

キウイフルーツかいよう病を起こす *Pseudomonas syringae* pv. *actinidiae* pv. nov.

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Pseudomonas syringae pv. *actinidiae* pv. nov.:
The Causal Bacterium of Canker of Kiwifruit in Japan

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Abstract

Bacterial canker of Kiwifruit (*Actinidia chinensis*) has recently been reported in Japan. The causal pathogen is classified in *Pseudomonas syringae* on the basis of laboratory tests and is similar to, but not identical with, *P. syringae* pv. *morsprunorum*. In inoculated kiwifruit, the pathogen from kiwifruit reproduces the characteristic canker and leaf spot symptoms. *P. syringae* pv. *syringae* and *P. syringae* pv. *morsprunorum* are only weakly virulent to kiwifruit. The pathogen from kiwifruit is weakly pathogenic to peach and Japanese apricot, but not to 24 other plant species tested. The pathogen is considered to be a pathovar of *P. syringae* and the name *P. syringae* pv. *actinidiae* pv. nov. is proposed. Strain Kw-11 (ICMP 9617) is designated as the pathotype strain.

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Key words: kiwifruit, bacterial canker, *Pseudomonas syringae* pv. *actinidiae* pv. nov.

INTRODUCTION

A bacterial canker disease of kiwifruit (*Actinidia chinensis*) has become one of the most destructive diseases in kiwifruit orchards in Japan in the past three to four years. The symptoms are characterized by cankers formed on leaders and trunks, shoot blight, and leaf spot lesions with halos^{18,19}. The causal pathogen has been isolated from all symptoms on kiwifruit and its pathogenicity to this host has been confirmed¹⁹. Our preliminary study indicated that the causal pathogen resembled to *Pseudomonas syringae* and was virulent to some stone fruit trees. In the work reported here, the pathogen is fully characterized, using laboratory and pathogenicity tests, is compared with *P. syringae* pv. *syringae* and *P. syringae* pv. *morsprunorum*, and is classified.

MATERIALS AND METHODS

Bacterial strains. Bacterial strains used in this study were listed in Table 1. Fourteen strains were isolated from kiwifruit in 1984, in the Shizuoka Prefecture, Japan. The isolations were made from leaf spots, blighted blossoms and canker lesions on leaders and shoots by conventional plating methods on nutrient agar plates. Strains of *P. syringae* pv. *syringae* and *P. syringae* pv. *morsprunorum*, kindly supplied by Dr. K. Takanashi, Fruit Tree Research

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Table 1. Bacterial strains used in this study

Strains (number)	Host plant (part)	Origin
Kiwifruit strains (14)	kiwifruit	This study
Kw 1, 11, 13, 21~25	(leaf)	
Kw 12	(blossom)	
Kw 30~32	(shoot)	
Kw 41, 42	(leader)	
<i>P. syringae</i>		
pv. <i>syringae</i> (3)		
W 7835, 7837, 7844	peach	K. Takanashi
pv. <i>morsprunorum</i> (5)		
group C		
U 7805, 7806, 8017	Japanese apricot	K. Takanashi
group B		
W 8011, 8107	Japanese plum	K. Takanashi

Station, Ibaraki, Japan, were included for comparative studies (see Table 1). Grouping of *P. syringae* pv. *morsprunorum* strains was designated by Takanashi according to the report of Tominaga *et al.*²⁵⁾ Group C and B include typical and variant strains of *P. syringae* pv. *morsprunorum*, respectively. All cultures were grown on potato peptone glucose agar (PPGA) medium (potato 200 g, peptone 5 g, glucose 5 g, $\text{Na}_2\text{HPO}_4 \cdot 12 \text{H}_2\text{O}$ 3 g, KH_2PO_4 0.5 g, NaCl 3 g, agar 15 g, distilled water 1 liter)¹³⁾ at 25 C and were suspended in sterile distilled water (*ca.* 10^8 cfu/ml). The suspension was used as an inoculum for physiological and biochemical tests.

Morphology and cultural properties. Cell morphology was observed by phase contrast microscopy of unstained preparations. Flagella insertion was determined by light microscopy of slide preparations which had been stained using modified Yamanaka's silver staining method²⁰⁾, and by transmission electron microscopy of preparations negatively stained with 1% phosphotungstate. Gram reaction was determined by the method of Ryu¹⁶⁾. Poly- β -hydroxybutyrate granules were detected by staining with Sudan black B²²⁾. Colony morphology was observed on nutrient agar plates.

Physiological and biochemical properties. Fluorescent pigment production was determined on medium B of King *et al.*¹⁰⁾ The oxidation/fermentation (OF) test was performed in the medium of Hugh and Leifson⁸⁾. For H_2S and ammonia production, cultures were grown in nutrient broth, and tested using lead-acetate paper and Nessler's reagent, respectively. In the test for indole production, NaCl tolerance and maximum temperature for growth, cultures were grown in peptone water. Indole was detected using Kovac's reagent. Nitrate respiration activity was detected using the method of Iizuka and Komagata⁹⁾. Phenylalanine deaminase activity was determined on the medium of Ewing *et al.*⁴⁾ Urease activity was determined on the Christensen's urea agar plates¹⁾. Dye's methods²⁾ were used in the tests for reducing substances from sucrose, nitrate reduction and reaction in purple milk. Lecithinase activity and V.P.-M.R. tests were performed as described in the Manual of Microbiological Methods²¹⁾, and tests for catalase activity and hydrolysis of casein and starch were performed as described in the Manual of Methods for General Bacteriology⁷⁾. Coronatine-like activity was assayed on potato slices as described by Nishiyama and Ezuka¹⁴⁾. Tests for arbutin hydrolysis, acid production in purple lactose agar, growth in sucrose broth, longevity on nutrient sucrose agar (NSA) and utilization of L-tyrosine and L-leucine as sole sources of both carbon and nitrogen were performed as described in Garrett *et al.*⁶⁾ Utilization of organic compounds as sole sources of carbon was determined on the medium of Ayers *et al.*²¹⁾, incorporating the carbohydrates at 1.0% and the other compounds at 0.2%. The organic compounds were autoclaved mo-

mentarily at 115 C with basal medium. Results were observed after 2, 4, 7, 14 and 21 days. A positive result was scored only when visible growth was observed. The followings were tested by the methods described by Lelliott *et al.*¹¹⁾: arginine dihydrolase, oxidase, lipase and tryptosinase activities, hydrolysis of Tween 80 and esculin, gelatin liquefaction, gluconate oxidation, levan production, potato soft rot, and tobacco hypersensitive reaction, with the exception of lipase test in which cotton-seed-oil was used instead of margarine.

Pathogenicity test. Two- to three-year-old plants grown from seedlings and adult six- to seven-year-old vines of kiwifruit (cv. Hayward) were inoculated by spraying or puncturing methods with all strains. For spray-inoculation, the leaf laminae of tested plants were wounded using a sterile needle and sprayed with the bacterial suspensions (*ca.* 10^9 cfu/ml) simply to run off. For puncture-inoculations, the plants were pricked with a needle through a drop of bacterial suspension placed on them. Young shoots of peach (*Prunus persica*) were also inoculated by the puncturing method with all strains.

Strains Kw-1 and Kw-11 from kiwifruit were selected for determining the host range. They were puncture-inoculated on the following plant species: *Castanea crenata* (Japanese chestnut), *Citrus natsudaidai* (natsudaidai), *Cucumis sativus* (cucumber), *Diospyros kaki* (Japanese persimmon), *Eriobotrya japonica* (loquat), *Ficus erecta*, *Ficus carica* (fig), *Glycine max* (soybean), *Lycopersicon esculentum* (tomato), *Malus pumila* (apple), *Morus bombycis* (mulberry), *Myrica rubra* (Chinese bayberry), *Nicotiana tabacum* (tobacco), *Phaseolus vulgaris* (kidney bean), *Photinia glabra* (Japanese photinia), *Pisum sativum* (pea), *Prunus jamasakura* (cherry), *Prunus mume* (Japanese apricot), *Prunus salicina* (Japanese plum), *Pyrus serotina* (Japanese pear), *Raphanus sativus* (radish), *Solanum melongena* (eggplant), *Syringa vulgaris* (lilac), *Thea sinensis* (tea) and *Zea mays* (corn). The plants of cucumber, kidney bean, soy bean, pea, tomato, eggplant, tobacco, corn and radish were grown in pots and kept under *ca.* 20 C in green house. They were inoculated at three to five true leaf stages. The other woody plants were grown in field and were inoculated on newly developed shoots. All inoculated plants were covered with polyethylene bags overnight to maintain high humidity.

With the exception of the inoculation of dormant vines of kiwifruit in December 1984, all other inoculations were made in June and July 1984.

RESULTS

Phenotypic characteristics

All the bacterial strains tested were gram-negative, aerobic, non-sporing, straight rods, and motile with one to three polar flagella. Poly- β -hydroxybutyrate granules were not accumulated. Strains metabolized glucose oxidatively, and produced catalase, ammonia and levan. They also produced reducing substances from sucrose, and gave a positive tobacco-hypersensitive reaction. All strains gave negative reactions in the following tests: arginine dihydrolase, oxidase, lecithinase and phenylalanine deaminase activities; growth at 40 C; production of H_2S , indole and 2-keto-gluconate; reduction of nitrate; nitrate respiration; hydrolysis of starch and cotton-seed-oil; V.P.-M.R. test; growth factor requirement; potato rot; and acid production in purple lactose agar. Coronatine-like activity was not observed.

All strains utilized the following organic compounds as sole sources of carbon: glucose, D-galactose, fructose, D-mannose, sucrose, glycerol, mannitol, sorbitol, citrate, gluconate, glycerate, L-malate, succinate, D-quinic acid, L-asparagine and γ -amino butyrate. No growth was observed on: D-arabinose, lactose, maltose, melibiose, L-rhamnose, cellobiose, trehalose, D-melezitose, dulcitol, adonitol, starch, salicin, arbutin, α -methyl-D-glucoside, triacetin, formate, *n*-butyrate, propionate, mesaconate, sebacate, levulinate, anthranilate, L-valine, L-isoleucine and β -alanine. Acid or alkali production respectively was observed in melibiose and formate without any visible growth.

All strains produced white, circular with entire to undulate margin, convex, butyrous or

slightly slimy, translucent and glistening colonies on nutrient agar plates. Colonies of *P. syringae* pv. *syringae* strains became visible after one day and 2~3 mm in diameter after 3 days. Colonies of strains of kiwifruit and *P. syringae* pv. *morsprunorum* became visible after 2 days and 1~2 mm in diameter after 3 to 4 days. Diffusible brown pigment was produced on nutrient agar slants only by the group B strains of *P. syringae* pv. *morsprunorum* and not by the other strains.

The results for tests, which distinguish the canker pathogen from *P. syringae* pv. *syringae* and pv. *morsprunorum*, are given in Table 2. The results of utilization test of L-tyrosine and L-leucine as sole sources of carbon and nitrogen were identical with the results of utilization test of them as sole sources of carbon.

Pathogenicity tests

All 14 strains from kiwifruit were highly virulent on kiwifruit trees. Following puncture-inoculation of leaves, the initial symptom occurred only around the wounds as a dark water-soaked area that expanded to produce angular spots measuring 2~5 mm. The lesions became red-brown from the center and were usually accompanied by large bright-yellow halos 10 to 20 mm in diameter. On the lower side of the lesions, scale-like bacterial exudates were observed. The initial water-soaked symptom of spray-inoculated leaves occurred primarily at the leaf margins and wound points, but other lesions were scattered over the leaf, indicating stomatal infection. The development of symptoms after water-soaking was the same as described for wound-inoculated plants.

When young shoots of kiwifruit were inoculated, water-soaked lesions appeared and elongated rapidly to 5~10 cm. The infected shoots became necrotic and showed typical shoot blight symptoms. Copious amounts of bacterial exudate were often formed at the inoculated point and the leaf axil of infected shoots, especially during wet weather.

Strains of *P. syringae* pv. *syringae* and pv. *morsprunorum* were also pathogenic to kiwifruit when inoculated on the leaves either by puncturing or by spraying. However, the lesions were small and circular and restricted to wounded sites, indicating that they could not infect *via* stomata or waterpores. The strains of *P. syringae* pv. *syringae* formed halos of 5 to 7 mm in diameter. When young shoots were inoculated in spring, strains of pv. *syringae* and pv. *morsprunorum* also produced small water-soaked lesions, which did not enlarge but became necrotic spots.

Following the inoculation of dormant vines in winter, only strains from kiwifruit gave rise to progressive symptom development. Symptoms appeared from February to March as blight of buds or of emerging shoots on the inoculated canes, and as cracks which formed on the canes which become canker lesions similar to those of natural infection. The strains of pv. *syringae* and pv. *morsprunorum* induced no symptoms.

All strains including pv. *syringae* and pv. *morsprunorum* were pathogenic on young shoots of peach, causing water-soaked lesions at the inoculated sites which enlarged rapidly to become 10~20 mm in length. The lesions became sunken and necrotic at the center and slightly swollen at the margin to form cankers.

Kiwifruit strains were also pathogenic on Japanese apricot forming similar canker lesions on the shoots, but smaller than those observed on peach shoots. They also produced small necrotic spots at inoculated sites on shoots of cherry, plum, mulberry and fig, and formed halos of 2~3 mm on natsudaïdai leaves. However, these reactions were considered to be hypersensitive reactions of the host plants or reactions to a toxin produced by the pathogen, and these plants are excluded from the host range of the kiwifruit pathogen. They did not produce any symptoms on the other plant species tested.

DISCUSSION

The bacterial isolates from kiwifruit which cause canker disease in Japan formed a homo-

Table 2. Bacteriological characteristics which differed among the pseudomonad strains used in this study

Characteristic	Kiwifruit strains	<i>P. syringae</i> pv. <i>syringae</i>	<i>P. syringae</i> pv. <i>morsprunorum</i>		<i>P. syringae</i>	
			Group C	Group B	pv. <i>syringae</i> ^{a)}	pv. <i>morsprunorum</i> ^{a)}
Fluorescent pigment						
on King's medium B	—	+	—	+	+	—
in Uschinsky's solution	—	+	—	+		
Gelatin liquefaction	— ^{b)}	+	—	—	+	—
Hydrolysis of						
Esculin	—	+	—	—	+	—
Arbutin	—	+	—	—	+	—
Casein	+	+	—	—	+	—
Tween 80	+	+	—	+		
Tyrosinase	—	—	+	+	—	+
Urease	—	+	—	+		
Purple milk reaction	Kw	KD	Kw	K		
Maximum NaCl tolerance	3% ^{d)}	4%	1%	3%	5%	3~5%
Maximum growth temperature	30 C	>35 C	32 C	32 C		
Growth in sucrose broth	white	yellow	white	white	yellow	white
Longevity on NSA (days)	>8	>8	<3	6~8	8~14	2~6
Utilization of						
D-Xylose	— ^{e)}	+	— ^{e)}	+		
L-Arabinose	(+) ^{f)}	+	—	+	+	+
D-Ribose	+	+	—	—		
Raffinose	+	+	+	—		
Inositol	+	+	—	+		
Erythritol	—	+	—	+		
DL-Tartrate	—	—	+	—		+
DL-Lactate	—	+	—	—	+	—
Malonate	+	+	—	+		
Acetate	(+)	+	+	+		
n-Caprate	—	+	—	+		
Glutarate	(+) ^{f)}	+	— ^{d)}	+		
Saccharate	+	+	(+)	+		
L-Histidine	—	+	— ^{d)}	+	+	+
L-Serine	(+)	+	—	+	+	+
L-Arginine	+	+	(+)	+	+	+
Betaine	+	+	—	—		
Trigonelline	—	+	—	—		
L-Leucine	(+)	+	— ^{d)}	+	+	—
L-Tyrosine	+	—	(+)	+	—	+

+: positive; —: negative; (+): delayed positive after 2 to 3 weeks; K: alkaline reaction; D: digestion; w: weak reaction.

a) Data from Garrett *et al.* (1966).

b) Kiwifruit strains showed delayed and weak liquefaction after 3 to 6 weeks.

c) Strain W 7837 negative.

d) Strain Kw 21 could grow in 2% but not in 3% NaCl.

e) Acid production was observed without any visible growth.

f) Strain Kw 22 negative.

g) Strains W 7844 and U 7805 negative.

h) Strain W 8107 negative.

i) Strain U 7805 positive.

geneous group in their bacteriological properties. They were gram-negative, obligately aerobic rods with 1~3 polar flagella, and formed white colonies, indicating that they should be included in the genus *Pseudomonas* Migula 1894. The kiwifruit pathogen did not produce fluorescent pigment, and did not accumulate poly- β -hydroxybutyrate, grow at 40 C, reduce nitrate or utilize L-valine, β -alanine or L-isoleucine. In the LOPAT determinative tests¹¹⁾, the cultures of the kiwifruit pathogen produced levan on sucrose, were oxidase negative, did not rot potato, were arginine dihydrolase negative, and produced a hypersensitive reaction in tobacco. Therefore they belong in LOPAT Group Ia. These results show that the pathogen is a member of *P. syringae*.

The kiwifruit pathogen is distinct from the strains of pv. *syringae* and pv. *morsprunorum* in the laboratory tests listed on Table 2, and also distinguishable from other pathovars reported elsewhere^{11,12,17,24)} in several laboratory tests.

Because the kiwifruit pathogen was pathogenic not only on kiwifruit but also on species of *Prunus*, we compared it with the stone-fruit pathogens, *P. syringae* pv. *syringae* and pv. *morsprunorum*. In a preliminary report²³⁾, we tentatively identified the kiwifruit pathogen as a variant of *P. syringae* pv. *morsprunorum* for the following reasons: 1) strains of *P. syringae* pv. *syringae* and pv. *morsprunorum* were pathogenic on kiwifruit, 2) the reactions of the kiwifruit pathogen in the tests of Garrett *et al.*⁶⁾, indicated that the pathogen was similar to pv. *morsprunorum* (Table 2), and 3) because pv. *morsprunorum* is heterogeneous, with variants having different bacteriological characteristics, and differing in their host ranges^{5,25)}, it seemed possible that the pathogen responsible for canker of kiwifruit could be classified as a variant of *P. syringae* pv. *morsprunorum*. However, the inoculation of dormant vines with pv. *morsprunorum* or pv. *syringae* did not produce typical canker symptoms on kiwifruit, and although they could produce small lesions at wound inoculations in leaves, they could not infect leaves *via* stomata or water-pores. The above data show that the pathogen from kiwifruit, although similar to other pathovars, differs significantly in laboratory and pathogenicity tests. In terms of the International Standards for Naming Pathovars of Phytopathogenic Bacteria³⁾, we concluded that the kiwifruit pathogen should be classified as a new pathovar of *P. syringae*. The name *P. syringae* pv. *actinidiae* pv. nov. is proposed and the strain Kw 11 is designated as the pathotype strain, which has been deposited in the International Collection of Micro-organisms from Plants (formerly Plant Disease Division Culture Collection (PDDCC)) under the number of ICMP 9617.

A canker disease of kiwifruit has been reported in California, U.S.A.¹⁵⁾ The canker symptom described resembles that found in Japan but leaf spots and infections of buds and flowers which occur in Japan were not reported in the U.S.A. The pathogen was identified as *P. syringae* and resembles *P. syringae* pv. *syringae*. *P. syringae* pv. *actinidiae* differs from the California pathogen in not producing fluorescent pigment, not liquefying gelatine and lacking ice nucleating activity (unpublished data).

Bacterial blight of kiwifruit has also been reported in New Zealand^{26,27)}. Symptoms of leaves and flowers affected by bacterial blight resembles to that found in Japan. The pathogen, however, was identified as *P. viridiflava* and is easily distinguishable from *P. syringae* pv. *actinidiae* in not producing levan type colonies and positive potato soft rot activity.

Description of *Pseudomonas syringae* pv. *actinidiae* pv. nov.

Pseudomonas syringae pv. *actinidiae* (actinidiae. M.L. f. n. *Actinidia* generic name of kiwifruit; M.L. gen. n. *actinidiae* of kiwifruit). Gram-negative rods, motile with 1~3 polar flagella and aerobic. Colonies on nutrient agar plates are round, convex, glistening, translucent and white. Growth factors are not required. Poly- β -hydroxybutyrate granules are not accumulated. Fluorescent pigment is not produced on King's B medium. Positive for following reactions: catalase, production of ammonia, levan and reducing substance from sucrose, hydrolysis of casein and Tween 80, and tobacco hypersensitive reaction. Negative for following reactions: oxidase, arginine dihydrolase, tyrosinase, urease, phenylalanine deaminase, lecithinase, reduction of nitrate, nitrate respiration, gelatin liquefaction, production of H₂S, indole and 2-keto-

gluconate, hydrolysis of esculin, arbutin, starch and cotton-seed-oil, and potato rot test. Maximum growth temperature is 30 C. Utilizes glucose, L-arabinose, D-ribose, fructose, sucrose, raffinose, mannitol, glycerol, inositol, sorbitol, gluconate, glycerate, malonate, acetate, glutarate, saccharate, L-malate, succinate, D-quinic acid, L-asparagine, L-serine, L-arginine, L-leucine, L-tyrosine and betaine. Does not utilize D-arabinose, D-xylose, lactose, maltose, melibiose, L-rhamnose, cellobiose, trehalose, melezitose, dulcitol, adonitol, salicin, arbutin, α -methyl-D-glucoside triacetin DL-tartrate, DL-lactate, formate, *n*-butyrate, propionate, mesaconate, *n*-caprate, sebacate, levulinate, anthranilate, L-valine, L-isoleucine, β -alanine, L-histidine, trigonelline. Pathogenic on *Actinidia chinensis*, *Prunus persica* and *Prunus mume*. Pathotype strain is Kw 11 (ICMP 9617).

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和 文 摘 要

瀧川雄一・芹沢拙夫・市川 健・露無慎二・後藤正夫：キウイフルーツかいよう病を起こす *Pseudomonas syringae* pv. *actinidiae* pv. nov.

キウイフルーツかいよう病の病原細菌の分類学的位置づけを明らかにするために、細菌の同定を行った。本菌はグラム陰性の桿菌で好気性、1~3本の極鞭毛を有し白色の集落を形成することから *Pseudomonas* 属である。蛍光色素は産生しないが、ポリβヒドロキシン酪酸を蓄積せず、40℃での生育、硝酸還元が陰性、valine, β-alanine, isoleucine を利用せず、LOPAT 試験の結果が +---+ で Ia 群であることなどから、*P. syringae* であると考えられる。これらの性質は、比較に供した *P. syringae* pv. *syringae* および pv. *morsprunorum* ともおおむね一致していたが、ゼラチンの液化、エスクリンの分解や数種有機化合物の利用性などにおいてこれらとの間に差異が認められた。接種試験の結果、本菌はキウイフルーツの葉や新梢に強い病原性を示し原病徴を再現したほか、冬季の接種によっても枝のかいよう症状を再現したのに対し、pv. *syringae* および pv. *morsprunorum* はキウイフルーツの葉に弱い病原性を示したが、冬季の接種では発病が認められなかった。本菌はキウイフルーツの他、モモ、ウメに対して病原性が認められたが、他の 24 種の植物には寄生性は認められなかった。以上の結果より、本菌を *P. syringae* の新病原型と同定し、*P. syringae* pv. *actinidiae* pv. nov. と命名するとともに、pathotype strain として Kw 11 (ICMP 9617) を指定した。