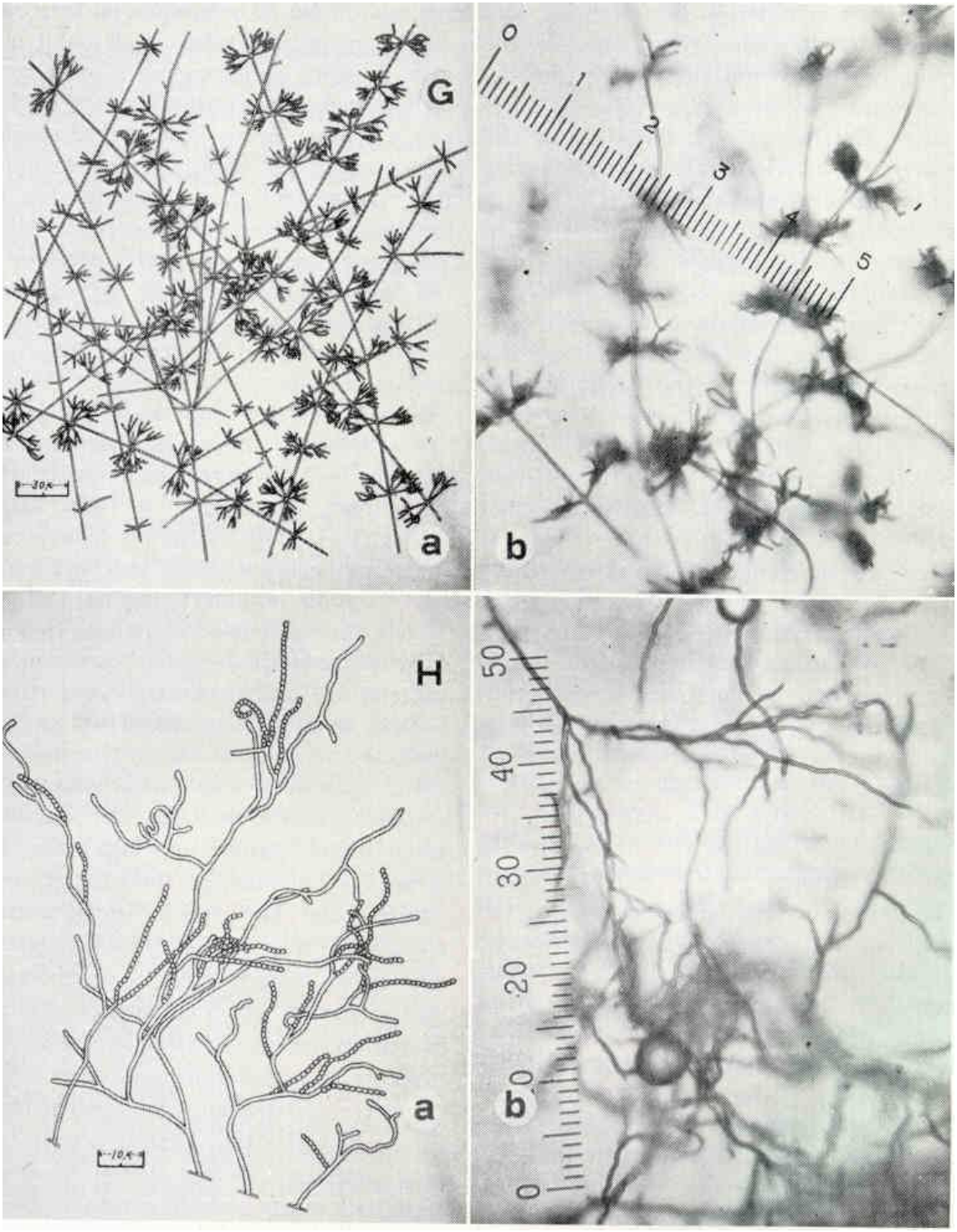

Moephological types of Streptomycetes according to Nomi (1959) IV

G Aerial hyphae verticillate, no spirals
H Aerial hyphae flexous or wavy, no long hyphae and no spirals

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Antibiotics for human use from *Streptomyces* species

Antibiotic	Year	Typ
Streptomycin	1944	Aminoglycosid
Chloramphenicol	1947	
Chlortetracyclin	1948	Tetracycline
Neomycin	1949	Aminoglycosid
Resistomycin	1951	Chinone
Carbomycin	1952	Macrolid
Amphomycin	1953	Acyl polypeptide
Leucomycin	1953	Macrolide
Novobiocin	1955	Coumarin
Cephalosporin C	1956	β-Lactam
Vancomycin	1956	Glycolipid
Kanamycin	1957	Aminoglycosid
Streptovaricin	1957	Ansamycin
Lincomycin	1962	
Tobramycin	1967	Aminoglycosid
Lividomycin	1970	Aminoglycosid
Ribostamycin	1970	Aminoglycosid
Clavulansäure	1976	β-Lactam
Thienamycin	1976	β-Lactam

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Tumor therapeutics from *Streptomyces* species

Antibiotic	Year	Typ
Actinomycine	1940	Chromopeptide
Mithramycin	1953	Chromomycin
Sarkomycin	1953	
Carcinophylin	1954	
Chromomycin A_3	1955	
Mitomycin	1956	
Streptonigrin	1960	
Daunorubicin	1963	Anthracyclin
Bleomycin	1966	Polypeptid
Adriamycin	1969	Anthracyclin

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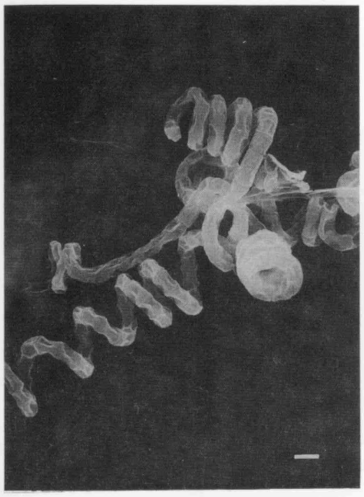
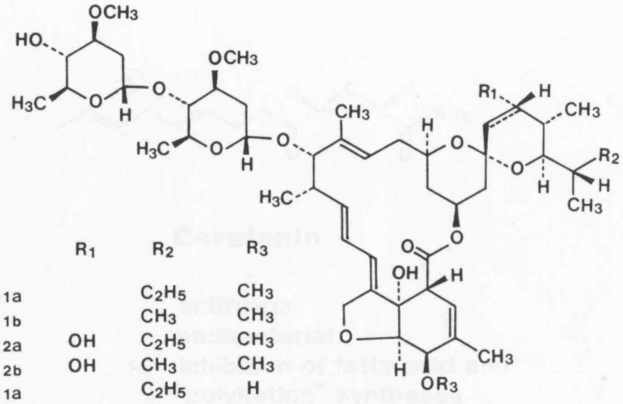
Some examples of metabolites from Streptomyces and Kitasatospora (Omura´s group)



S. avermitilis sp. nov.



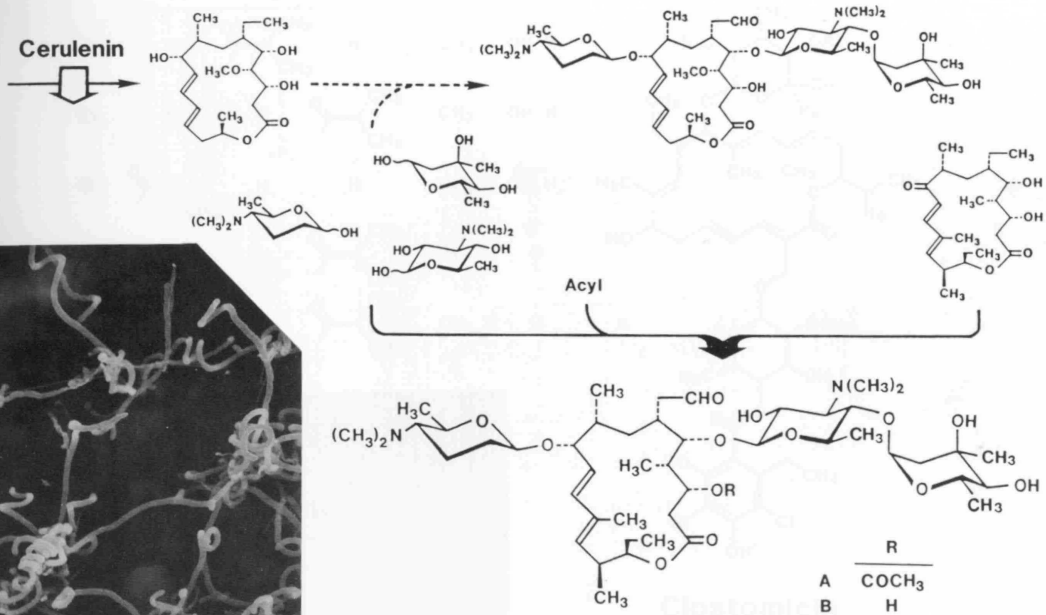
	R_1	R_2	R_3
A 1a		C_2H_5	CH_3
A 1b		CH_3	CH_3
A 2a	OH	C_2H_5	CH_3
A 2b	OH	CH_3	CH_3
B 1a		C_2H_5	H
B 1b		CH_3	H
B 2a	OH	C_2H_5	H
B 2b	OH	CH_3	H

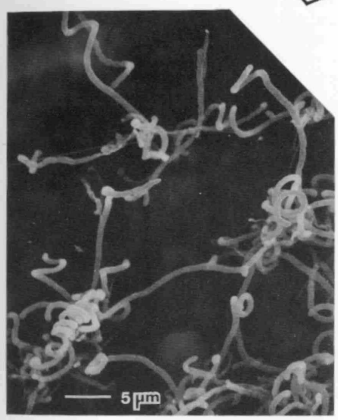
Avermectin

Where R_1 is absent, the double bond (⋯) is present.
Both sugars are α-L-oleandrose.

anthelmintic

Antimicrob. Agent Chemother., 15, 361–378(1979). Am. J. Vet. Rec., 40, 1187–1188(1979).
Vet. Rec., 105, 168(1979).





S. ambofaciens ATCC 15154

Chimeramycin

J. Antibiot., 36, 927–930(1983).

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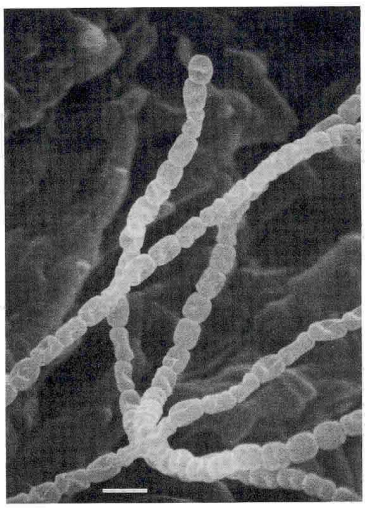
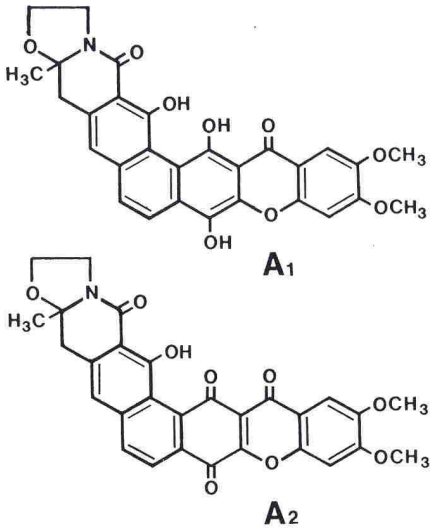


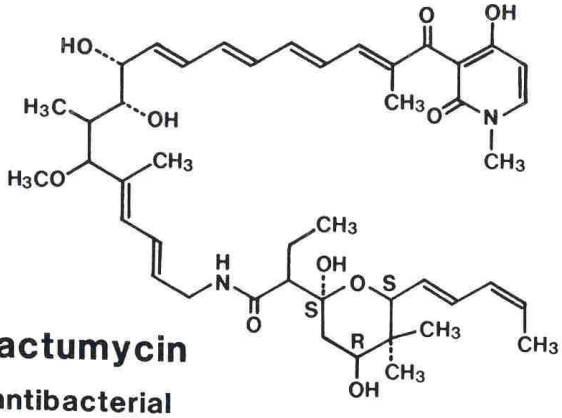
S. cervinus sp. nov.



J. Antibiot., 35, 645–652(1982).
J. Antibiot., 40, 301–308(1987).
J. Am. Chem. Soc., 108, 6088–6089(1986).

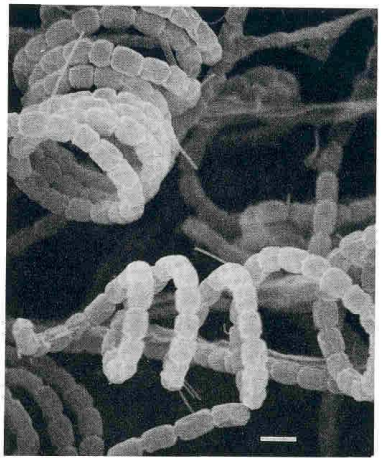
Cervinomycin

antibacterial



Factumycin

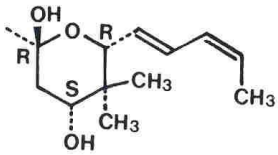
antibacterial



S. lavendulae MA-4758

A-73A

antibacterial



Jpn. Kokai, 81–2980(1981). J. Antibiot., 35, 1705–1707(1982).

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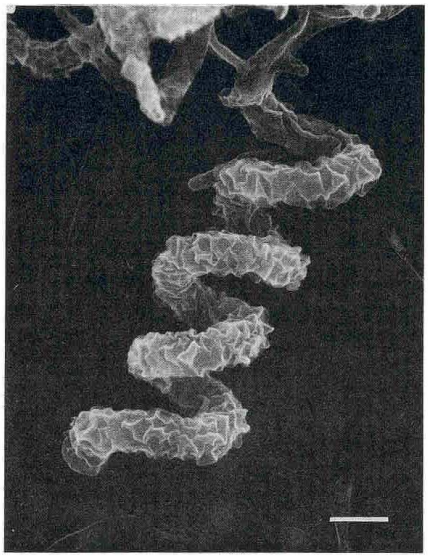
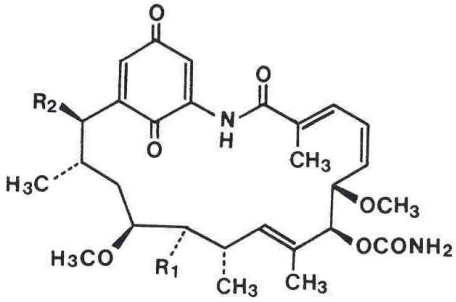


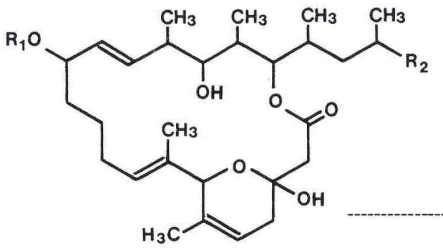
S. hygroscopicus **AM-3672**



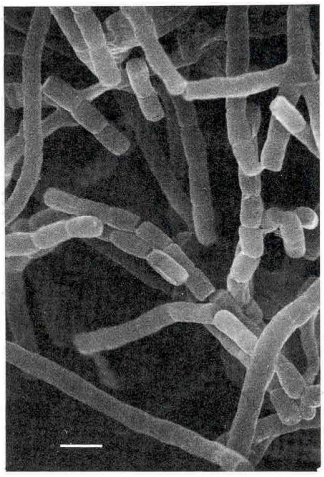
	R_1	R_2
Herbimycin A	OCH_3	OCH_3
B	OH	H

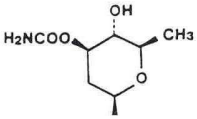
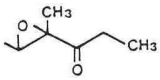
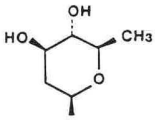
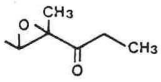
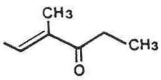
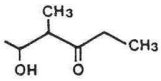
herbicidal
anticancer
anti-TMV

J. Antibiot., 32, 255–261(1979). Tetrahedron Lett., 4323–4326(1979).
J. Antibiot., 33, 1114–1119(1980). Nippon Kagaku Kaishi, 892–894(1981).



S. subflavus **subsp.** ***irumaensis*** **subsp. nov.**



	R_1	R_2
Irumamycin antifungal		
3'-O-Decarbamoyl-irumamycin antifungal		
Irumanolide I	H	
II	H	

J. Antibiot., 35, 256–257(1982). J. Org. Chem., 47, 5413–5415(1982). J. Antibiot., 36, 931–933(1983).
J. Antibiot., 38, 1266–1269(1985).

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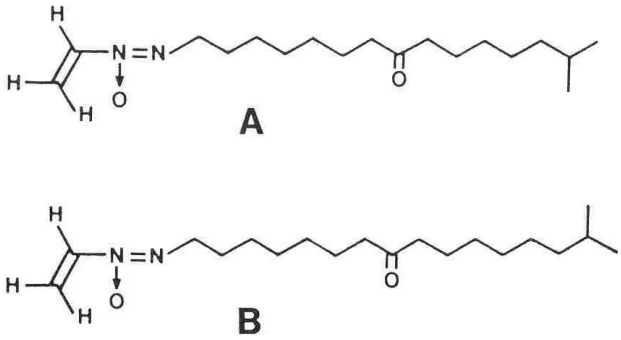
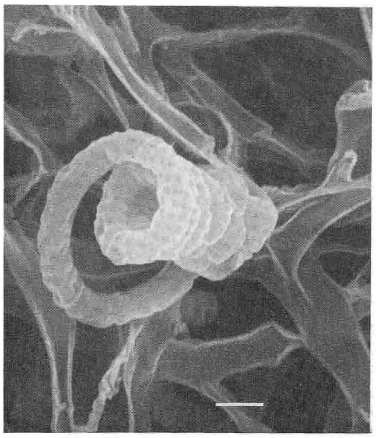


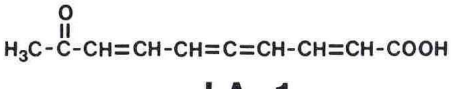


Jietacin

antinematoda

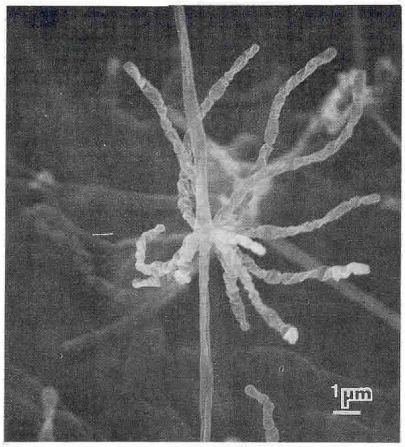
Streptomyces sp. KP-197

J. Antibiot., 40, 623–629(1987).

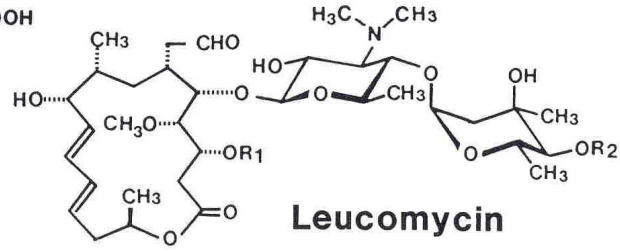


LA-1

antibacterial



Streptoverticillium sp.



Leucomycin

antibacterial

	R_1	R_2
A_1	H	$COCH_2CH(CH_3)_2$
A_3	$COCH_3$	$COCH_2CH(CH_3)_2$
A_4	$COCH_3$	$COCH_2CH_2CH_3$
A_5	H	$COCH_2CH_2CH_3$
A_6	$COCH_3$	$COCH_2CH_3$
A_7	H	$COCH_2CH_3$
A_8	$COCH_3$	$COCH_3$
A_9	H	$COCH_3$
U	$COCH_3$	H
V	H	H

J. Antibiot., Ser.A 6, 87–89(1953). J. Antibiot., 21, 532–538(1968).
J. Antibiot., 25, 105–108(1972). J. Med. Chem., 20, 732–736(1977).
Chem. Pharm. Bull., 24, 3139–3143(1976).

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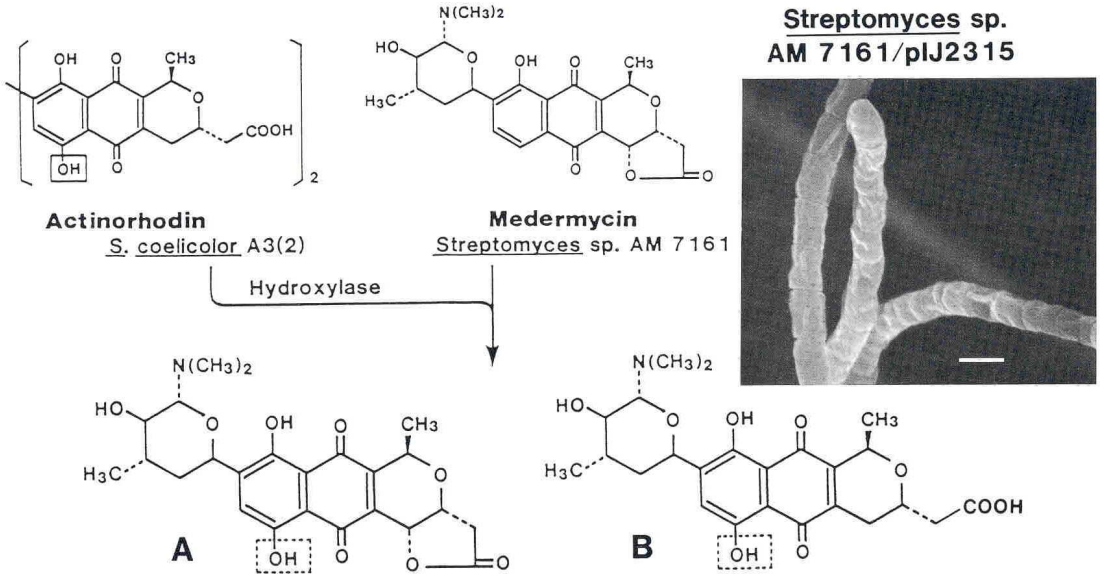
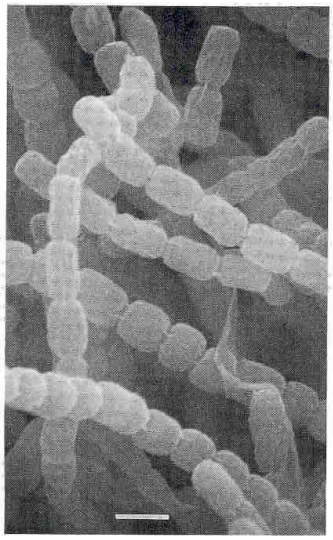


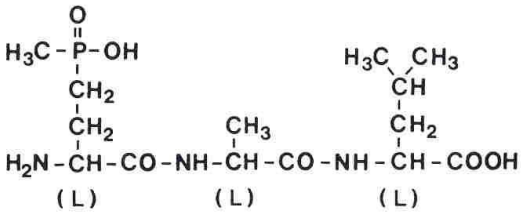
Mederrhodin

antibacterial

Antimicrob. Agent Chemother., 29, 13–19(1986).
Nature, 314, 642–644(1985).



***Kitasatosporia phosalacinea* sp. nov.**



Phosalacine

(L-Phosphinothricyl-L-alanyl-L-leucine)

glutamine synthetase inhibitor
herbicidal

J. Antibiot., 37, 829–835(1984). ibid., 37, 939–940(1984).

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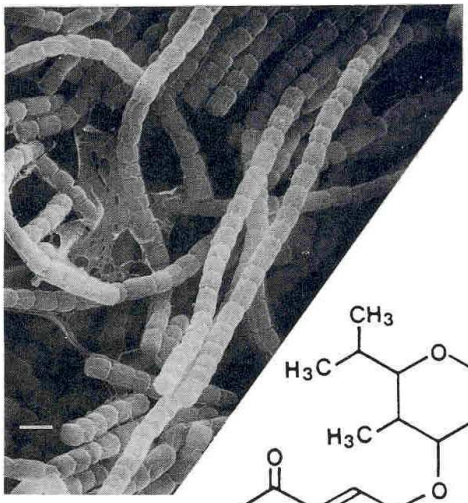
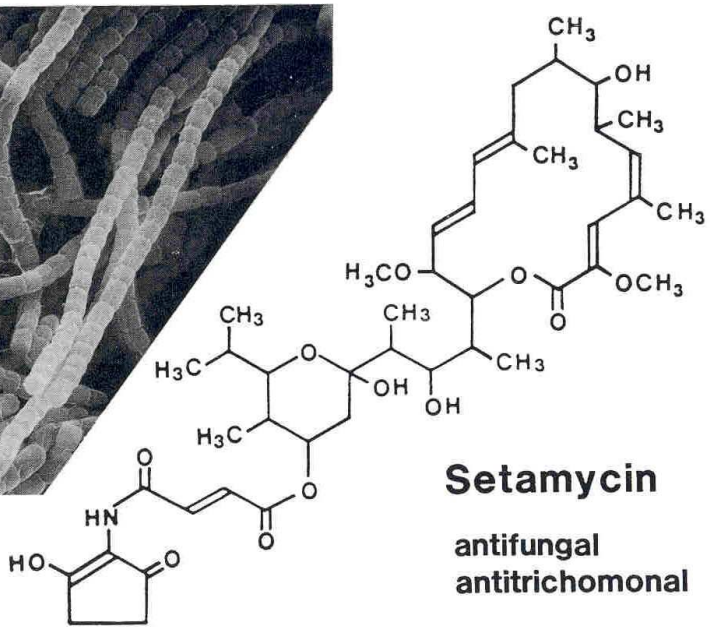
***Kitasatosporia setae* gen. nov. sp. nov.**





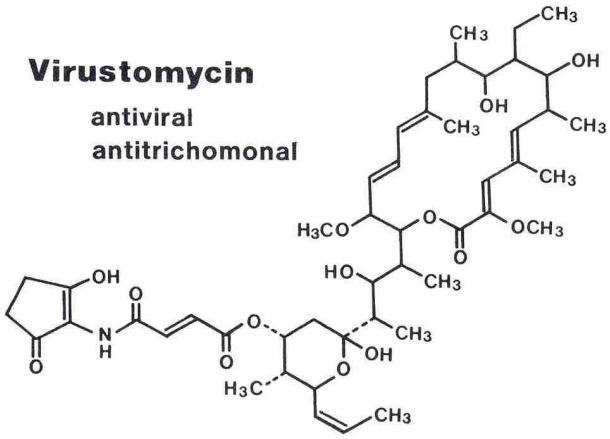
Setamycin

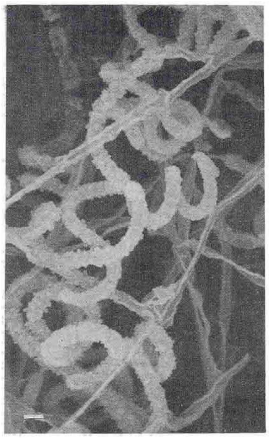
antifungal
antitrichomonal

J. Antibiot., 34, 1253–1256(1981).
ibid. 35, 1013–1019(1982).

Virustomycin

antiviral
antitrichomonal





J. Antibiot., 35, 1632–1637(1982).
ibid., 36, 1783–1786(1983).

***Streptomyces* sp. AM-2604**

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Improved description of the genus *Streptoverticillium* (Baldacci, 1958)
Actinomycetes. 14. 36-43

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A new genus of the *Actinomycetales*:*Microellobosporia* gen. nov.
J. gen. Microbiol. 31: 421-429

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Characterisation of hairy spored *Streptomycetes*.
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Name:	*Streptomyces albus* subsp. *albus* (Type species)
Authors:	(Rossi Doria 1891) Waksman and Henrici 1943
Status:	Approved Lists
Reference(s):	Int. J. Syst. Bacteriol. 30:371 (AL)
Risk group:	1 (German classification)
Type strain:	ATCC 3004, IMET 40241, DSM 40313

Name:	*Streptomyces albus* subsp. *pathocidicus*
Authors:	Nagatsu et al. 1962
Status:	Approved Lists
Reference(s):	Int. J. Syst. Bacteriol. 30:371 (AL)
Risk group:	1 (German classification)
Type strain:	ATCC 14510, DSM 40799

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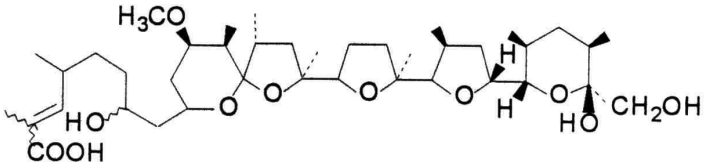
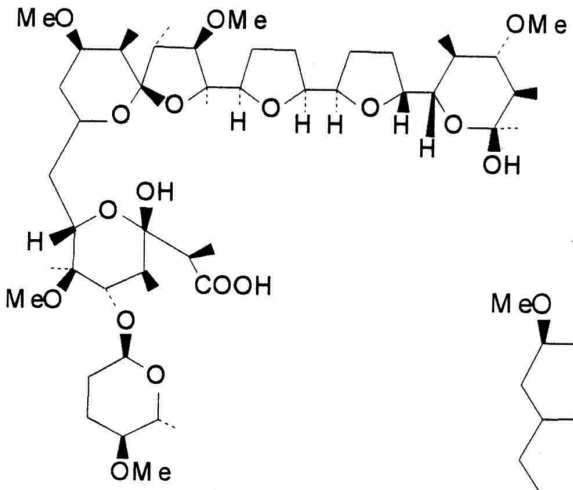
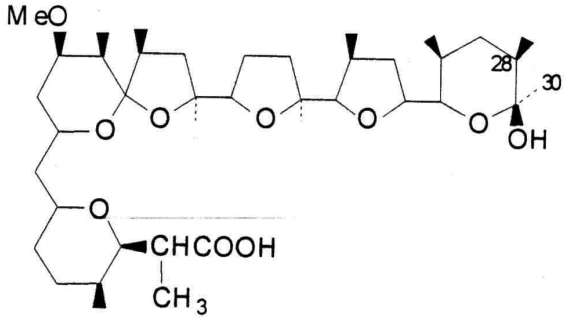
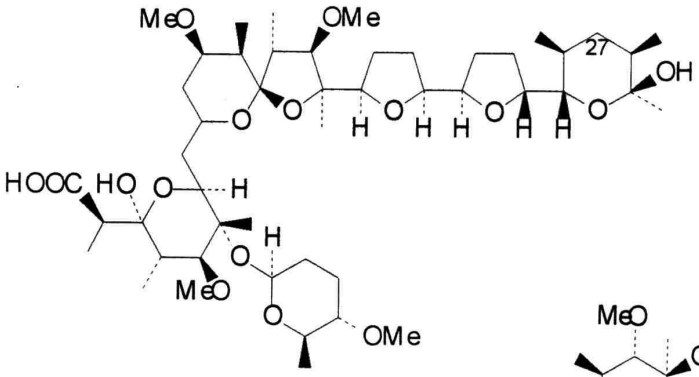
Secondary metabolites from *Streptomyces albus*

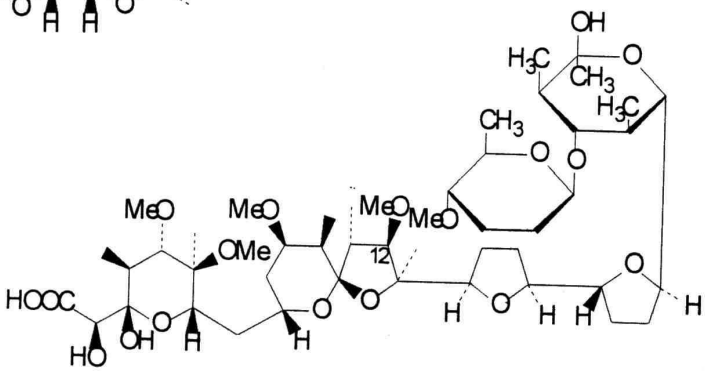
Polyether antibiotics which often show activity against gram-positive and –negative bacteria, viruses and fungi. They have ionophoric activity and are used as anticoccidial compounds











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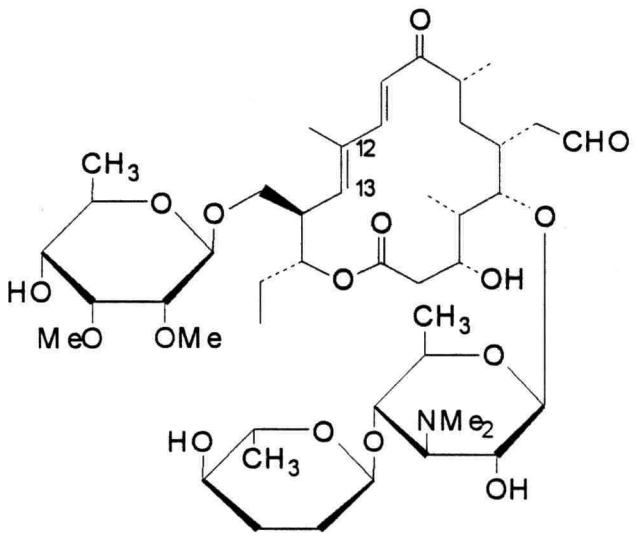
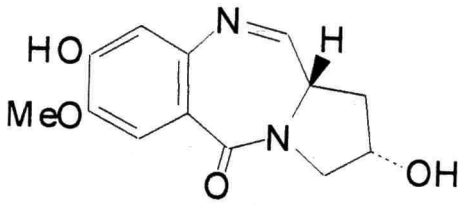
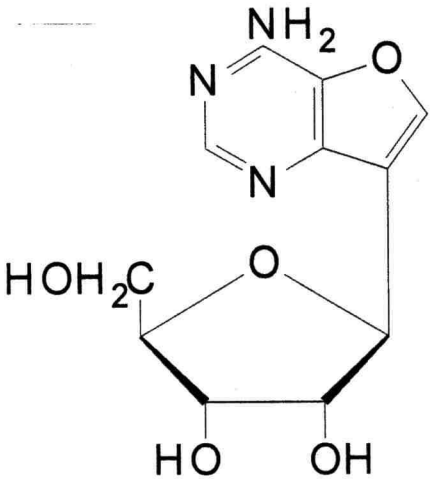
Macrolide antibiotic active against gram-positive and -negative bacteria



Chicamycin B, anthramycin antibiotic, active against tumors



Pyrrolosine, nucleosid-type antibiotic, inhibitor of RNA synthesis



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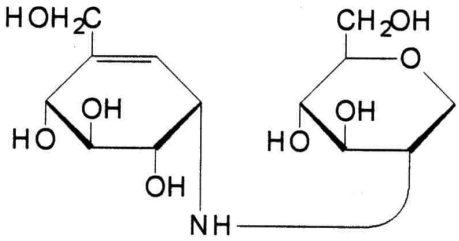
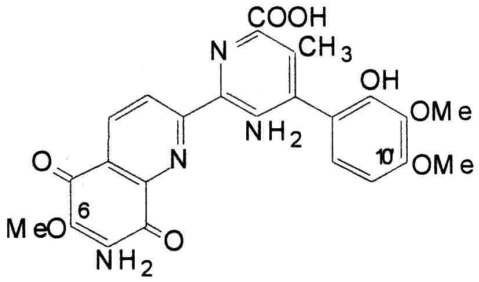
Salbostatin, aminoglycoside antibiotic, inhibitor of trehalase and potential plant pesticide



Streptonigrin, benzoquinone antibiotic, shows immunosupressant, antineoplastic, anti-HIV and antileukaemic activity



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Genus: ***Streptomyces*** **FH 2130**
Species: ***albus*** **Subspecies:** ***albus***
Numbers in other collections: DPDU 0777 (DSM 40313)

Morphology:

	G	R
ISP 2	good	yellow
	A	SP
	white	none
	G	R
ISP 3	good	yellow
	A	SP
	white	none
	G	R
ISP 4	good	ivory
	A	SP
	white	none
	G	R
ISP 5	good	yellow
	A	SP
	white	none
	G	R
ISP 6		
	A	SP
	G	R
ISP 7		
	A	SP

Spore chains: RF Spore surface: rugose
Sporangia: Fragmentation:

Melanoid pigment: -
NaCl resistance: 2,5 %
Lysozyme resistance: below 0,1 %
pH: Value- Optimum-
Temperature : Value- Optimum- 30℃

Carbon utilization:

Glu	Ara	Suc	Xyl	Ino	Man	Fru	Rha	Raf	Cel
+	-	-	+	-	+	+	-	-	-

Enzymes:

Gel	Cit	Ure	Arg	Onp	Trp	Lys	Odc	VP	Ind	H2S
+	-	+	-	+	-	-	-	-	-	-

Comments:

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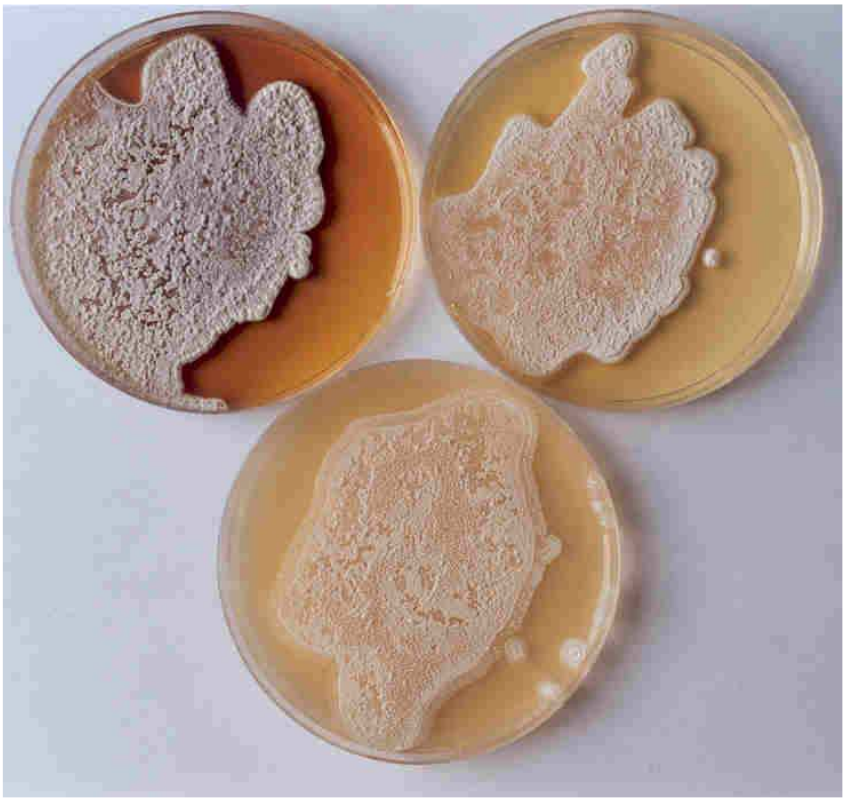

Streptomyces albus* subsp. *albus

A and B – Agar plates medium 5006, 5265 and 5315

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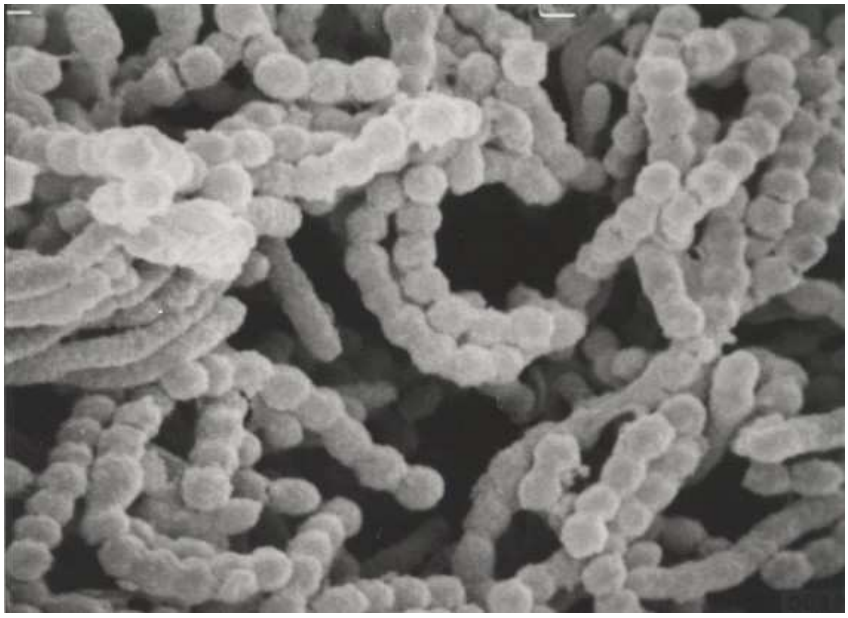

Streptomyces albus* subsp. *albus

C – Microplate with ISP- and melanin media

D – Smooth spore surface and RF spore chains in SEM (x 7.500)

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Genus: ***Streptomyces*** **FH 1620**
Species: ***albus*** **Subspecies:** ***albus***
Numbers in other collections: ATCC 21838

Morphology:

	G	R
ISP 2	good	broom yellow
	A	SP
	none	broom yellow
	G	R
ISP 3	good	broom yellow
	A	SP
	none	broom yellow
	G	R
ISP 4	good	colorless
	A	SP
	none	none
	G	R
ISP 5	good	colorless
	A	SP
	none	none
	G	R
ISP 6	good	colorless
	A	SP
	none	none
	G	R
ISP 7	good	colorless
	A	SP
	none	none

Spore chains: Spore surface:
Sporangia: Fragmentation:

Melanoid pigment: **- - + -**
NaCl resistance: 2,5 %
Lysozyme resistance:
pH: Value- Optimum-
Temperature : Value- Optimum- 30℃

Carbon utilization:

Glu	Ara	Suc	Xyl	Ino	Man	Fru	Rha	Raf	Cel
+	-	+	+	+	+	+	+	+	+

Enzymes:

Gel	Cit	Ure	Arg	Onp	Trp	Lys	Odc	VP	Ind	H2S
+	+	-	-	+	-	-	-	+	-	-

Comments: Strain produces Salinomycin

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Streptomyces albus* subsp. *albus
A and B – Agar plates medium 5006, 5265 and 5315

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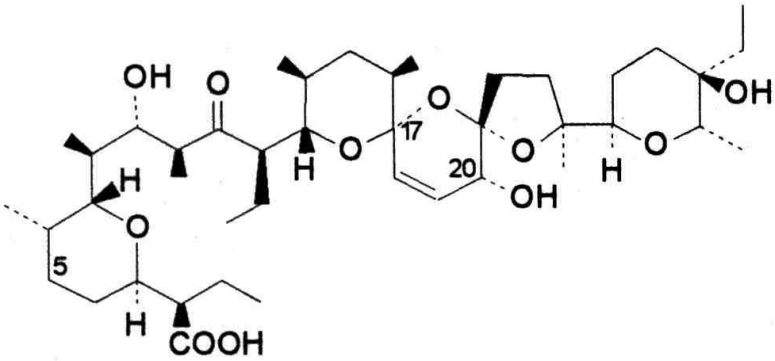

Streptomyces albus* subsp. *albus
C – Microplate with ISP- and melanin media
D – Salinomycin, product of *Streptomyces albus* ATCC 21838

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