Influence of Rootstocks on the Resistance of Grafted Cucumber (*Cucumis sativus* L.) Scions to Powdery Mildew (*Podosphaera xanthii* U. Braun & N. Shishkoff)

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Whether or not powdery mildew resistant and susceptible rootstock cultivars would impart these characteristics to the grafted cucumber scions was investigated. Two newly released pumpkin rootstock cultivars used for bloomless cucumber production, ‘Tokiwa Power Z’ and ‘White Power’, were found to be highly resistant to powdery mildew from the seedling stage (tested parts: cotyledons) to the adult stage (tenth true leaves) at cool to moderate temperatures. The accession PPMR-1, a blooming rootstock, showed moderate to high levels of resistance, especially during the adult stage. The conventional bloomless rootstock ‘Hikari Power Gold’ and the conventional blooming rootstock ‘Shin-tosa’ were found to be susceptible. The rootstocks had little to no influence on the resistance to powdery mildew of the grafted scions at younger stages, even though the levels of resistance of the rootstock cultivars differed considerably. Scions, grafted onto PPMR-1 or ‘Shin-tosa’ rootstocks, showed increasing powdery-mildew resistance or tolerance with growth (tested parts: fifth and seventeenth true leaves). The powdery-mildew-resistant ‘Tokiwa Power Z’ and ‘White Power’ did not impart high levels of resistance to scions, whereas ‘Hikari Power Gold’, which is used for bloomless cucumber production, reduced the resistance of scions to powdery mildew. These results indicate that rootstock cultivars, including certain pumpkin rootstocks, e.g., PPMR-1, can alter the powdery-mildew resistance or tolerance of cucumber scions at the adult stage.

Key Words: cucumber, grafting, powdery mildew, resistance, rootstock.

Introduction

The main objectives of grafting cucumbers are to avoid soilborne diseases and to obtain higher yields than with non-grafted seedling plants. Grafting contributes to sustainable agriculture by reducing the amount of agrochemicals used for disinfecting soil and higher yields result in higher income for farmers. In Japan, the use of the pumpkin cultivars ‘Shirokikuza’ (*Cucurbita moschata* Duch.) and ‘Shin-tosa’ (*C. maxima* Duch. × *C. moschata*), as rootstocks for the production of cucumber (*Cucumis sativus* L.), began around 1960 (Fujieda, 1994) and is now common, being used at rates of up to 80% generally and nearly 100% in glass and plastic greenhouse production. This practice reduces damage from *Fusarium* wilt (*Fusarium oxysporum* Schlechtendahl f. sp. *cucumerinum* Owen) and also increases yield. Moreover, grafting makes the plants tolerant to cool temperatures (Oda, 2002). In the mid-1980s, the adoption of a new type of pumpkin cultivar (*Cucurbita moschata*), which does not bloom, allowed

the production of attractive, lustrous cucumber fruits.

However, the use of bloomless rootstock cultivars has been observed to alter several characteristics of the grafted cucumbers, such as their susceptibility to disease. Hazama et al. (1993) reported that the use of these rootstocks resulted in an increased incidence of more severe damage by powdery mildew (*Podosphaera xanthii* [Castagne] U. Braun & N. Shishkoff). In contrast, Morishita et al. (1999) observed the suppression of powdery mildew growth on the leaves of a susceptible cultivar grafted onto a resistant wild-type cucumber. These results suggest that the rootstock may transmit the resistance of cucumber scions to powdery mildew.

Recently, several new bloomless rootstock cultivars that exhibit tolerance to powdery mildew have been released by Japanese cucumber seed companies. There is demand for new bloomless rootstock cultivars that confer powdery-mildew tolerance or resistance to cucumber scions, although the potential effects of grafting are unclear. We had selected a powdery-mildew resistant pumpkin (*C. moschata*) accession, PPMR-1, from a local Japanese cultivar of ‘Shima-kabocha’ (unpublished). And the powdery-mildew-resistant cucumber accession PI 197088-1 had been selected previously from the Indian wild-type cucumber

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accession PI 197088 (Morishita et al., 2002). The many pumpkin and cucumber cultivars with various levels of powdery-mildew resistance that have recently become available were used to investigate the influence of rootstocks on the occurrence of powdery mildew on cucumber scions.

In this study, we examined the powdery-mildew resistance of the rootstock cultivars, including the newly released bloomless rootstock cultivars and the influence of these rootstock cultivars on the resistance of cucumber scions.

Materials and Methods

Plant materials

The rootstocks and scions (Table 1): 'Hikari Power Gold' (HP), 'Agura' (AG), 'All-Star' (AS), 'King Kitora' (KK), and 'Tokiwa Power Z' (TP) are F₁ hybrid rootstock cultivars of *C. moschata* Duch. PPMR-1 (PM) was selected from the local Japanese *C. moschata* cultivar 'Shima-kabocha' and is resistant to powdery mildew (unpublished). 'White Power' (WP) and 'Shin-tosa' (ST) are interspecific F₁ hybrid rootstocks between *C. maxima* Duch. and *C. moschata*. HP, AG, AS, KK, TP, and WP are rootstock cultivars used for bloomless fruit production. AG, AS, TP, and WP that were released recently are claimed by their distributors to show tolerance to powdery mildew. ST is a conventional Japanese rootstock cultivar, whereas 'Shishigadani' (SS) is a local Japanese *C. moschata* cultivar. 'Encore 10' (A10) is a typical Japanese cultivar whose fruits grow to about 20 cm and weigh 100–120 g; it is highly susceptible to powdery mildew. A10 was used as a scion and rootstock; PI 197088-1 (PI) is powdery mildew resistant (Morishita et al., 2002).

Powdery-mildew resistance of rootstock cultivars

To evaluate the resistance of the rootstock cultivars, seeds were sown in plastic pots (9 cm diam.) filled with

the sterilized and fertilized soil mix, Engei-baido (Kureha Chemical Industry Co., Ltd. Japan); the plantlets were grown in a greenhouse.

Powdery mildew used in this study was *Podosphaera xanthii* [Castagne] U. Braun & N. Shishkoff, formerly known as *Sphaerotheca fuliginea*. Preparation of the inoculum, inoculation by spraying leaf with a conidial suspension (10⁵/mL) and incubation them as described by Morishita et al. (2002).

Cotyledons detached from various rootstock cultivars for the first test, were inoculated and incubated at 20°C or 26°C because the resistant reaction of some cucumber cultivars is temperature-dependent (Morishita et al., 2002). The first true leaves of rootstock-plantlets for the second test were inoculated at the three-leaf stage and were grown in a plastic greenhouse. For the third test, the tenth true leaves on seven rootstock plants of each cultivar were planted in a plastic greenhouse without replication on 30 May 2002; they were inoculated 4 weeks after transplanting.

The disease index for evaluating the resistance of each plant was assessed on a 0–9 scale (0 = no visible symptoms to 9 = completely covered with mycelia with dense conidia). The disease-index data were analyzed with a Kruskal-Wallis ANOVA by using Stat Macros (developed by T. Hirota, International Christian University, Japan).

Powdery-mildew resistance of cucumber scions grafted onto rootstocks

To evaluate the influence of the rootstocks, seeds were sown in vermiculite and grown in a germination cabinet kept at 30°C. Nine to 13 days after sowing, individual scions and rootstocks were united at the hypocotyls by using the approach-grafting method; the grafted plants were transplanted into 9 cm plastic pots as above. Nine to 12 days after grafting, the root systems of the scions were severed.

Table 1. The plant materials used in this study.

Species/Cultivar name	Cultivar abbreviation	Cultivar type	Bloom	Source
<i>Cucurbita moschata</i>				
Hikari Power Gold	HP	F ₁	No	Tokiwa Kenkyujo, JP
Agura	AG	F ₁	No	Kurume Vegetable Breeding Co., LTD, JP
All Star	AS	F ₁	No	SaitamaGensyu Ikuseikai Co., LTD, JP
King Kitora	KK	F ₁	No	Nanto Seed Co., LTD, JP
Tokiwa Power Z	TP	F ₁	No	Tokiwa Kenkyujo, JP
PPMR-1	PM	pure-bred	Yes	Selection from a local variety of 'Shimakabocya' of Okinawa, JP
Shishigadani	SS	pure-bred	Yes	Local variety of Kyoto, JP
<i>C. maxima</i> × <i>C. moschata</i>				
White Power	WP	F ₁	No	Tokiwa Kenkyujo, JP
Shin-tosa	ST	F ₁	Yes	Tokiwa Kenkyujo, JP
<i>Cucumis sativus</i>				
Encore 10	A10	F ₁	Yes	Tokiwa Kenkyujo, JP
PI 197088-1	PI	pure-bred	Yes	Selection from a PI 197088 of Indian wild cucumber

Cotyledons, detached from scions grafted onto various rootstocks for first test, were inoculated and incubated at 20°C. The fifth true leaves of the grafted plantlets for the second test were inoculated and the plantlets were incubated as above. For the third test, the seventeenth true scion leaves on 14 grafted plants of each paired combination were inoculated on 20 December 2001, 30 May 2002, and 22 September 2004, respectively and the plants were grown in a plastic greenhouse that was kept above 15°C. The Japanese standard training system for cucumber, which consisted of a single vine trained vertically and lateral shoots pinched at one or two nodes, was used. Inoculations to seventeenth leaves were performed 4–8 weeks after transplanting. A plant, grafted onto a rootstock of cultivar HP, is referred to as HP-grafted; similar descriptions are used for the other cultivars.

Results and Discussion

Powdery-mildew resistance of rootstock cultivars

The powdery-mildew resistances of the rootstock cultivars (Table 2, 3) reveal that TP, WP, and PI, tested by detached cotyledons incubated at 20°C, were the most

resistant. The symptoms on the leaf surfaces of these cultivars were nearly undetectable, because they exhibited very few sporulations under microscope. HP, AG, AS, SS, ST, and A10 were severely infected and thus regarded as susceptible, while PM was moderately resistant. Nearly identical results were obtained when the cultivars were incubated at 20 or 26°C. TP and WP, the newly released bloomless rootstock cultivars, were highly resistant compared with the conventional rootstock cultivars HP (bloomless type) and ST (blooming type). The claimed resistances of AG and AS were not confirmed, but the resistance of PI, which had been selected as a highly resistant cucumber cultivar, was confirmed. PM has been regarded as resistant, but at the cotyledonary stage, it was not completely so.

The cultivars that showed the most resistance in the first true leaves were TP and PI. PM also showed complete resistance in this test, but incomplete resistance in another (data not shown). The resistance of PM was therefore deemed to be moderate; HP, ST, and A10 were severely infected.

The accession/cultivar that showed the most resistance in the tenth true leaves were PM and PI, lacking any

Table 2. Powdery mildew resistance in detached cotyledons of rootstock cultivars.

Rootstock cultivar	Disease index ^z			
	20°C (RE) ^y		26°C (RE)	
Hikari Power Gold	8.5 a ^x	(S)	7.4 a	(S)
Agura	7.9 abc	(S)	4.8 ab	(M)
All Star	7.9 ab	(S)	7.3 a	(S)
Tokiwa Power Z	0.4 d	(R)	0.0 b	(R)
PPMR-1	5.2 bcd	(M)	4.0 ab	(M)
Shishigadani	8.3 ab	(S)	6.5 a	(S)
White Power	0.7 d	(R)	0.4 b	(R)
Shin-tosa	8.2 ab	(S)	4.4 ab	(M)
Encore 10	8.0 ab	(S)	5.7 a	(S)
PI 197088-1	0.3 d	(R)	0.0 b	(R)

^z Disease index: 0 = no symptom—9 = totally and thickly covered with hyphae and spores.

^y Resistance Evaluation: S, susceptible; M, moderate resistant; R, resistant.

^x Mean separation within columns by Kruskal and Wallis ANOVA at $P < 0.05$.

Table 3. Powdery mildew resistance of rootstock cultivars grown in greenhouse.

Rootstock cultivar	Disease index ^z			
	First true leaf		Tenth true leaf	
	Greenhouse in June 2002 (RE) ^y		Greenhouse in June 2002 (RE)	
Hikari Power Gold	7.3 a ^x	(S)	5.0 a	(S)
Tokiwa Power Z	0.0 b	(R)	1.0 bc	(R)
PPMR-1	0.0 b	(R)	0.0 c	(R)
White Power	2.7 ab	(M)	1.0 bc	(R)
Shin-tosa	7.6 a	(S)	3.9 ab	(M)
Encore 10	6.1 a	(S)	2.6 ab	(M)
PI 197088-1	0.0 b	(R)	0.0 c	(R)

^z Disease index: 0 = no symptom—9 = totally and thickly covered with hyphae and spores.

^y Resistance Evaluation: S, susceptible; M, moderate resistant; R, resistant.

^x Mean separation within columns by Kruskal and Wallis ANOVA at $P < 0.05$.

visible symptoms. The resistance of PM increased with further growth. TP and WP were also found to be resistant, with visible minimal, mycelial growth, on the leaves. HP, ST, and A10 were found to be susceptible to moderately resistant.

TP, WP, and PI were consistently resistant to powdery mildew from the cotyledonary stage to the adult stage at cool to moderate temperatures, whereas, PM exhibited moderate to high resistance, especially during the adult stage. The mechanisms of powdery mildew resistance may differ between the resistance of TP (or WP) and that of PM.

Powdery-mildew resistance of cucumber scions grafted onto rootstocks

The levels of powdery-mildew resistance in cucumber

scions, grafted onto various rootstocks (Table 4), show that no differences in the powdery-mildew resistance of cotyledons, detached from scions grafted onto various rootstocks tested at 20°C. However, the fifth true leaves of plants tested at 20°C and the seventeenth true leaves from plants tested in a plastic greenhouse, reacted differently that of the cotyledons. Fifth leaves of PM- and ST-grafted plants showed some powdery-mildew resistance or tolerance, whereas those of HP- and A10-grafted plants were susceptible; PI-grafted plants exhibited intermediate response. In the first seventeenth-leaf experiment, PM-grafted plants were distinctly resistant (Fig. 1), whereas HP-, TP-, SS-, WP-, A10-, and PI-grafted plants were less resistant. However, in the second seventeenth-leaf experiment, HP-, TP-, and WP-grafted plants were less resistant or tolerant than

Table 4. Powdery mildew resistance in cucumber scions grafted onto various rootstock cultivars.

A10/Rootstock cultivar	Disease index ^z									
	Detached cotyledon		Fifth true leaf		17th true leaf					
	20°C (RE ^y)		20°C (RE)		(exp. 1) Greenhouse in Jan. 2002 (RE)	(exp. 2) Greenhouse in July 2002 (RE)	(exp. 3) Greenhouse in Nov. 2004 (RE)			
Hikari Power Gold	4.7 ns ^x	(S)	5.1 a	(S)	6.4 a	(S)	6.9 a	(S)	6.8 ab	(S)
Tokiwa Power Z	2.6 ns	(S)	— ^w		4.1 abc	(S)	6.9 a	(S)	—	
King Kitora	—		—		—		—		7.4 a	(S)
PPMR-1	2.9 ns	(S)	2.0 b	(R)	0.4 d	(R)	3.0 cd	(R)	5.1 c	(M)
Shishigadani	—		—		5.2 ab	(S)	—		—	
White Power	3.2 ns	(S)	—		3.9 bc	(S-M)	6.0 ab	(S)	—	
Shin-tosa	3.6 ns	(S)	2.6 b	(R)	—		4.3 bc	(M)	5.8 bc	(M)
Encore 10	3.6 ns	(S)	5.5 a	(S)	3.8 bc	(S-M)	2.7 d	(R)	5.8 bc	(M)
PI 197088-1	2.1 ns	(S)	3.5 ab	(M)	3.2 c	(M)	1.8 d	(R)	—	

^z Disease index: 0 = no symptom—9 = totally and thickly covered with hyphae and spores.

^y Resistance Evaluation: S, susceptible; M, moderate resistant; R, resistant.

^x Mean separation within columns by Kruskal and Wallis ANOVA at $P < 0.05$.

^w Not examined.

Fig. 1. Symptoms of powdery mildew in 17th leaves of scions grafted onto 'Hikari Power Gold' (HP), PPMR-1 (PM) and PI 197088-1 (PI), 11 days after inoculation. Disease index of each plate is 9 (HP), 1 (PM), and 3 (PI), respectively.

PM-, ST-, A10-, and PI-grafted plants. The results of the third seventeenth-leaf experiment were similar to those of the second experiment, except that scions, grafted onto the bloomless rootstock cultivar KK, were susceptible. Hence, HP and certain other bloomless rootstocks lowered the resistance to powdery mildew in contrast to the blooming rootstocks ST and others. These results are consistent with the findings that cucumbers grafted onto bloomless rootstocks were less resistant to powdery mildew than those grafted onto conventional rootstocks (Chiba and Tomita, 1993; Hazama et al., 1993; Morishita et al., 1999). This effect has been postulated to be related to a less-efficient absorption and distribution of SiO₂ (Yamanaka and Sakata, 1993), which is thought to confer powdery mildew resistance, by bloomless rootstock cultivars than blooming-type rootstock cultivars (Motojima, 1991). However, the relationship between powdery-mildew resistance and the SiO₂ concentrations in leaves of cucumbers is still unclear, because scions grafted onto the blooming cultivar of 'Shishigadani' (*C. moschata*) were very susceptible to powdery mildew. Thus, some of the blooming rootstock cultivars may bestow some resistance or tolerance to the scions; conversely, all of (or most of) the bloomless rootstock cultivars reduce the tolerance of the grafted scions.

The results of the seventeenth-leaf tests implied that the differences in resistance or tolerance between PM-grafted and ST-grafted plants may be small. However, PM is a good candidate for a new rootstock breeding material, because it shows moderate to high resistance to powdery mildew and imparts some resistance or tolerance to the scions. Furthermore, PM is an accession of *C. moschata*, that is easy to hybridize with other rootstock cultivars (*C. moschata*) used in Japan. Contrarily, ST is an interspecific hybrid that has some difficulty in hybridization with *C. moschata* or *C. maxima*.

The powdery-mildew-resistant rootstock TP and WP did not give a high level of resistance to scions in this study, nor in that of Sakiyama (personal communication). The differences in the resistances among TP- and WP-grafted and PM- and ST-grafted plants may be attributed to specific rootstock resistance mechanisms.

The reactions of scions grafted onto cucumber rootstocks were not consistent in this study, e.g., in a test of fifth leaves, A10-grafted plants were as severely damaged by powdery mildew as HP-grafted plants, but in the seventeenth leaf tests, the former showed more tolerance than did the latter. The inconsistency of the reactions of A10-grafted plants may be explained by the difference in their ages, climatic and pathological conditions. In the second seventeenth-leaf experiment, a natural infection with downy mildew (*Pseudoperonospora cubensis* [Berk. & Curt] Rostow.) occurred on cucumber plants grafted onto A10 and PI rootstocks. It is possible that the reaction of the plants to downy mildew

led to induced resistance to powdery mildew in this particular experiment.

The studies published on the resistance against foliar diseases or pests imparted by grafting with a resistant rootstock are limited. There have been no reports on foliar diseases and pest attack, whereas there are several reports on transferred resistance, e.g., the cowpea aphid (*Aphis craccivora* Koch) in cowpea (*Vigna unguiculata* (L.) W ALP.) (Ansari and Emden, 1989) and to the carmine spider mite (*Tetranychus cinnabarinus* Boisduval) in pumpkin (*Cucurbita* spp.) (Edelstein et al., 2000). We found some rootstock influences of grafting on scions, but further investigations are needed, especially for foliar diseases. In addition, the side effects of grafting, such as superior (or inferior) fruit quality, adaptability to climatic conditions, should be evaluated.

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台木品種がキュウリ穂木のうどんこ病抵抗性に及ぼす影響

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台木品種がキュウリ穂木のうどんこ病抵抗性に及ぼす影響を明らかにするため、台木用品種そのもののうどんこ病抵抗性、また、抵抗性のレベルの異なる台木品種に接ぎ木されたキュウリ穂木の抵抗性について評価した。近年発表されたブルームレス台木‘ときわパワーZ’および‘ホワイトパワー’は、子葉から第10本葉に至るまで、20℃程度の冷温から26℃、加温ハウスレベルの適温条件まで、高いレベルのうどんこ病抵抗性を示した。PPMR-1は、成育が進むにつれ、高度な抵抗性を示した。従来から利用されているブルームレス台木‘ひかりパワーG’及びブルーム台木の‘新土佐’は罹病性であり、‘ひかりパワーG’はより激しく罹病した。うどんこ病抵抗性が異なる台木を用いた場合にも接ぎ木されたキュウリ穂木の子葉の抵抗性には有意な差異はなく、幼苗期に

においては台木品種が抵抗性に及ぼす影響はないまたは小さいと考えられた。一方、接ぎ木キュウリの成育に伴い、PPMR-1あるいは‘新土佐’に接ぎ木された穂木（第5本葉、あるいは17本葉）は、うどんこ病に対して抵抗性あるいは耐性を増した。うどんこ病に高度な抵抗性を有する‘ときわパワーZ’および‘ホワイトパワー’を台木に用いた場合には、キュウリ穂木が抵抗性になることはなかった。ブルームレス台木の‘ひかりパワーG’は穂木の抵抗性を弱めた。これらの結果から、台木品種は穂木のうどんこ病に対する抵抗性または耐性を変え、PPMR-1のような抵抗性または耐性を付与することのできるカボチャ台木品種を利用することにより、うどんこ病被害を軽減できることが示唆された。