Preventive Effect and Mode of Action of Repetitive Hot Water Spraying against Powdery Mildew in Strawberry

Tatsuo Sato¹*, Harufumi Saito¹, Keisuke Maejima¹, Keiko Kuba¹, Ani Widiastuti² and Mioko Yoshino¹

¹Field Science Center, College of Agriculture, Ibaraki University, Ami 300-0331, Japan
²Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia

This study aimed to investigate the preventive effect of periodic hot water spraying against powdery mildew in strawberry as an alternative to chemical application as a protection method. Young upper leaves of ‘Sachinoka’ were dipped in hot water at 50°C for 20 s. Conidia of powdery mildew were inoculated 24 h after the treatment. The occurrence and growth rates of powdery mildew were apparently lower on leaves dipped in hot water than on those left untreated. Thus, resistance against powdery mildew was thought to be successfully induced by heat shock. Change in leaf temperature was tested using a prototype of a hot water sprayer at 57 ± 2°C. The resultant rise in temperature and temperature attained varied widely across the leaves. Nonetheless, the minimum requirement of a leaf temperature of 50°C in 10 s for inducing systemic resistance against crown rot could be attained in the treated plants. In this study, weekly hot water spraying treatments were conducted in ‘Sachinoka’ in 2008 and in ‘Tochiotome’ and ‘Hitachi-hime’ in 2009. In 2008, powdery mildew occurred explosively in the non-treated plants. However, its occurrence in plants treated with hot water spraying was less than that in the controls, but more than that after chemical application. In 2009, the occurrence rate was lower than that in the non-treated group of 2008 and extremely low after hot water spray treatment and chemical protection in both the varieties. Whether the difference in the occurrence of powdery mildew in both the years was because of the difference in environmental conditions or the difference between the varieties is not known. The plant height of ‘Hitachi-hime’ tended to become short after hot water spraying; however, no serious effects were noted on the growth and yield of strawberry plants. In conclusion, heat shock treatment by using hot water spraying can be considered an alternative method to chemical protection against mild powdery mildew incidence in strawberry.

Key Words: heat shock-induced resistance, heat stress, plant protection, systemic acquired resistance.

Introduction

One cropping period of strawberry extends over one year, and plants experience various diseases and pest infestations during the growth stage. Therefore, chemical fungicides and pesticides need to be applied many times. This leads to the development of chemical resistance in various pathogens and insects. Since the 1990s, this problem has been addressed by applying high-temperature treatments as an alternative protection technique. Hot water dipping against thrips (Kitamura and Kashio, 2000), powdery mildew, and spider mites (Koitabashi and Nishimura, 2002; Koitabashi et al., 2002); greenhouse closure against powdery mildew (Masunaga et al., 1998; Okayama et al., 1997) in nursery; hot water dipping against strawberry crimp nematode (Qiu et al., 1993); hot water drenching against cyclamen mite (Mizukoshi and Goto, 2004) and hot water spraying against powdery mildew (Ogawara et al., 2012; Yamagishi et al., 2009) in the production field; and hot water dipping against gray mold (Garcia et al., 1996) after harvest have already been reported. Each treatment was developed and utilized as a uni-effect or transient method and was not integrated with chemical rotation as a repetitive method throughout the cropping period except in the study by Ogawara et al. (2012). Most studies did not specify the details of the

Received; February 6, 2017. Accepted; July 7, 2017.
First Published Online in J-STAGE on September 8, 2017.
This work was supported by the Research and Development Projects for Application in Promoting New Policy of Agriculture, Forestry and Fisheries from the Japan Ministry of Agriculture, Forestry and Fisheries.
* Corresponding author (E-mail: sugar@mx.ibaraki.ac.jp).
mode of action of high temperature, although the direct impact against pathogens and pests was generally recognized.

Nonetheless, Konishi et al. (2010) reported a preventive effect of hot water spraying before the inoculation of crown rot and gray mold. Widiastuti et al. (2013b) found that hot water dipping of strawberry seedlings at 50°C for 20 s induced resistance against crown rot. This resistance could be induced systemically by partial treatment of leaves. After hot water dipping, salicylic acid was found to accumulate in the aerial part of plants, and the chitinase gene expression level increased. These results showed that heat shock likely induced systemic acquired resistance (SAR). Similar findings have been reported in melon (Widiastuti et al., 2011, 2013a) and cucumber (Sato et al., 2003; Yoshino et al., 2011) against gray mold. SAR is recognized as nonspecific and has a broad spectrum of action against various pathogens, including viruses, bacteria, and fungi (Métraux and Boller, 1986). Thus, this mode of action might have been responsible for the positive effects of heat treatment in previous studies.

Widiastuti et al. (2013b) also assumed the existence of heat shock-induced resistance (HSIR) that involves multiple modes of action, and SAR was one of the major elements of HSIR, although whether this is the mode of action in strawberry against powdery mildew is not yet known. Powdery mildew is one of the most serious pathogens in field crops. This study aimed to evaluate the effect of hot water dipping and hot water spraying on the induction of resistance in strawberry plants. The study was conducted using three cultivars—‘Sachinoka’ ‘Tochiotome’, and ‘Hitachi-hime’—which were reported to be genetically susceptible to powdery mildew (Ishihara et al., 1996; Miyagi et al., 2009; Morishita et al., 1997). Further, field studies were conducted with multiple hot water spraying treatments against powdery mildew over an entire cultivation period. The effect of hot water spraying treatment on the yield and growth of strawberry has been discussed.

**Materials and Methods**

1. **Inducing resistance against powdery mildew by hot water treatment**

Inoculum of strawberry powdery mildew was collected in a plastic film house at the Field Science Center, College of Agriculture, Ibaraki University, in 2007 and maintained on young strawberry seedlings. Seedlings of strawberry ‘Sachinoka’ were cultivated using runner cutting until 7–8 leaves had completely expanded in the plastic film house. Upper leaves of the seedlings were cut and dipped in hot water at 50°C for 20 s (HS, hereafter). Non-treated leaves were used as negative control (NT). For comparison, leaves sprayed with 1,2-benzisothiazol-3(2H)-one,1,1-dioxide (BIT; Wako Pure Chem Industries, Osaka, Japan; 1 g·L⁻¹ per leaf) were used. BIT is known to be a chemical activator of SAR in Arabidopsis (Yoshioka et al., 2001). Plants were inoculated 24 h after heat shock or BIT treatment by thoroughly spraying entire plants with 1 mL of powdery mildew spore suspension (1 × 10⁵ conidia·mL⁻¹) per leaf. Subsequently, leaves were placed on a wet paper towel and enclosed in plastic cases to maintain the moisture saturation of the air. Disease severity was scored daily from the fourth day after inoculation (DAT) until the seventh day. The score was determined by lesion area as follows: 0, healthy leaf; 1, less than 10%; 2, 10% or more; 3, 30% or more; and 4, more than 50%. Disease index was calculated as follows: disease index = [Σ(n × v)·N⁻¹ × Z] × 100%, where n is the lesion score class, v is the number of samples in the score class, N is the highest score value, and Z is the total number of samples. The experiment was repeated 3 times, with 1 leaf from 10 plants (total 10 leaves) per replicate. Steel–Dwass multiple range test (P < 0.05) was used to assess the effect of hot water treatment on powdery mildew incidence based on the daily assessment.

2. **Changes in leaf temperature during hot water spraying**

A prototype of a hot water sprayer (Fig. 1) developed by Yoshino et al. (2012) was tested for the seedlings of strawberry ‘Sachinoka’ under practical field cultivation to record temperature and ensure uniformity. Seedlings at the same stage were treated as described above. Type T thermocouples (diameter: 0.32 mm) were adhered to the back of four randomly selected leaves by using a surgical tape. Each seedling was covered with styrene foam-cozy and maintained under semi-closed condition. Hot water at 57 ± 2°C was sprayed at 3.5 L·min⁻¹ from the upper side of the box. The changes in leaf temperature were recorded using a data logger (GL-800; Graphitech, Yokohama, Japan). Temperature readings were obtained from 5 s before to 30 s after the application of the hot water treatment. The measurements were repeated 3 times on different plants.

3. **The effect of hot water spray for preventing powdery mildew**

The experiment was conducted in a plastic film house (5.4 m width × 45 m length). Seedlings were planted 25 cm apart in a two-row zigzag style on September 22 in 2008 and 2009. Spacing between rows was 105 cm. The planting density was 7.62 plants·m⁻². Runs were covered with black mulching film on November 4 in 2008 and on October 19 in 2009. European honeybee was used for pollination during cultivation. The heating and ventilation temperatures were set at 7°C and 35°C, respectively. Side windows of the house were managed manually in order to maintain the room temperature between 15°C and 25°C. Runners, lateral buds, and old leaves were removed weekly. Liquid fertilizer (Yoekidoko 2; Otsuka Chemical, Tokyo,
Japan, N-P₂O₅-K₂O: 14-8-25%) was applied using the drip tube method as described by Aoki et al. (2001).

In 2008, three treatments, i.e., hot water spray for 30 s at 57 ± 2°C at 3.5 L·min⁻¹ described in experiment 2 (HW), conventional chemical protection (CP), and non-treatment (NT), were compared in ‘Sachinoka’. Hot water spray and chemical application were performed weekly from October 8 and 9, 2008 until April 27 and 28, 2009, respectively (total 29 times). For CP, acequinocyl, acetamiprid, acrinathrin, azoxystrobin, bifonazole, carbosulfan, chlorfenapyr, cyflufenamid, cyflumetofen, dodecylbenzenesulphonic acid bisethylenediamine copper [II] salt, emamectin benzoate, etoxazole, fenbutanoxide, fluvalinate, iminoctadine albesilate, indoxacarb MP, kresoxim-methyl, mepanipyrim, milbemecin, myclobutanil, nitenpyram, polioxin, pyridaben, pyridalyl, pyrimidifen, quinoa-line, tebufenpyrad, thioclazopride, and triflumizole were used. Some application times or periods did not follow Japanese agricultural chemical regulation for experimental reasons or had already been deregistered.

Twenty-four seedlings were planted in a randomized block design in each plot with two replications. For the evaluation of disease severity of spontaneously generated powdery mildew, the 3 longest leaves of 6 plants each that were randomly selected from each row of the zigzag planting style were scored every 7 days after transplanting until 31 December. For suppressing the spread of powdery mildew from NT to other plots, fungicides were applied on all plots on January 1, 8, 15, and 22 by using acrinathrin, cyflufenamid, cyflumetofen, dodecylbenzenesulphonic acid bisethylenediamine copper [II] salt, fenbutanoxide, iminoctadine albesilate, milbemecin, and triflumizole. The measurements were continued until May 6. The fruits were harvested twice a week until May 7. Harvested fruits were classified into 4 classes, i.e., fine-shaped fruits, powdery mildew fruits, gray mold fruits, and deformed and small fruits. Fine-shaped fruits were harvested when 80% of the area of the fruit surface turned red. The number of fruits and weight were recorded. Fruits of other classes were removed immediately after measurement, and only the number of fruits was recorded. In 2009, ‘Tochiotome’ and ‘Hitachi-hime’ were used for the study. Twenty seedlings were planted in each plot with 3 replications. Treatments were started on October 15. Disease severity was evaluated until March 25. Harvest was continued twice a week from December 7 until May 28. In addition, plant height and leaf number were measured monthly on October 14, November 14, December 15, and January 13 in 10 plants from each plot from October until January. Other managements were the same as those in 2008.

Results and Discussion

1. Induction of resistance against powdery mildew by hot water treatment

The changes in disease index after hot water treatment are shown in Figure 2. The symptoms of powdery mildew appeared 3 DAT in NT and BIT and 4 DAT in HS. No significant difference was found between NT and HS during the study; however, the incidence of powdery mildew was significantly lower after hot water dipping at 4 and 5 DAT. The disease index continued to increase daily in HS, and, hence, no difference was found among the three treatments at 7 DAT. Widiastuti et al. (2013a) obtained similar results for the effect of heat-shock treatment against crown rot. Konishi et al. (2010) also reported that pretreatment with hot water spray for more than 10 s showed a preventive effect against crown rot and gray mold. Thus, heat shock was found to be effective against powdery mildew in strawberry as well as crown rot; further, the duration of resistance was also less than 1 week. However, BIT showed no effect against powdery mildew in strawberry. Thus, another unknown mode of action might be implied in the resistance induced by heat shock.

2. Changes in leaf temperature during hot water spraying

The typical trends of changes in leaf temperature by using the prototype hot water sprayer are shown in

Fig. 1. Schematic diagram of the hot water sprayer. Modified from Yoshino et al. (2012). a: nozzle, b: cozy, c: vinyl hose, d: boiler, e: check valve, f: mixing valve, g: constant flow valve, h: disk filter, and i: reducing valve.
Figure 3. The increase in temperature in each leaf was uneven. In plant 1, the leaf temperature increased more rapidly and reached 50°C within 3 s after the beginning of hot water spray, unlike that in the other three leaves. The increase in leaf temperature in plant 2 was generally slower than that in plant 1: 2 leaves reached 50°C at 17 s after the start of the treatment. This could be because the upper leaves were blown away by the pressure of hot water. Konishi et al. (2010) reported that the preventive effect of heat treatment of 50 and 40°C appeared in the leaves at 10 and 30 s, respectively, against crown rot and gray mold. If this resistance was caused by HSIR, disease resistance could be induced even if only one leaf was appropriately treated (Widiastuti et al., 2013a, b). Partial treatment was also found to be effective in cucumber (Yoshino et al., 2011). In this study, hot water spraying was found to induce disease resistance.

3. The effect of hot water spray for preventing powdery mildew
Weekly hot water spraying was successfully performed until the end of cultivation. Although a slight burning occurred in some leaves, serious damage was not recognized in HW. The changes in disease index in ‘Sachinoka’ in 2008 are shown in Figure 4. The difference among the treatments was very evident, and some of the observed values were zero; hence, statistical analysis was not performed. Powdery mildew appeared within 1 month after transplanting, and the infection continued to increase. In particular, in NT, the disease index became 95.8 on December 17. In contrast, the disease index of powdery mildew in CP and HW was 13.2 and 24.3, respectively, which was lower than that in NT. Spreading of powdery mildew from NT to other plots was prevented by intensively applying chemicals 4 times in January. On January 28, the disease index of NT, CP, and HW decreased to 44.7, 1.6, and 4.9, respectively. The disease index of NT continuously decreased until March 18. This could be because of the delayed effect of intensive chemical application during January and the changes in plant condition under long-
day condition and higher insolation toward spring. Subsequently, the disease index increased again until the end of cultivation. The side windows of the plastic film house were opened for a longer time during spring; changes in ventilation might have caused the spread of powdery mildew in the plastic film house. There was only a slight increase in powdery mildew in CP and HW from January until the middle of April, and the infection increased until the end of the experiment. The reason for the occurrence of powdery mildew in HW at a certain level might have been the source of infection in the NT plots. In addition, unlike fungicides that have a short persistent effect, resistance induced by heat shock was attenuated during a week, as was noted in experiment 1. Therefore, the protective effect of HW was not continuously observed at the field level.

The changes in disease index in 'Tochiotome' and 'Hitachi-hime' in 2009 are shown in Figure 5A and 5B, respectively. Slight powdery mildew was noted in all plots until the end of January in this cropping. Subsequently, the disease index increased in only NT in both the varieties. The occurrence of powdery mildew was less than that in 2008, and the spread of infection from NT plots was negligible. Heat shock produced using the hot water sprayer likely successfully induced resistance against powdery mildew. Further, hot water might have killed powdery mildew. These factors could have been associated with the protective effect of hot water spraying, although we could not confirm this. In general, the growth and pathogenicity of powdery mildew were found to be suppressed after high temperature treatment (Jhooty and McKeen, 1965). Koitabashi and Nishimura (2002) reported that hot water dipping destroyed the conidium-producing ability of strawberry powdery mildew after treatment with 45°C for 210 s or 50°C for 30 s. Yamagishi et al. (2009) reported that powdery mildew could be suppressed when strawberry leaves were dipped in hot water for 1 s at 53.6°C. This result suggested that a direct effect of hot water could not be ruled out. However, they also reported that 3 repetitions of spraying at 55°C were needed for the suppression of powdery mildew even if the occurrences were considerably fewer in the field. On the other hand, Masunaga et al. (1998) and Okayama et al. (1997) reported the suppressive effect of a long duration of mild high temperature (30–35°C) against strawberry powdery mildew. Our result suggested that the temperature attained by treated leaves was uneven and tended to be less than the expected temperature in most of the leaves. Therefore, the direct effect of high temperature against powdery mildew was estimated to be less than that of the induced resistance. In other words, previous studies

![Figure 5A](image1)

![Figure 5B](image2)

**Fig. 5.** Effect of hot water spraying against powdery mildew (A: 'Tochiotome', 2009; B: 'Hitachi-hime', 2009).
likely did not investigate the effect of inducing resistance by heat shock. In addition, Porat et al. (2000) suggested that washing with hot water prevented postharvest decay caused by spores on the surface of citrus. Such an effect needs to be tested against powdery mildew in strawberry.

The result of growth measurement is shown in Table 1. Hot water spraying likely suppressed the increase in plant height, especially in ‘Hitachi-hime’, which showed significantly lower height in HW than in NT in November and January. Miyagi et al. (2009) indicated that the petioles of ‘Hitachi-hime’ tended to grow spindly. No significant difference was noted in the number of leaves among treatments except in January when the number of leaves was significantly more in HW than in CP, although the reason for this was not clear. Therefore, the appropriateness of this suppressive effect needs to be further investigated.

The yield results are shown in Table 2. In fine-shaped fruit, the fruit number and weight were significantly affected by the treatments. The fruit number and weight of HW were significantly higher than those of NT except for the weight in ‘Sachinoka’; no significant difference in weight was noted between HW and NT. Significantly more fruits were affected by powdery mildew in NT than in CP, and HW did not show any significant difference between NT or CP in ‘Sachinoka’ and ‘Tochiotome’. Further, no significant difference between CP and HW was noted in ‘Hitachi-hime’. Only a few fruits were infected by gray mold in all varieties, although a significant difference was noted between CP and other treatments only in ‘Hitachi-hime’. Gray mold

### Table 1. Influence of hot water spraying on the growth of strawberry plants.

| Cultivars | Treatment | Plant height (cm) | Number of leaves |
|-----------|-----------|-------------------|-----------------|
|           |           | Oct 14 | Nov 14 | Dec 12 | Jan 13 | Oct 14 | Nov 14 | Dec 12 | Jan 13 |
| Tochiotome | HW        | 14.2   | 16.0 a | 16.8 a | 13.9 a | 6.5 a  | 8.2 a  | 10.5 a | 11.4 a |
|           | CP        | 15.1   | 16.3 a | 15.9 a | 13.9 a | 7.0 a  | 8.4 a  | 10.5 a | 11.0 a |
|           | NT        | 15.7   | 17.4 a | 16.4 a | 16.4 a | 7.1 a  | 8.6 a  | 10.7 a | 11.4 a |
| Hitachi-hime | HW      | 15.6   | 18.5 B | 19.6 A | 16.3 B | 6.4 A  | 9.6 A  | 11.2 A | 10.6 A |
|           | CP        | 15.1   | 19.9 AB| 20.3 A | 17.8 AB| 6.0 A  | 9.0 A  | 11.2 A | 10.2 B |
|           | NT        | 16.5   | 21.8 A | 20.0 A | 18.6 A | 6.5 A  | 9.5 A  | 11.5 A | 10.3 AB|

| F-test* |
|---------|
| Cultivars | n.s  | *    | n.s. | n.s. | n.s. | n.s. |
| Treatment | n.s. | **   | **   | **   | *    | *    |
| Treatment × Cultivars | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |

* n.s, no significance; * and ** significance at P<0.05 and P<0.01, respectively.

### Table 2. Influence of hot water spraying on the yield of strawberry.

| Cultivars | Treatment | Fine-shaped | Powdery mildew | Gray mold | Deformation and small fruits | Total |
|-----------|-----------|-------------|----------------|-----------|-------------------------------|-------|
|           |           | no./plant  | g/plant   | no./plant | no./plant | no./plant | no./plant |
| Sachinoka* | HW       | 12.7 b     | 158 ab    | 7.5 ab    | 0.3 a     | 5.4       | 25.9     |
|           | CP        | 16.2 a     | 192 a     | 3.5 b     | 0.2 a     | 7.2       | 27.1     |
|           | NT        | 7.0 c      | 101 b     | 15.9 a    | 0.2 a     | 5.0       | 28.1     |
| Tochiotome* | HW      | 11.1 A     | 166 A     | 1.1 AB    | 0.1 A     | 5.8       | 18.1     |
|           | CP        | 13.9 A     | 167 A     | 0.1 B     | 0.0 A     | 3.9       | 17.9     |
|           | NT        | 5.0 B      | 113 B     | 6.4 A     | 0.1 A     | 4.1       | 15.6     |
| Hitachi-hime* | HW    | 10.6 a     | 205 a     | 1.8 b     | 0.1 a     | 3.3       | 15.8     |
|           | CP        | 10.3 a     | 185 a     | 2.7 b     | 0.6 b     | 2.6       | 16.1     |
|           | NT        | 3.2 b      | 74 b      | 13.8 a    | 0.1 a     | 1.8       | 18.9     |

| F-test* |
|---------|
| Cultivars | **   | n.s.  | **    | n.s.   | **   | n.s.  |
| Treatment | **   | **    | **    | n.s.   | n.s. | n.s.  |
| Treatment × Cultivars | n.s. | n.s.  | n.s.  | n.s.   | n.s. | n.s.  |

* Harvest period from Jan. 1 to May 7, 2009.

* Harvest period from Dec. 7, 2009 to Mar. 28, 2010.

* n.s, no significance; ** significance at P<0.01.

* Different letters indicate significant difference (P<0.05) between treatments by ANOVA followed by Tukey’s multiple range test.

HW: Hot-water treatment; CP: Chemical protection; NT: Non-treated.
is a polyxenous and field-indigenous disease and tends to occur under humid conditions. Therefore, humidity management after hot water spraying needs to be considered during field application. No difference was found in the number of deformed and small fruits among all cultivars and the treatments. The total number of fruits was not significantly different among the treatments. These results suggested that hot water spraying did not cause serious environmental or physical damage to the growth and yield of strawberry despite the slight suppression of plant height and slight increase in the risk of occurrence of gray mold. In this study, the positive effect of hot water on fruits was not investigated. The influence of heat shock for inducing resistance and changing fruit quality should be investigated in the future.

In conclusion, heat-shock treatment, which requires the maintenance of 50°C for 20 s at least in one leaf in the entire plant by using hot water spraying method, was effective in suppressing strawberry powdery mildew after field application. Inducing resistance as well as the direct effect of hot water against powdery mildew is suggested to be the possible mode of action for the effect. The spraying method used in this study should be improved for practical purposes.

Literature Cited

Aoki, H., N. Umetsu and S. Ono. 2001. Yoekidoko saibai no riron to jissai. p. 94 (in Japanese). Seibundoshinkosha, Tokyo.

Garcia, J. M., A. Cayetano and M. Jiménez. 1996. Gray mold in and quality of strawberry fruit following postharvest heat treatment. HortScience 31: 255–257.

Ishihara, Y., K. Takano, M. Ueki and H. Tochigi. 1996. New strawberry cultivar ‘Tochiotome’. Bull. Tochigi. Agr. Exp. Stn. 44: 109–123.

Jhoo, J. S. and W. E. McKeen. 1965. Studies on powdery mildew of strawberry caused by Sphaerotheca macularis. Phytopathology 55: 281.

Kitamura, T. and T. Kashio. 2000. An insecticidal test of western flower thrips Frankliniella occidentalis (Pergande) by hot water treatment on strawberry leaves. Kyushu Agr. Res. 62: 89.

Koitabashi, M. and N. Nishimura. 2002. Fungicidal test of powdery mildew by hot water treatment on strawberry leaves. Jpn. J. Phytopathol. 68: 48.

Koitabashi, M., M. Nakashima, T. Kashio and N. Nishimura. 2002. Pest control test of powdery mildew and spider mite by hot water treatment on strawberry. Jpn. J. Phytopathol. 68: 197.

Konishi, K., T. Ogawara, K. Shimamoto and Y. Tomita. 2010. Hot water spraying for the control of anthracnose and gray mold on strawberry. Bull. Hort. Inst. Ibaraki Agr. Center. 17: 43–46.

Masunaga, T., H. Ikeda, K. Ohno, K. Ogata and T. Matsunaga. 1998. Incidence of strawberry powdery mildew during nursery stage and its control with high temperature treatment. Bull. Fukuoka Agr. Res. Center 17: 87–91.

Métraux, J. P. and T. H. Boller. 1986. Local and systemic induction of chitinase in cucumber plants in response to viral, bacterial and fungal infections. Physiol. Mol. Plant Pathol. 28: 161–169.

Miyagi, M., K. Yashiro, Y. Takatsu and K. Tomita. 2009. New released strawberry variety ‘Hitachi-hime’. Bull. Ibaraki Plant Biotech. Inst. 11: 9–14.

Mizukoshi, T. and M. Goto. 2004. Control of cyclamen mite, Stenoptarsonemus pallidius (Banks) (Acaria: Tarsonemidae), by pouring of hot water on strawberry. Ann. Rep. Plant Prot. North Japan 55: 232–235.

Morishita, M., T. Mochizuki, Y. Noguchi, K. Sone and O. Yamakawa. 1997. ‘Sachinoka’, a new strawberry variety for forcing culture. Bull. Natl. Res. Inst. Veg. Ornam. Plants Tea 12: 91–115.

Ogawara, T., H. Konishi, A. Yamabe, K. Shimamoto, T. Sato, M. Kikuchi, M. Kaneda, Y. Tomita and T. Kashima. 2012. Reducing the use of chemicals for strawberry disease and pest control by using hot water spraying. Bull. Hort. Inst. Ibaraki Agr. Center 19: 39–46.

Okayama, K., T. Sugimura and S. Matsutani. 1997. Effects of heat and high humidity treatment on the occurrence of strawberry powdery mildew. Bull. Nara Agr. Exp. Stn. 28: 29–34.

Porat, R., A. Daus, B. Weiss, L. Cohen, E. Fallik and S. Droby. 2000. Reduction of postharvest decay in organic citrus fruit by a short water brushing treatment. Postharvest Biol. Technol. 18: 151–157.

Qi, J., B. B. Westerdahl, R. P. Buchner and C. A. Anderson. 1993. Refinement of hot water treatment for management of Aphelechenoides fragariae in strawberry. J. Nematol. 25: 795–799.

Sato, T., M. Kubo and S. Watanabe. 2003. Heat shock induces a systemic acquired resistance (SAR)-related gene via salicylic acid accumulation in cucumber (Cucumis sativus L.). Jpn. J. Trop. Agr. 47: 77–82.

Widiastuti, A., M. Yoshino, M. Hasegawa, Y. Nitta and T. Sato. 2013a. Heat shock-induced resistance increases chitinase-1 gene expression and stimulates salicylic production in melon (Cucumis melo L.). Physiol. Mol. Plant Pathol. 82: 51–55.

Widiastuti, A., M. Yoshino, H. Saito, K. Maejima, S. Zhou and H. Odani. 2011. Induction of disease resistance against Botrytis cinerea by heat shock treatment in melon (Cucumis melo L.). Physiol. Mol. Plant Pathol. 75: 157–162.

Widiastuti, A., M. Yoshino, H. Saito, K. Maejima, S. Zhou, H. Odani, K. Narisawa, M. Hasegawa, Y. Nitta and T. Sato. 2013b. Heat shock-induced resistance in strawberry against crown rot fungus Colletotrichum gloeosporioides. Physiol. Mol. Plant Pathol. 84: 86–91.

Yamagishi, N., N. Eguchi, H. Tokutake and S. Kinebuchi. 2009. Hot water treatment for control of powdery mildew of strawberry. Ann. Rep. Kanto-Tosan Plant Protection Soc. 56: 39–41.

Yoshino, M., A. Widiastuti, M. Hasegawa and T. Sato. 2011. Induction of disease resistance against gray mold by heat shock using hot water dipping in cucumber and its underlying mechanism. Hort. Res. (Japan) 10: 429–433.

Yoshino, M., A. Widiastuti, S. Zhou, H. Odani, M. Hasegawa and T. Sato. 2012. Improvement of heat shock treatment and trial development of hot water sprayer for inducing disease resistance in cucumber (Cucumis sativus L.). Hort. Res. (Japan) 11: 121–126.

Yoshioka, K., H. Nakashita, D. F. Klessig and I. Yamaguchi. 2001. Probenazole induces systemic acquired resistance in Arabidopsis with a novel type of action. Plant J. 25: 149–157.