表 5　昆虫病原細菌を含む細菌群と属名

内生胞子産生桿菌および球菌	グラム陽性球菌
Bacillaceae（バシラス科）	Streptococcaceae（ストレプトコッカス科）
Bacillus	*Streptococcus*
Clostridium	
グラム陰性通性嫌気性桿菌	リケッチャ
Enterobacteriaceae（腸内細菌科）	Rickettsiales（リケッチャ目）
Serratia	Rickettsiaceae（リケッチャ科）
Proteus	*Wolbachia*
Enterobacter	*Rickettsiella*
グラム陰性好気性桿菌および球菌	マイコプラズマ
Pseudomonadaceae（シュードモナス科）	Mollicutes（モリクテス綱）
	Mycoplasmatales（マイコプラズマ目）
Pseudomonas	*Spiroplasma**

Bergey's Manual（第8版）による.

* 科の所属は未決定.

「昆虫病理学」　福原敏彦編

昆虫病原細菌を含む細菌群と属名

内生胞子産生桿菌および球菌	グラム陽性球菌
Bacillaceae (バシラス科)	Streptococcaceae(ストレプトコッカス科)
Bacillus	Melissococcus
Paenibacillus	Enterococcus
Clostridium	リケッチア
グラム陰性通性嫌気性桿菌	Anaplasmataceae(アナプラズマ科)
Enterobacteriaceae (エンテロバクター科)	Wolbachia
Serratia	Rickettsiaceae(リケッチア科)
Proteus	Rickettsia
Enterobacter	マイコプラズマ
グラム陰性好気性桿菌	Spiroplasmataceae(スピロプラズマ科)
Pseudomonadaceae(シュードモナス科)	Spiroplasma
Pseudomonas	

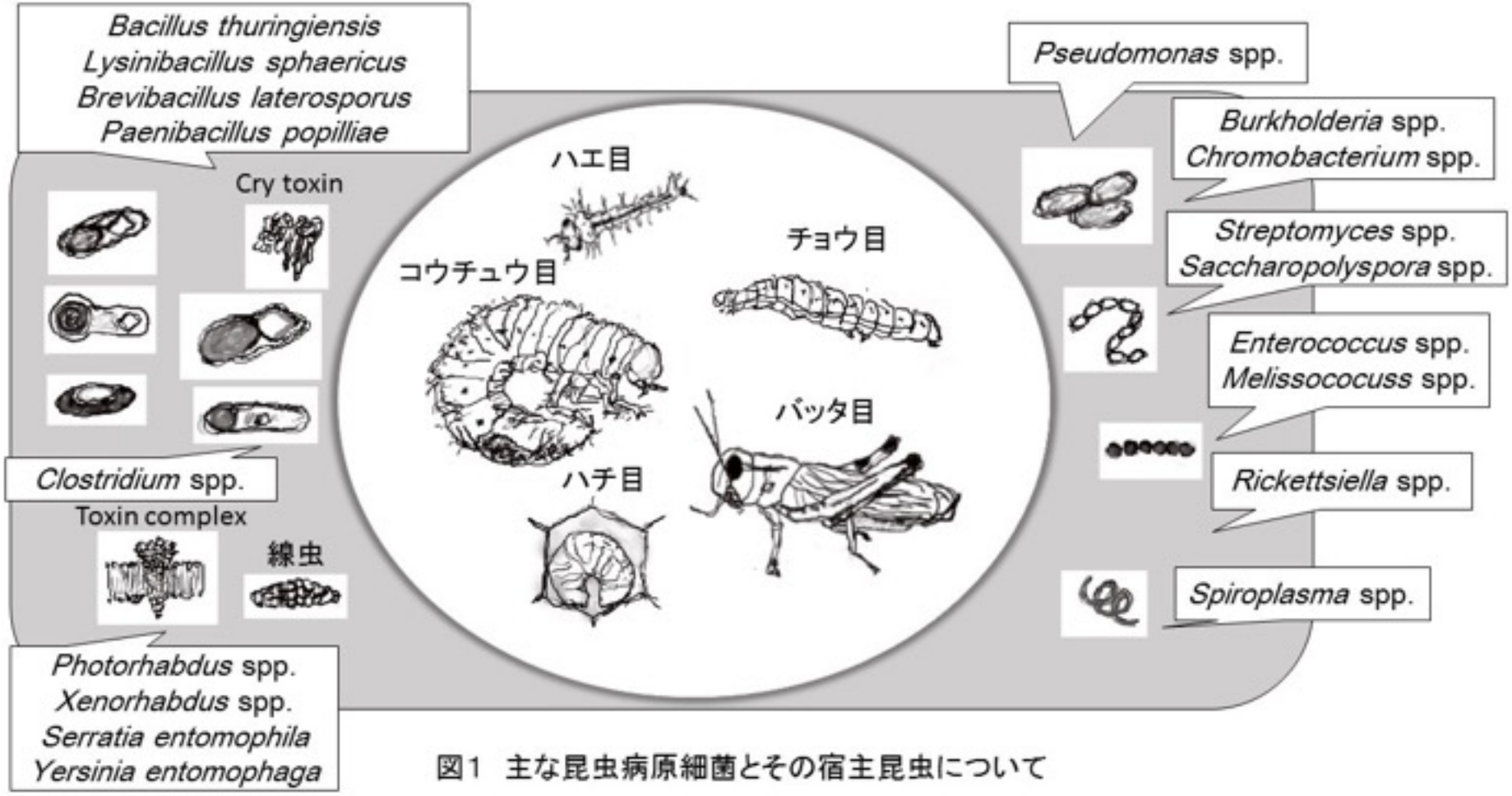


図1　主な昆虫病原細菌とその宿主昆虫について

「昆虫と自然」2016(3)　細菌による昆虫の病気

Bacillaceae (バシラス科)

Bacillus → Group I : *B. thuringiensis*

→ Group II : *B. laterosporas*

→ Group III : *B. sphaericus*

Paenibacillus alvei : European foulbrood

larvae ：American foulbrood

popilliae (lentimorvus) :Milky disease

Lysinibacillus sphaericus : Binary toxin, Mtx proteins

Brevibacillus laterosporus : canoe-shaped parasporal body (CSPB)

insecticidal secreted proteins (ISPs)

Clostridium bifermentans serovar malaysia

brevifaciens

B. sphaericus

spore

Culex sp. (イエカ)

Aedes sp. (ヤブカ)

Anopheres sp. (シマカ)

等の幼虫に殺虫活性

Crystal：Binary toxin　51.4kDa，41.9kDaのペプチド

Baumann L. *et al* (1988)

抵抗性の獲得：　Nielsen-Leroux C. *et al* (1995)

Binary toxinレセプター(グルコシデース)の消失による

Ahmed, et al. Proposal of *Lysinibacillus boronitolerans* gen. nov. sp. nov., and transfer of *Bacillus fusiformis* to *Lysinibacillus fusiformis* comb. nov. and ***Bacillus sphaericus*** *to* ***Lysinibacillus sphaericus*** comb. nov. Int J Syst Evol Microbiol. 2007 May;57(Pt 5):1117-25.

Lysinibacillus sphaericus vegetative cells of certain strains produce mosquitocidal toxins (Mtx proteins).

The Cry48Aa/Cry49Aa mosquitocidal two-component toxin was recently characterized from *Bacillus sphaericus* strain IAB59 and is uniquely composed of a three-domain Cry protein toxin (Cry48Aa) and a binary (Bin) toxin-like protein (Cry49Aa). Its mode of action has not been elucidated, but a remarkable feature of this protein is the high toxicity against species from the *Culex* complex, besides its capacity to overcome *Culex* resistance to the Bin toxin, the major insecticidal factor in *B. sphaericus*-based larvicides.

Mtx toxins from *Lysinibacillus sphaericus* enhance mosquitocidal cry-toxin activity and suppress cry-resistance in *Culex quinquefasciatus*

- Mtx proteins are toxic toward larval *Culex quinquefasciatus*.
- Toxicity was also shown toward Cry-resistant *Cx. quinquefasciatus* larvae.
- Mtx and Cry proteins show greater activity from synergy.
- Mtx and Cry synergy suppresses Cry-resistance in mosquito larvae.

Brevibacillus (former *Bacillus*) *laterosporus* is a pathogen of invertebrates and a broad spectrum antimicrobial species.

Ruiu, L. *Brevibacillus laterosporus*, a pathogen of invertebrates and a broad-spectrum antimicrobial species. *Insects* **2013**, *4*, 476–492.

During sporulation it produces a typical canoe-shaped parasporal body (CSPB) firmly associated with the spore coat, which gives this species a unique morphological feature. The insecticidal action of different *B. laterosporus* strains has been reported against insects in different orders, including Coleoptera, Lepidoptera and Diptera, and against mollusks, nematodes, phytopathogenic bacteria and fungi. In relation to its antifungal and antibacterial properties, due to the production of antibiotics, it has also found use in medicine.

The whole genome of *B. laterosporus* has recently been published, which reveals the potential to produce different toxins.

Djukic, M.; Poehlein, A.; Thürmer, A.; Daniel, R. Genome sequence of *Brevibacillus laterosporus* LMG 15441, a pathogen of invertebrates. *J. Bacteriol*. **2011**, *193*, 5535–5536.

Sharma, V .; Singh, P .K.; Midha, S.; Ranjan, M.; Korpole, S.; Patil, P .B. Genome sequence of *Brevibacillus laterosporus* strain GI-9. *J. Bacteriol*. **2012**, doi:10.1128/JB.06659-11.

B. laterosporus certain strains showing toxicity against the corn rootworms (*Diabrotrica spp*.) and other coleopteran larvae, produce insecticidal secreted proteins (ISPs) that act as binary toxins in the insect midgut and have high homology with *B. thuringiensis* vegetative insecticidal proteins (VIPs).

B. laterosporus specific strains toxic to mosquitoes produce parasporal inclusion bodies reminiscent of those produced by *B. thuringiensis*. These bodies contain proteins and their implication in the mosquitocidal action has been reported.

Zubasheva, M.V.; Ganushkina, L.A.; Smirnova, T.A.; Azizbekyan, R.R. Larvicidal activity of crystal-forming strains of *Brevibacillus laterosporus*. *Appl. Biochem. Microbiol*. **2010**, *46*, 755–762.

Spores of a strain lacking parasporal crystals are highly toxic to the house fly *Musca domestica* L., and the mode of action implies histopathological changes in the midgut with disruption of the microvillar epithelium.

Ruiu, L.; Satta, A.; Floris, I. Observations on house fly larvae midgut ultrastructure after *Brevibacillus laterosporus* ingestion. *J. Invertebr. Pathol*. **2012**, *111*, 211–216.

蚊・ハエに対して殺虫活性を有する

Clostridium bifermentans serovar *malaysia*

66kDa mosquitocidal protein (Cbm66): Cry16A

71kDa mosquitocidal protein (Cbm71): Cry17A

Culex pipiens (アカイエカ)

Aedes aegypti（ネッタイシマカ）に殺虫活性

Clostridium bifermentans serovar *paraiba*

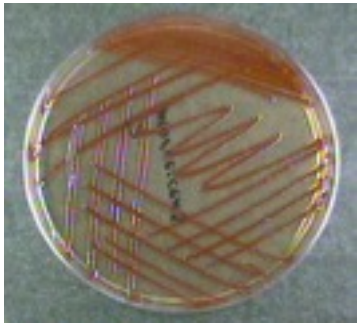
カレハガに縮小病を引き起こす

Clostridium brevifaciens

(ウメケムシの一種　*Malacosoma pluviale*)

3) Facultative pathogens

Serratia marcescence :赤色病



Serratia marcescens has been isolated from

Orthoptera (*Schistocerca gregaria; Periplaneta americana*)　直翅目：バッタ

Coleoptera (*Melolontha melolontha; Tenebrio molitor*),
Hymenoptera (*Neodiprion lecontii*),　膜翅目：ハチ

Lepidoptera (*Bombyx mori; H. zea; H. virescens; Malacosoma spp.; Carpocapsa pomonella*),

S. marcescens infected larva

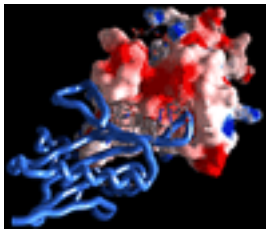
Serratia marcescence に感染した

ニセアメリカタバコガ (*Heliothis virescens*)

and Diptera (*Drosophilia* sp.; *Ceratitis capitata*;*Dacus dorsalis*; *Musca domestica*)

(Krieg, 1987; Thomas and Poinar, 1973).

蚊類では、腸内細菌として腸管に持っている種もいる



Chitinase A :AcNPVの物と相同性が高い（水平遺伝子転移か?）
蚕ゲノム中にも細菌型キチナーゼが存在している

A protein from *S. marcescens* as a model for antibiotic resistance

- セラチアの問題点
  多剤耐性菌が多いため日和見感染の原因菌となりやすい。
  エンドトキシンを産生するためエンドトキシンショックを生じやすい。
  特に湿潤環境に定着しやすく、病院環境に一旦定着・蔓延すると長期間生息し消滅させることが難しい。
  消毒薬に馴化し抵抗性を示しやすい。
  メタロβ-ラクタマーゼ産生株が分離されている。

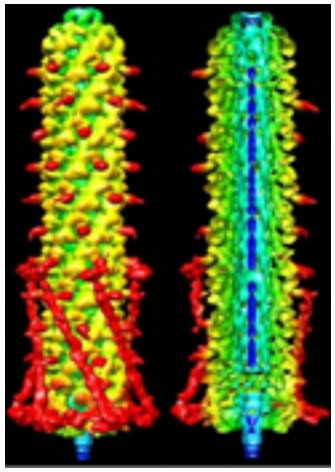
The association of *Serratia spp.* with insects or with entomopathogenic nematodes is well documented.

Zhang, C.-X.; Yang, S.-Y.; Xu, M.-X.; Sun, J.; Liu, H.; Liu, J.R.; Liu, H.; Kan, F.; Sun, J.; Lai, R.; *et al*. *Serratia nematodiphila* sp. nov., associated symbiotically with the entomopathogenic nematode *Heterorhabditidoides chongmingensis* (Rhabditida: Rhabditidae). *Int*. *J*. *Syst*. *Evolut*. *Microbiol*. **2000**, *59*, 1603–1608.

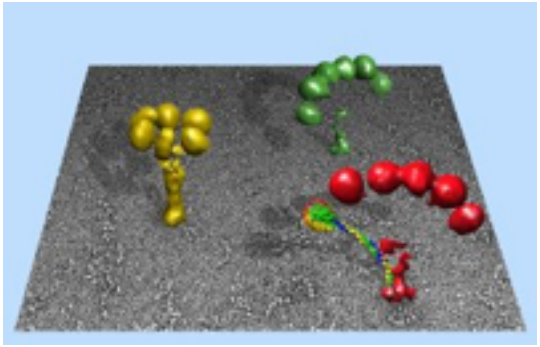
Serratia entomophila

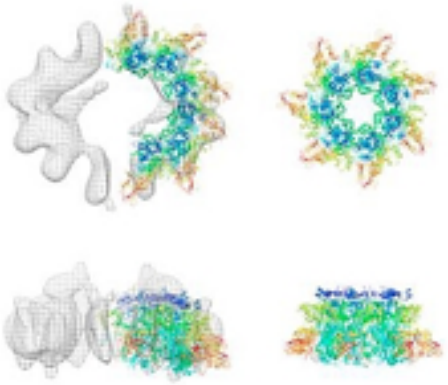
コガネムシに摂食障害活性を引き起こす

（New Zealand grass grub, *Costelytra zealandica*）



摂食障害活性を引き起こすのは、植物ウイルス様のタンパク質を産生することによる





Common is the production of toxin complexes analogous to those produced by *Xenorhabdus* spp. and *Photorhabdus* spp. *S. entomophila* Grimont *et al*., a pathogen of the grass grub, *Costelytra zealandica* (White) (Coleoptera: Scarabaeidae), produces Sep proteins (SepA, SepB, SepC), a group of insecticidal toxins showing similarities to the insecticidal toxins of *P. luminescens*.

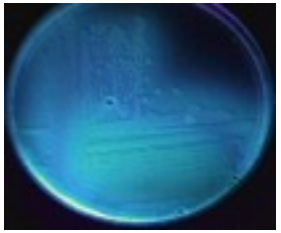
Hurst, M.R.; Glare, T.R.; Jackson, T.A.; Ronson, C.W. Plasmid-located pathogenicity determinants of *Serratia entomophila*, the causal agent of amber disease of grass grub, show similarity to the insecticidal toxins of *Photorhabdus luminescens*. *J. Bacteriol*. **2000**, *182*, 5127–5138.

潜勢病原細菌

Potential pathogens. Such pathogens multiply extracellularly in the hemocoel of insects and produce a lethal septicemia. They grow readily in culture and attack a wide range of insects. Example: *Pseudomonas aeruginosa*, which infects *Heliothis* spp. (Bell et al., 1981).

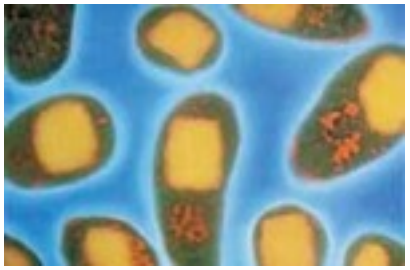
*Pseudomonas*属、*Proteus*属、*Enterobacter*属など

P. aeruginosa, P. chlororaphis, P. fluorescence, P. putida
P. vulgaris, P. mirabilis, P. rettgeri
E. cloacae



好気性の細菌で、通常嫌気条件の昆虫腸管内では増殖しないので経口的に腸管に進入しても排泄される。損傷を受けた腸管から、血体腔に進入することにより感染が成立する。

The complete sequence of the genome of *P. aeruginosa* strain PAO1 was determined in a collaboration among the Cystic Fibrosis Foundation, the University of Washington Genome Center and PathoGenesis Corporation. The largest bacterial genome sequenced to date when published, the 6.3-Mbp genome contains 5570 predicted genes on one chromosome. **http://www.pseudomonas.com/**

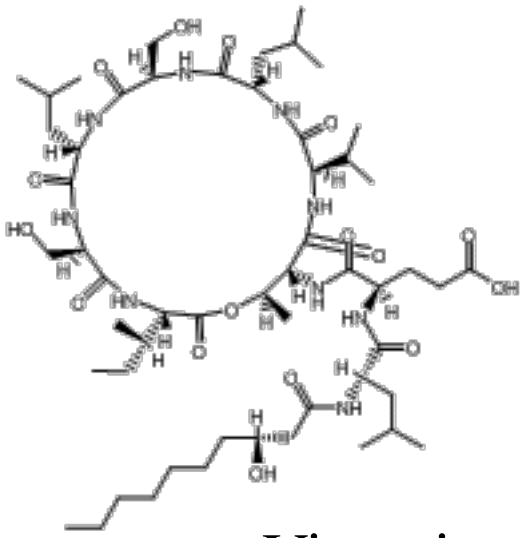


シュードモナス菌に作らせたＢＴ結晶蛋白質

日本応用動物昆虫学会誌(応動昆)
第40巻 第4号:287-292 (1996)

アブラムシ類に殺虫活性を示す細菌に関する研究
細菌の分離と殺虫活性の生物検定

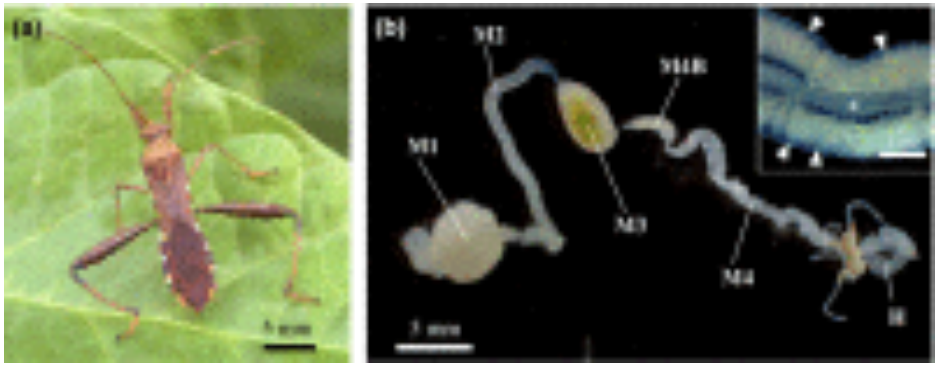
橋本庸三
北海道立中央農業試験場



Viscosin

Bacterial isolates with insecticidal activity against aphids were examined. 1,100 bacterial isolates were isolated from 617 samples (aphids: 437, other insects: 5, plants: 175) collected in the Tokachi district of Hokkaido from 1986 to 1990. Six of 582 isolates demonstrated insecticidal activity by spraying (HS) against the Foxglove Aphid (*Aulacorthum solani*) and the Green Peach Aphid (*Myzus persicae*). Six of 518 isolates also showed insecticidal activity by peroral inoculation (HP) against the Foxglove Aphid and showed a positive reaction to the Potato Rot Test. The mortality of the Cotton Aphid (*Aphis gossypii*) sprayed with HS isolates in a green house was high, but spraying of HP isolates caused low mortality.
Key words: entomopathogenic bacteria, *Aulacorthum solani, Myzus persicae*, *Aphis gossypii*, spraying, peroral inoculation

Different insect species harbor symbiotic bacteria of the genus *Burkholderia*, mostly in association with specific gut regions. In addition to these mutualistic relationships with insects, *Burkholderia* sp. has recently been reported to affect ovipositon and fecundity of the bean bug *Riptortus pedestris* (Fabricius) (Hemiptera: Alydidae).



The pontential of *Burkholderia* species as biocontrol agents against different plant pathogens has also been reported. More recently, the insecticidal properties of a new strain isolated in soil from Japan and identified as *B*. *rinojensis* sp. nov., were discovered. Whole cell broth cultures of this bacterial strain, named A396, show oral toxicity and contact effects against the beet armyworm *Spodoptera exigua* Hübner (Lepidoptera: Noctuidae) and the two-spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae). Insecticidal and miticidal properties are maintained after heat-treatment, hence commercial formulations against a variety of chewing and sucking insects and mites are based on heat-killed cells and spent fermentation media.

Cordova-Kreylos, A.L.; Fernandez, L.E.; Koivunen, M.; Yang, A.; Flor-Weiler, L.; Marrone, P.G. Isolation and characterization of *Burkholderia rinojensis* sp. nov., a non-*Burkholderia cepacia* complex soil bacterium with insecticidal and miticidal activities. *Appl*. *Environ*. *Microbiol*. **2013**, *79*, 7669–7678.

胞子非形成細菌による病気

Bucher (1963) classified the non-sporeforming bacterial pathogens of insects into three groups: 1) obligate pathogens, 2) potential pathogens, and 3) facultative pathogens.

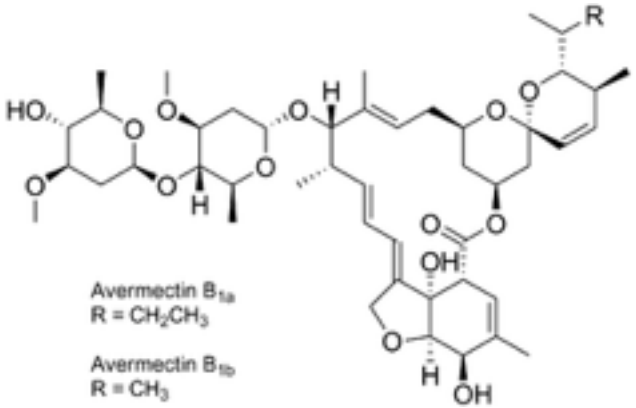
Obligate pathogens. These bacteria are very difficult to culture in vitro. In nature, they multiply only within the bodies of host insects where they cause specific diseases. They have a narrow host range. Example:*Melissococcus pluton (=Streptococcus pluton)* is the causative agent of European foulbrood, which affects honeybees.

Streptococcus pluton：European foulbrood (ミツバチの病気)

改名→*Melissococcus pluton*→*Melissococcus plutonius*

Streptococcus faecalis
→ *Enterococcus faecalis*
Streptococcus facium
→ *Enterococcus faecium*
(ハチミツガ、マイマイガの病気)

Streptomyces species and strains in this genus produce a variety of metabolites acting as potent toxins against either phytopathogenic microbials or insect pests. Among the first discovered insecticidal substances produced by *Streptomyces* species are flavensomycin, antimycin A, piericidins, macrotetralides and prasinons. Later on, the insecticidal and anthelmintic activities of avermectins produced by the soil Actinomycete *Streptomyces avermitilis* MS & Dwas, were discovered.



2015年のノーベル生理学・医学賞は、アベルメクチンの発見を評してウイリアム・キャンベルおよび大村智に、アルテミシニン発見を評して屠呦呦に送られた。

These macrocyclic lactone derivatives target the gamma-aminobutyric acid (GABA) receptor in the insect peripheral nervous system. The enhancement of GABA binding generates a cascade of events resulting in the inhibition of neurotransmission and paralysis of the neuromuscular systems.

Insecticides based on avermectins include a mixture of avermectin B1a and avermectin B1b, known as abamectin, that act by contact and ingestion and have a limited plant translaminar activity. Analogous substances produced by *Streptomyces* species include Emamectin, especially toxic to Lepidoptera, and Milbemectin, isolated from *S. hygroscopicus* Jensen. A variety of other secondary metabolites produced by diverse *Streptomyces* species, have been isolated and characterized so far. Commercialized products have been very successful against ectoparasites and endoparasites with medical and veterinary importance.