Plant Pathol. J. 25(3) : 270-279 (2009)

The Plant Pathology Journal

Reducing Fungicidal Spray Frequency for Major Apple Diseases by Increasing the Spray Interval from 15 to 25 days

Dong Hyuck Lee[2], Ho Cheol Shin[3], Rae Hong Cho[4] and Jae Youl Uhm[1]*

[1]School of Applied Biology and Chemistry, Kyungpook National University, Daegu 702-701, Korea
[2]Apple Experiment Station, National Horticultural Research Institute, Gunwi 716-812, Korea
[3]Central Research Institute, Kyung Nong Co. Ltd, Gyeongju 780-110, Korea
[4]Crop Protection Research Team, AgroLife Research Institute, Daejeon 305-708, Korea

(Received on May 5, 2009; Accepted on August 21, 2009)

During the course of a study to develop a spraying program at 15-day spray intervals, two important findings were identified allowing for further reduction of spray frequency by increasing the spray interval. In evaluating the contribution of fungicides from a 15-day spray interval program, control of white rot, which is of prime importance in Korea, was not affected, in spite of the extended spray interval caused by omitting the fungicides during the season. In another experiment assessing the duration of the protective activities of several key fungicides used in the 15-day spray interval program, infection control was maintained for almost 30 days for some fungicide. Based on these two findings, a basic spraying program with a 25-day spray interval was developed. This program was modified for four successive years to improve the control efficacy against bitter rot and Marssonina blotch, which sometimes causes as much damage as white rot.

Keywords : bitter rot, apple white rot, fungicidal spraying program, spray frequency, *Marssonina* blotch

In Korea, white rot, bitter rot and *Marssonina* blotch are major diseases which sometimes substantially reduce the quality and yield of apple (Uhm, 1998). Among the three diseases, white rot, caused by *Botryospaeria dothidea* (Moug) Ces. & De Not., is of prime importance to apple production (Kim et al., 2001; Lee et al., 2006; Uhm, 1998). In a series of experiments designed to improve management of the disease, two important findings were obtained. The first was that the infected fruit can be effectively cured by the application of ergosterol biosynthesis inhibitors (EBIs), especially tebuconazole, in early or mid-August, regardless of the time of infection (Kim and Uhm 2004). The second was that some fungicides, whether they were systemic or nonsystemic, confer high post-infection activity against white rot (Lee et al., 2007). Based upon these findings, a basic spraying program of 15-day spray intervals (from petal fall to late August) that efficiently controlled white rot was developed (Lee et al., 2008).

During the course of the experiments directed toward improving the spray program, we attempted to evaluate the contribution of each fungicide used in the 15-day spraying interval program for control of white and bitter rot. We compared the incidence of white and bitter rot in plots treated with the complete spraying program with that of plots in which the spraying of each individual fungicide was sequentially omitted for each application, resulting in an effective interval for each fungicide of about 30 days. Despite increased spray intervals that lasted until early or mid-August, no significant increase in the incidence of white rot was found, and in some plots a significant decrease was observed. The decrease in incidence suggested that the fungicide that was omitted had made a negative contribution to the control of white rot. The protective fungicides were selected as constituents of a 15-day interval spraying program based upon their after-infection activities against white rot wherein the efficacy of control against white rot was not lowered even when the spraying of one of the protective fungicides was omitted. The same experiment was repeated with the same spraying program, and the results were similar with only slight differences in spite of a much more severe epidemic in the subsequent year. The duration of the protective activities of the key fungicides against white rot was examined in an attempt to elucidate this last observation. Considerable protective activities were maintained for almost 30 days for some fungicides. This may be why omission of individual fungicides did not influence the ultimate control of white rot. As the protective activity of some fungicides was maintained for almost 30 days, exclusion of a single fungicide during the 15-day interval spraying program made no difference in the control of the disease. Therefore, we interpreted these data as providing decisive evidence of the efficacy of the increased spray interval.

*Corresponding author.
Phone) +82-53-950-5763, FAX) +82-53-950-6758
E-mail) jyuhm@knu.ac.kr

Table 1. Details of fungicides used in this experiment.

Common name	Commercial name	a.i. (%)	Formula-tiona	Manufacturer	Abbrevia-tion
Azoxystrobin	Amistar	10	WP	Syngenta Korea	Azx
Pyraclostrobin+Boscalid	Bellisplus	6.8+13.6	WG	Kyungnong	BEL
Captan	Captan	50	WP	Dongbu HiTek	Cap
Dithianon	Delan	43	SC	Kyungnong	Dit
Fluazinam	Frowncide	50	WP	Dongbu HiTek	Flz
Folpet	Folpet	50	WP	Kyungnong	Fol
Iminoctadine-triacetate	Befran	25	SL	Bayer crop science Korea	Ita
Kresoxim-methyl	Hebichi	42	SC	Sungbo Chemical	Krx
Metiram	Polyram	55	WG	Hankooksamkong	Met
Metconazole	Salimkkun	20	SC	Dongbang Agro	Mtz
Propineb	Antracol	70	WP	Youngil Chemical	Pro
Pyraclostrobin	CabrioA	18.8	WG	Youngil Chemical	Pyr
Fluquinconazole+Flusilazole	Singgeurong	7+1.5	SC	Dongbu HiTek	SIN
Mancozeb+myclobutanil	Systhane M	65+2	WP	Kyungnong	SYM
Tebuconazole	Silbacur	20	SC	Bayer crop science Korea	Teb
Trifloxystrobin	Flint	22	SC	Bayer crop science Korea	Trx

[a] SL=soluble concentrate, WP=wettable powder, SC=suspension concentrate, WG=water dispersible granule

Working from this premise, we attempted to develop a spraying program with a 25-day spray interval beginning from petal fall to late August, and thus the number of application per crop season could be reduced from 9 times with 15-day interval spraying program to 7 times.

Materials and Methods

Orchard characteristics and chemical application. The experiments were conducted over seven years, including six years (2000-2005) in a commercial orchard near Daegu City, Korea, where cv. Fuji on M.26 rootstock spaced at 4× 6 m was grown. The trees were 13 years old in 2000, when this experiment was initiated. The orchard was located in an area conducive to the development of disease due to poor airflow caused by surrounding farmhouses and hills. The plant conditions and orchard management were as previously described (Lee et al., 2008). In 2006, the experiment was conducted in a different commercial orchard located in Cungsong, Gyungbuk Province, where 18-year-old trees of cv. Fuji on MM106 rootstock spaced at 5×7 m were grown. The orchard was located at a high altitude (450 m sea level), and *Marssonina* blotch habitually occurs every year. Management of the orchard was undertaken using nearly the same methods as described above. The fungicides and their abbreviations are given in Table 1.

Application of fungicides and control of insect pests. Insecticides for Lepidoptera were not used; rather, this group of insects was managed using a pheromone that disrupts mating (Shin-Etsu Chemical Co. Ltd., Tokyo, Japan). Aphids and mites were controlled with pesticide spraying when required. However, because the experimental orchard was located in a collective apple growing area, in 2006 insecticides for the Lepidoptera were used separately from the fungicides. The fungicides were applied until runoff with a single-nozzle spray gun at 3.5 MPa.

Disease incidence. Methods to determine disease incidence were basically as previously described (Lee et al., 2007, 2008). In this experiment, however, the infection frequency of white rot was not determined except during the experiments to identify the duration of the protective activities, as it has no meaning in practical agriculture. The incidence of white rot and bitter rot was determined as the total number of diseased fruit found until harvest relative to the total number of fruit on each tree counted at harvest. The infection frequency of white rot was calculated by combining the disease incidence until harvest and the latent infection frequency, which was measured by incubating symptom-free fruit at 25°C for four weeks (Kim and Uhm, 2002). The incidence of *Marssonina* blotch was determined by the percent of defoliated leaves until mid-September on 10 small shoots per tree that had been selected and marked during early July, when shoot growth had nearly terminated and the symptoms of blotch had not yet appeared (Uhm 1998). Around mid-September, most of the diseased leaves that had been infected during the early growing season had abscised from the trees. Some leaves with lesions, mostly spots, remained on the tree but were ignored because they did not affect fruit quality. However, in one of the experiments on the development of the basic spraying program, the percentage of diseased leaves was counted to calculate disease incidence.

Evaluation of the contribution of each fungicide used in the 15-day interval spraying program for control of white rot and bitter rot. The 15-day spray interval program was applied to seven experimental plots, each containing six trees; spraying was omitted in one plot during each spraying starting from the third cover spray, except for in one plot that served as the complete spray control (Table 2). The effect of each omitted fungicide on the control of white and bitter rot was evaluated by comparing the incidence in the control plot where no fungicide had been omitted and that in the plots where the spraying of one of the individual fungicide treatments had been omitted during each spraying.

Duration of protective efficacy of fungicides against white rot. The duration of protective efficacy of key fungicides used in the 15-day interval spraying program against white rot was examined to understand why the omission of each fungicide, in turn, before early August does not affect the control efficacy against white rot. The apple trees used in this trial were managed with a standard spray program for 2001 until mid-June. The test fungicides-azoxystrobin, dithianon, folpet, and iminoctadine-triacetate-were applied to six trees each on June 25, just prior to the beginning of the rainy season. The untreated controls were six trees that had been managed in the same manner until mid-June but were not sprayed until the final bagging. Soon after the spraying solution was completely dried, 100 fruit from the six trees were bagged with two-layered fruit bags to restrict additional infection, and the bagging was repeated at 10-day intervals for 40 days after application of the chemical spray. Soon after the 40-day bagging, iminoctadine-triacetate was sprayed on all of the trees to control *Marssonina* blotch. Samzinwang, a combined formulation of iminoctadine-triacetate and difenoconazole, was sprayed on August 25 to control *Marssonina* blotch as well. The incidence and infection frequency of white rot were examined as previously described.

Design of the basic spraying program with a 25-day spray interval. The spraying program was designed to spray fungicides seven times in one cropping season for late season varieties, mainly cv. Fuji (Table 3). During the first cover spray before bloom, iminoctadine-triacetate, a broad-spectrum fungicide, was scheduled for control of *Alternaria* blotch, *Marssonina* blotch, moldy core, and possibly *Valsa* canker. For the second cover spray at the petal fall stage, Systhane M (a combined formulation of myclobutanil and mancozeb; Kyungnong Co. Ltd., Seoul, Korea) was scheduled mainly to control rust, bitter rot, and other diseases. These two sprays are routine in practice and were not changed during the early stages of this work. The sixth and seventh cover sprays were also unchanged, because tebuconazole at the sixth cover is essential for curing fruit infected with white rot, and Samzinwang (a combined formulation of iminoctadine-triacetate and difenoconazole; Kyungnong Co. Ltd.) at the seventh cover spray plays a similar role. Therefore, the chemicals used from the third to fifth cover sprays could be varied, and spray intervals were also extended to essentially 25 days. In our previous work, iminoctadine-triacetate played a very important role in the control of white rot and *Marssonina* blotch (Lee et al., 2008). However, its control efficacy against bitter rot, especially

Table 2. Effect of each fungicide consist of 15-day interval spraying program on the control of white rot and bitter rot (2000)

Cover Spray	Date sprayed	Fungicide spray programs and disease incidence (%)								
		Comp	-Pro	-Fol	-Dit	-Azx	-Ita	-Teb	-SAM	Unta
1	4, Apr	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita
2	2, May	SYM	SYM	SYM	SYM	SYM	SYM	SYM	SYM	SYM
3	23, May	Pro	–	Pro	Pro	Pro	Pro	Pro	Pro	–
4	8, Jun	Fol	Fol	–	Fol	Fol	Fol	Fol	Fol	–
5	25, Jun	Dit	Dit	Dit	–	Dit	Dit	Dit	Dit	–
6	10, Jul	Azx	Azx	Azx	Azx	–	Azx	Azx	Azx	–
7	25, Jul	Ita	Ita	Ita	Ita	Ita	–	Ita	Ita	–
8	17, Aug	Teb	Teb	Teb	Teb	Teb	Teb	–	Teb	–
9	28, Aug	SAM	SAM	SAM	SAM	SAM	SAM	SAM	–	–
WRb (%)	2000	1.0	1.3	0.3*	0.0*	0.5	0.4	2.5*	2.2*	11.8
	2001	3.3	3.4	5.6*	0.4*	3.5	3.2	5.8*	3.0	23.6
BRc (%)	2000	2.9	3.4	1.8	6.0	12.0*	8.4*	7.9*	3.1	12.2
	2001	1.6	2.7	3.7	4.4*	1.8	1.5	2.3	1.8	8.0

[a] untreated control, [b] White rot, [c] Bitter rot, LSD (0.05)

Table 3. Fungicidal spray sequence and possible target diseases for developing the basic spraying program with 25-day spray interval (2002)

Cover spray	Date Sprayed	Spray programs							Possible target Diseases
		02-1	02-2	02-3	02-4	02-5	02-6	Unt[a]	
1	4, Apr	Ita	Ita	Ita	Ita	Ita	Ita	Ita	MC[b], VC[c], AB[d]
2	2, May	SYM	SYM	SYM	SYM	SYM	SYM	SYM	Rust, AB, BR[e]
3	27, May	Krx	Krx	Krx	Krx	Trx	Trx	–	WR[f], BR, AB, SB[g]
4	23, Jun	Dit	Flz	Dit	Flz	Dit	Flz	–	WR, BR, AB, MB[h]
5	15, Jul	Ita+Cap	Ita+Cap	Trx	Trx	Ita+Cap	Ita+Cap	–	WR, BR
6	17, Aug	Teb	Teb	Teb	Teb	Teb	Teb	–	WR, MB
7	28, Aug	SAM	SAM	SAM	SAM	SAM	SAM	–	MB, WR

[a] untreated control; [b] Moldy core; [c] *Valsa* canker; [d] *Alternaria* blotch; [e] Bitter rot; [f] white rot; [g] Sooty blotch; [h] *Marssonina* blotch

that caused by *Collectotrichum acutatum*, is not reliable (personal communication from the manufacturer). However, as iminoctadine-triacetate was thought to be essential for the control of white rot and *Marssonina* blotch, it was mixed with a half dosage of captan in the fourth cover spray in some programs to supplement the control efficacy against bitter rot (Table 3). In developing the basic spraying program, we used the fungicides used in the 15-day interval program developed in 2001 (Lee et al., 2008). The spraying programs were designed to evaluate the contribution of each fungicide to the control of the three major diseases by comparing the control efficacies of the spraying programs, which differed from one another by substituting one fungicide at a specific spraying time for another fungicide (Table 3). In the third cover spray kresoxim-methyl and trifloxystrobin were used, in the fourth cover spray dithianon and fluazinam were used, and in the fifth cover spray trifloxystrobin and a tank mixture of iminoctadine-triacetate and captan were used for comparison (Table 4). The seven spraying programs and one untreated control were applied to the experimental orchard, and the control efficacy against the three major diseases was compared, as done in the previous work (Lee et al., 2008).

Improvements of the spray programs. The modified spraying programs were applied to the orchard together with the basic program, and the incidences of the apple diseases were determined as described above. To determine the severity of the disease in each year, we completely excluded fungicides from the third cover spray in the six-tree plot with the untreated control. Different trees were assigned to this untreated control each year to avoid any possible effects of the exclusion of the fungicide.

Design of experiments and analyses of data. Statistical analyses were performed as previously described (Lee et al., 2008). However, in the experiment to evaluate the contribution of each fungicide to the control of white and bitter rot, the disease incidence in the complete spray plot was compared with those of the plots where the relevant fungicide at each spraying time was omitted using the least significance test at the 0.05 level.

Results and Discussion

Evaluation of the 15-day interval spraying program. The incidence of white rot in the untreated plot was less than 12%, but that of bitter rot, which previously had been a minor disease on cv. Fuji, increased considerably in 2000 (Table 2). In this experiment, if the incidence of a disease in the plot where a specific fungicide was omitted was significantly higher than that of the complete spray plot, the omitted fungicide was considered to have made a positive contribution to the control of the disease; when lower, to have made a negative contribution. Based upon these criteria, folpet and dithianon contributed negatively, tebuconazole and Samzinwang contributed positively, and the other fungicides had no influence on the control of white rot (Table 2). As for bitter rot, azoxystrobin, iminoctadine-triacetate, and tebuconazole contributed positively to its control, and the other fungicides had no influence (Table 2).

Among the seven chemicals tested, folpet, azoxystrobin, and iminoctadine-triacetate were selected as constituents of the spraying program based upon their post-infection activities. However, they did not contribute positively to the control of white rot; folpet, especially, contributed negatively. As these results were difficult to interpret, the same experiment was repeated in 2001, and similar results for white rot were obtained (Table 2). For bitter rot, however, considerably different results were obtained in 2001, which might have been due to the differences in the epidemics between the two years. Because white rot infection begins around two weeks after petal fall (Kohn and Hendrix, 1983) and is highly epidemic during the rainy season from late June to late July (Hayashi, 1984; Ogata, 1997), it is difficult to explain why the exclusion of the chemicals in those seasons did not affect the final control efficacy. However, these results suggested the possibility for further increases in the spray interval without lowering control efficacy.

Duration of protective efficacy of the fungicides against white rot. In 2001, the incidence of bitter rot was very low even in the untreated plot and was ignored. In the untreated control plot, the infection frequency and disease incidence of the fruit bagged on June 25, the initiation date of this trial, were 22.7% and 3.3%, respectively (Table 4). In the plots treated with azoxystrobin, folpet, and iminoctadine-triacetate, the infection frequencies were much lower than those of the untreated control (Table 4). The lower infection frequencies in these plots were thought to be caused by the post-infection activities of the three chemicals against white rot, which has been elucidated in a separate work (Lee et al., 2007). However, the infection frequency in the plot treated with dithianon was much higher than in the plots treated with other fungicides, suggesting that dithianon confers no post-infection activity. The incidence of disease, however, did not vary among the plots, including the untreated control, except in the plot treated with azoxystrobin and folpet, in which no diseased fruit were observed (Table 4).

Infection frequency and disease incidence increased slowly until 30 days post-spray in most of fungicide-treated plots but increased rapidly thereafter (Table 3). Infection frequencies of the fruit bagged 40 days after chemical spraying in the plots treated with dithianon, folpet, and iminoctadine-triacetate were higher than those of the untreated control, but disease incidence in those plots was lower than in the untreated controls, except for treatment with iminoctadine-triacetate. Azoxystrobin showed very high control efficacy against white rot, as the infection frequencies and disease incidence of the fruit bagged after 40 days were 15.2% and 3.8%, respectively, which was much lower than those observed for the other fungicides (Table 3).

These results provided some explanation as to why the exclusion of a chemical does not affect the final control efficacy. As the protective activities of the fungicides were maintained for nearly 30 days, the exclusion of one fungicide from the 15-day interval spraying program might not have made a difference in control of the disease. At any rate, these results served as decisive evidence for increasing the spray interval to more than 15 days.

Design of the basic spraying program with 25-day spray interval. In the plot not treated with fungicides in 2002, 34.7% and 12.9% of apples had white rot and bitter rot symptoms, respectively, at harvest (Table 5). The incidence of *Alternaria* blotch on fruit was so low that it could almost be ignored. Active rust lesions were not detected in mid-September, but leaf spot lesions cured by EBI, which had been applied at petal fall in a combined formulation, were occasionally found (data not shown). *Marssonina* blotch was severe, with disease symptoms on 94.8% of the leaves and with 64.1% defoliation by mid-September (Table 5). Sooty blotch and flyspeck disease were also found on all of the fruit in the untreated plot.

In 2002, the spray interval between the sixth and seventh cover sprays was extended to as much as 32 days because of continuous rain for 11 days from early to mid-August. In spite of these adverse weather conditions and the extended spray interval, the diseases were moderately well controlled as a whole, even when the spraying interval was increased to 25 days from petal fall to mid-August.

In designing the basic program, we noted that changes in only one fungicide in a spraying program greatly influenced the final control efficacy against specific diseases. This result had been observed during the entire course of our work on the development of the 15-day interval spray program (Lee et al., 2008). In the 25-day spray interval experiment, we examined the contribution level of dithianon and fluazinam in the fourth cover spray on the control of the three major diseases after variations in the third and fifth cover sprays. Programs 02-1 and 02-2 were designed to

Table 4. Duration of protective efficacy of selected fungicides against white rot (2001)

Days[a] after spray	Disease incidence and infection frequency (%)									
	Azoxystrobin		Dithianon		Folpet		Iminoctadine		Untreated	
	Dis[b]	Inf[c]	Dis	Inf	Dis	Inf	Dis	Inf	Dis	Inf
0	0.0	2.4	2.6	22.7	0.0	2.2	2.9	8.0	3.3	15.3
10	0.0	2.4	2.9	24.1	1.3	11.4	2.9	9.3	6.8	20.4
15	1.4	4.8	2.9	22.8	1.2	21.4	4.9	22.6	7.0	33.7
20	2.6	4.1	4.1	34.9	5.3	23.7	1.3	40.4	10.4	36.5
30	2.6	4.4	4.5	32.0	6.0	26.0	5.8	43.8	16.0	53.6
40	3.8	15.2	9.2	81.8	11.6	69.5	26.7	76.3	18.0	56.0

[a] Chemical sprayed on 25, June, [b] Disease incidence, [c] Infection frequency. [c)] Infection refers to the total of disease incidence until harvest (%) and latent infection (%) that were symptomless at harvest but developed symptoms when incubated at 25C for 28 days.

compare the contributions of the two fungicides when a tank mixture of iminoctadine-triacetate and captan was applied in the fifth cover spray. Program 02-1 (dithianon) showed significantly higher control efficacy against *Marssonina* blotch than 02-2 (fluazinam) but showed no significant difference against the other two diseases (Table 5). In programs 02-3 and 02-4, the same comparison was made when trifloxystrobin was applied in the fifth cover spray. The contribution of dithianon to the control of the three major diseases was higher than that of fluazinam, but not significantly so. In programs 02-5 and 02-6, the same comparison was made when trifloxystrobin and a tank mixture of iminoctadine-triacetate and captan were applied in the third and fifth cover sprays, respectively. Program 02-5 containing dithianon showed higher control efficacy against white rot and *Marssonina* blotch than 02-6 containing fluazinam, but the results were not significant (Table 5).

In comparisons of the three pairs of programs, dithianon usually showed better control efficacy against white rot and *Marssonina* blotch regardless of variations in the third and fifth cover sprays. In this trial, the programs were also designed to enable us to compare the fungicides used in the third and fifth cover sprays. In comparing those fungicides, the fungicide used for the fourth cover spray should be held constant. Because dithianon always showed higher control efficacy than fluazinam, the contribution of fungicides in the third and fifth cover sprays was compared in programs containing dithianon in the fourth cover spray. When comparing programs 02-1 and 02-5, which contained kresoxim-methyl and trifloxystrobin in the third cover spray, respectively, we found no difference in the control of disease (Table 5). Programs 02-1 and 02-3 used different fungicides in the fifth cover spray: 02-3 containing trifloxystrobin showed better control efficacy than 02-1, which contained a tank mixture of iminoctadine-triacetate and captan that was effective against all three of the diseases; but the effect was not always significant. Although no significant differences among the six programs were found, except for 02-2 with regard to the control of *Marssonina* blotch, program 02-3, which showed moderately good control efficacy, was selected as the basic program that was subjected to further modification.

Control of apple diseases by the modified spraying program in 2003. In 2003, the basic program (02-3) selected in the previous year was modified in seven ways by replacing one or two of the chemicals from the third to fifth cover sprays (Table 6). The modified spraying programs, including the basic program, were divided into two groups based upon the chemicals used in the third cover spray: kresoxim-methyl and azoxystrobin. Each group was subdivided four ways based upon the chemicals used in the fourth and fifth cover sprays (Table 6). In the fourth cover spray, dithianon and metiram were compared, and in the fifth cover spray, a tank mixture of iminoctadine-triacetate and captan was compared with Belisplus, a combined formulation of pyraclostrobin and boscalid (Kyungnong Co. Ltd.).

In 2003, a severe epidemic of the three major diseases was caused by adverse weather conditions, i.e., 58 days of rain during the four months from May to August, during which time the apple trees were highly susceptible to most diseases. In the untreated plot, 31.8% and 17.2% of the fruit developed symptoms of white rot and bitter rot, respectively, at harvest (Table 6). *Marssonina* blotch was so severe that nearly all of the leaves were diseased, and 90.5% of the leaves were lost by mid-September.

Comparing the contribution of dithianon (03-0) and metiram (03-1) in the fourth cover spray following the application of kresoxim-methyl in the third cover spray, we found that dithianon showed significantly higher control efficacy against white rot and *Marssonina* blotch than metiram, but no significant difference was detected between them for the control of bitter rot (Table 6). When

Table 5. Control of apple diseases by different spray programs with 25-day spray interval from petal fall to late August (2002)

Spray programs[a]	Incidence (%)					
	White Rot	Bitter Rot	Sooty, Flyspeck[b]	Alternaria blotch	Marssonina blotch	
					Disease	Defoliation
02-1	2.8 a[c]	2.1 a	0.0 c	0.0 a	24.2 a	1.0 a
02-2	2.7 a	1.5 a	0.0 c	0.3 a	61.9 b	10.5 b
02-3	1.6 a	0.9 a	0.0 c	0.2 a	30.4 a	1.1 a
02-4	3.2 a	1.7 a	0.4 b	0.5 a	26.6 a	2.0 a
02-5	3.6 a	1.7 a	0.0 c	0.0 a	27.3 a	0.3 a
02-6	1.7 a	2.0 a	0.3 b	0.0 a	32.9 a	5.8 ab
untreated	34.7 b	12.9 b	100 c	4.8 b	94.8 c	64.1 c

[a] Refer to Table 3 for fungicides sequence of each program, [b] In most case sooty blotch and flyspecs concur on same fruit, [c] Within a column, means followed by the same letter are not significantly different at the 5% level by DMRT

comparing the contribution of the first two chemicals following application of azoxystrobin in the third cover spray instead of kresoxim-methyl, dithianon (03-4) still showed significantly higher control against *Marssonina* blotch but significantly lower control against white rot(03-5) than metiram (Table 6). Therefore, metiram, in spite of its high control efficacy against white rot when used with azoxystrobin (03-5), did not appear to be useful in this spraying program due to its poor contribution to the control of *Marssonina* blotch. Comparing the contributions of trifloxystrobin (03-0), a tank mixture of iminoctadine-triacetate and captan (03-2), and Belisplus (03-3) in the fifth cover spray following the application of kresoxim-methyl and dithianon in the third and fourth cover spray, respectively, trifloxystrobin and Belisplus made a greater contribution to the control of white rot and bitter rot than the tank mixture of iminoctadine-triacetate and captan. When kresoxim-methyl was replaced with azoxystrobin (03-4, 03-6, 03-7), the tank mixture of iminoctadine-triacetate and captan (03-7) made a greater contribution to the control of *Marssonina* blotch than did the other two chemicals, particularly trifloxystrobin (Table 6). This trial again demonstrated that changing a single fungicide in the spraying program greatly influenced the final control efficacy. The results were so complicated that selection of a single program that would best serve as a basic spraying program for subsequent modification was difficult. Therefore, four spraying programs (03-0, 03-3, 03-6, 03-7) that had shown relatively good performance were selected for further testing.

Control of apple diseases by the spraying programs selected in the 2003 trial and the modified spraying program of 2004. In 2004, the four spraying programs selected in the previous year were tested again to confirm their control of the major diseases. In addition to the four spray programs, one new spray program was designed in which trifloxystrobin and Belisplus were introduced in the third and fifth cover sprays, respectively. Trifloxystrobin was tested once in 2002 as the chemical used in the third cover spray. It made a much greater contribution to the control of *Marssonina* blotch when used with a tank mixture of iminoctadine-triacetate and captan, but control of white and bitter rot was poor (Table 3, 5). However, because the control efficacy of a spraying program might be changed by replacing the chemicals in the other rounds of cover spraying, we felt that the combination of trifloxystrobin and Belisplus was worth testing.

In 2004, due to good weather conditions (722.5 mm of rain for 45 days from May to August), the incidence of the three major diseases in the untreated plot was much lower than in the previous year (Table 7). The decrease in the incidence of white rot was especially conspicuous and was later revealed as the beginning of a decline in the white rot epidemic.

Comparing the contributions of trifloxystrobin (03-0) and Belisplus (03-3) in the fifth cover spray following application of kresoxim-methyl in the third cover spray, we found that Belisplus made a greater contribution than trifloxystrobin to the control of white rot, but not significantly so (Table 7). However, when we replaced kresoxim-methyl with azoxystrobin in the third cover spray, a tank mixture of iminoctadine-triacetate and captan (03-6) made a greater contribution to the control of *Marssonina* blotch than Belisplus (03-7) but was still not significant. Therefore, as no significant differences were found, these results were quite similar to those obtained in previous years. The combination of trifloxystrobin and Belisplus in the third and fifth cover sprays, respectively, demonstrated a lower control of both white rot and *Marssonina* blotch than the other spraying programs (Table 7).

Table 6. Effect of modification of spray program on the control of apple white rot, bitter rot and *Marssonina* blotch (2003)

Cover Spray	Date sprayed	Fungicide spray programs and disease incidence (%)								
		03-0[a]	03-1	03-2	03-3	03-4	03-5	03-6	03-7	Unt[b]
1	12, Apr	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita
2	3, May	SYM	SYM	SYM	SYM	SYM	SYM	SYM	SYM	SYM
3	28, May	Krx	Krx	Krx	Krx	Azx	Azx	Azx	Azx	–
4	25, Jun	Dit	Met	Dit	Dit	Dit	Met	Dit	Dit	–
5	14, Jul	Trx	Trx	Ita+Cap	BEL	Trx	Trx	Ita+Cap	BEL	–
6	5, Aug	Teb	Teb	Teb	Teb	Teb	Teb	Teb	Teb	–
7	22, Aug	SAM	SAM	SAM	SAM	SAM	SAM	SAM	SAM	–
White rot (%)		3.3 c[c]	6.6 b	6.7 b	3.1 c	2.5 c	1.0 d	2.5 c	2.6 c	31.8 a
Bitter rot (%)		2.1 b	3.0 b	4.5 c	2.6 b	3.5 b	1.7 b	3.4 b	1.7 b	17.2 a
Marssonina (%)		6.9 d	46.0 b	12.6 dc	8.1 dc	18.7 c	39.7 b	4.0 d	13.0 dc	90.5 a

[a] Basic program for 2003 was selected among the six programs tested in the experiment of previous year, [b] untreated control, [c] Within a line, means followed by the same letter are not significantly different at the 5% level by DMRT

Table 7. Effect of modification of spray program on the control of apple white rot, bitter rot and *Marssonina* blotch (2004)

Cover Spray	Date sprayed	Fungicide spray programs and disease incidence (%)					
		03-0[a]	03-3[a]	03-6[a]	03-7[a]	04-1	Unt[b]
1	12, Apr	Ita	Ita	Ita	Ita	Ita	Ita
2	3, May	SYM	SYM	SYM	SYM	SYM	SYM
3	28, May	Krx	Krx	Azx	Azx	Trx	–
4	25, Jun	Dit	Dit	Dit	Dit	Dit	–
5	14, Jul	Trx	BEL	Ita+Cap	BEL	BEL	–
6	5, Aug	Teb	Teb	Teb	Teb	Teb	–
7	22, Aug	SAM	SAM	SAM	SAM	SAM	–
White rot (%)		2.0 ab[c]	1.2 ab	1.7 ab	1.8 ab	4.3 b	11.8 a
Bitter rot (%)		0.0 b	0.0 b	0.0 b	0.0 b	0.2 b	2.2 a
Marssonina (%)		4.9 c	5.8 c	3.7 c	6.0 c	10.4 b	49.0 a

[a] The four programs were selected in the experiment of previous year, as they are not significantly different among other in the control of white rot, bitter rot and *Marssonina* blotch, [b] Untreated control, [c] Within a line, means followed by the same letter are not significantly different at the 5% level by DMRT

The contributions of the chemicals in the fifth cover spray were influenced by the chemicals in the third cover spray. This was also the case with the chemicals in the fourth cover spray; therefore, it was conceivable that the spraying program might be further improved by changing one chemical in the spraying program.

Control of apple diseases by the modified spraying program in 2005. The primary inoculum of *Marssonina* blotch is the ascospores produced in apothecia on over-wintered leaves that were diseased in previous year, and the dispersal of spores usually begins from latter half of April (Harada et al., 1974). In Korea, small number of spores had been detected until middle of June until 2002. However, since 2003, the mass dispersal of the *Marssonina* blotch primary inoculum has been beginning earlier, and we observed it occurring as early as early May (Lee et al., 2008). At first we did not consider this change to be significant, but the same phenomenon was confirmed again in the subsequent year, and an earlier initial outbreak of the blotch was also observed. Therefore, modification of the spraying program to block the primary infection was made by replacing Systhane M with metconazole or Singgeurong (a combined formulation of flusilazole and fluquinconazole; Dongbu Hightech, Seoul, Korea), which we found in the pesticide guidebook (Korea Crop Protection Association 2004). As those two chemicals are EBIs, they are also effective against rust, which also needs to be controlled around that same time. These two chemicals were tested for curative efficacy against white rot by substitution for tebuconazole in the sixth cover spray (Table 8). In addition to the replacement of Systhane M in the second cover spray and tebuconazole in the sixth cover spray with either metconazole or Singgeurong, respectively, two spray programs in which the two newly introduced EBIs were reciprocally arranged in the second and sixth cover sprays were designed (Table 8). The control efficacies of the seven programs, including the basic program for control of the major diseases, were evaluated by the methods previously described.

In the untreated plot, the incidence of white rot was no more than 6.4%, which was still less than in 2004 despite more frequent rain. A gradual decrease in the white rot epidemic continued later on. Fruit with bitter rot symptoms was so rare even in the untreated plot that it was excluded from examination. However, the incidence of *Marssonina* blotch was high enough for evaluation.

When Systhane M was replaced with metconazole (05-1) and Singgeurong (05-2) in the second cover spray, the contribution of both chemicals to the control of *Marssonina* blotch significantly increased (Table 8). However, the replacement of tebuconazole with metconazole (05-3) and Singgeurong (05-4) did not make any difference compared to the incidence of *Marssonina* blotch in the basic spray program in which Systhane M was maintained in the second cover spray. These results coincided well with our hypothesis that the control efficacy against *Marssonina* blotch could be increased by replacing Systhane M with chemicals of high control efficacy against the blotch.

In addition to the control of *Marssonina* blotch, the control efficacy of the two EBIs against white rot was tested. When tebuconazole was replaced with Singgeurong in the sixth cover spray (05-4, 05-5), the incidence of white rot was significantly higher than in the plots where metconazole or tebuconazole was used (Table 8). This fact indicated that not all of the EBIs were equally effective in the control of white rot when they were applied in early- or mid-August. *Marssonina* blotch was also effectively controlled

Table 8. Effect of modification of spray program on the control of apple white rot, bitter rot and *Marssonina* blotch (2005)

Cover Spray	Date sprayed	Fungicide spray programs and disease incidence (%)							
		05-0[a]	05-1	05-2	05-3	05-4	05-5	05-6	Unt[b]
1	15, Apr	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita
2	8, May	SYM	Mtz	SIN	SYM	SYM	Mtz	SIN	SYM
3	31, May	Krx	Krx	Krx	Krx	Krx	Krx	Krx	–
4	23, Jun	Dit	Dit	Dit	Dit	Dit	Dit	Dit	–
5	17, Jul	Trx	Trx	Trx	Trx	Trx	Trx	Trx	–
6	9, Aug	Teb	Teb	Teb	Mtz	SIN	SIN	Mtz	–
7	28, Aug	SAM	SAM	SAM	SAM	SAM	SAM	SAM	
White rot (%)		0.5 cd[c]	0.2 cd	0.7 cd	1.3 c	7.6 a	4.2 b	0.0 d	6.4 b
Bitter rot (%)		0.0 b	0.0 b	0.1 b	0.0 b	0.0 b	0.0 b	0.0 b	0.3 a
Marssonina (%)		25.0 b	0.0 c	5.1 c	27.5 c	33.3 b	6.3 c	5.0 c	55.5 a

[a]Basic program for 2005 was selected among the four programs tested in the experiment of previous two year, [b]Untreated control, [c]Within a line, means followed by the same letter are not significantly different at the 5% level by DMRT

by the two spraying programs in which metconazole and Singgeurong were reciprocally arranged in the second and sixth cover sprays. Given these results, we determined that tebuconazole, which is highly efficient for control of white rot but expensive, could be replaced with metconazole.

Control of apple diseases by a modified spraying program in 2006. The introduction of metconazole or Singgeurong in the second cover spray significantly increased the control efficacies of the spraying programs against *Marssonina* blotch. As repeatedly revealed throughout this research, because the contributions of the later applied chemicals to the control of diseases were influenced by a change in a single chemical early in the growing season, an attempt was made to improve the spraying program by introducing the two EBIs in the second cover spray and by changing the chemicals in the fifth cover spray.

Six modified spraying programs were designed by replacing the chemicals in the second and fifth cover sprays. The modified spraying program was divided into two groups based upon the chemicals in the second cover spray: metconazole and Singgeurong. The programs were subdivided by the chemicals in the fifth cover spray: trifloxystrobin, Belisplus, and pyraclostrobin. In addition to these six programs, one programs in which Singgeurong and metconazole were arranged in the second and fifth cover sprays, respectively were tested. Because this last one program had shown good control efficacy against *Marssonina* blotch in a previous experiment, its control efficacy against the major diseases were checked again.

In 2006, in spite of adverse weather conditions (21 and 19 days of rain in July and August, respectively), the incidences of white and bitter rot were so low, even in the untreated plot, that their incidences in the chemical-treated plots were not measured. However, *Marssonina* blotch was severe, with disease symptoms on nearly all leaves, and 83.7% of

Table 9. Effect of modification of spray program on the control of apple white rot, bitter rot and *Marssonina* blotch (2006)

Cover Spray	Date sprayed	Fungicide spray programs and disease incidence (%)							
		06-0[a]	06-1	06-2	06-3	06-4	06-5	06-6	Unt[b]
1	15, Apr	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita
2	8, May	Mtz	Mtz	Mtz	SIN	SIN	SIN	SIN	Mtz
3	31, May	Krx	Krx	Krx	Krx	Krx	Krx	Krx	–
4	23, Jun	Dit	Dit	Dit	Dit	Dit	Dit	Dit	–
5	17, Jul	Trx	BEL	Pyr	Trx	BEL	Pyr	Trx	–
6	9, Aug	Teb	Teb	Teb	Teb	Teb	Teb	Mtz	–
7	28, Aug	SAM	SAM	SAM	SAM	SAM	SAM	SAM	–
White rot (%)		0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b	3.3 a
Bitter rot (%)		0.2 b	0.0 b	0.0 b	0.3 b	0.4 b	0.0 b	0.0 b	2.8 a
Marssonina(%)		22.2 b[b]	20.3 b	14.6 b	24.5 b	26.2 b	15.0 b	14.8 b	83.7 a

[a]Basic program for 2006 was selected among the seven programs tested in the experiment of previous year, [b]Untreated control, [c]Within a line, means followed by the same letter are not significantly different at the 5% level by DMRT

the leaves were defoliated by mid-September (Table 9).

No significant differences in the control efficacy against *Marssonina* blotch were found among the seven spraying programs. However, the contribution of pyraclostrobin in the fifth cover spray was greater than that of trifloxystrobin or Belisplus regardless of changes in the chemicals in the second cover spray, but not significantly so. Although insignificant, control efficacy was also increased by substituting metconazole for tebuconazole in the sixth cover spray (06-6) without replacing trifloxystrobin with pyraclostrobin in the fifth cover spray (Table 9).

Among the seven programs tested in 2006, three (06-0, 06-3, 06-6) had also been tested in the previous year. The incidence of *Marssonina* blotch in 2006 in the three plots was much higher than that of the previous year as a whole. This difference was thought to derive from both the epidemic of disease caused by the adverse weather conditions in 2006 and the geographical situation of the experimental orchard used in 2006, which was conducive to development of the blotch because of the high elevation. However, a defoliation frequency of less than 15% until mid-September did not affect the quality of the fruit. Therefore, it was concluded that the 25-day interval spray program could be adopted for farming, though some room for further improvement still remains. Based on the results of five years of trials, we recommend a spray program for cv. Fuji containing the following fungicides: Singgeurong in the second; trifloxystrobin in the third; dithianon in the fourth; either kresoxim-methyl, Belisplus, a tank mixture of iminoctadine-triacetate and captan, or pyraclostrobin in the fifth; and metconazole in the sixth cover sprays. At present, several hundred farms have already implemented this program, and the number of farms adopting it is steadily increasing. Efforts to further improve the program are still ongoing.

References

Harada, Y., Sawamura, K. and Kono, K. 1974. Diplocarpon mali sp. Nov., the perfect state of apple blotch fungus Marssonina coronaria. *Ann. Phytopathol. Soc. Jpn.* 40:412-418.

Hayashi, S. 1984. Epidemiology and control of apple ring rot. *Plant Protection* 38:553-556 (in Japanese).

Kim, K. W., Park, E. W., Kim, Y. H., Ahn, K. K., Kim, P. G. and Kim, K. S. 2001. Latency-and defense-related ultrastructural characteristics of apple fruit tissues infected with Botryosphaeria dothidea. *Phytopathology* 91:165-172.

Kim, D. H. and Uhm, J. Y. 2002. Effect of application timing of ergosterol biosynthesis-inhibiting fungicides on the suppression of disease and latent infection of apple white rot caused by Botryosphaeria dothidea. *J. Gen. Plant Pathol.* 68:237-245.

Kohn, F. C. Jr. and Hendrix, F. F. 1983. Influence of sugar content and pH on development of white rot on apples. *Plant Dis.* 67:410-412.

Korea Crop Protection Association. 2005. Pesticide guidebook

Lee, D. H., Lee, S. W., Choi, K. H., Kim, D. A. and Uhm, J. Y. 2006. Survey on the occurrence of apple diseases in Korea from 1992 to 2000. *Plant Pathol. J.* 22:375-380.

Lee, D. H., Kim, D. H., Woo, H. and Uhm, J. Y. 2007. After-infection activities of protective fungicides against apple white rot. *Plant Pathol. J.* 23:166-173.

Lee. D. H., Choi, K. H., Lee, S. W. and Kim, D. A. 2008. Recent status of apple diseases in the major apple producing areas in Korea. In: Report of Horticultural Research in 2008, p. 827-828. Apple Experiment Institute, RDA, Korea.

Ogata, T. 1997. Environmental and cultural factors affecting the occurrence cycle of *Botryosphaeria* fruit rot of apple, and its control measures. *Plant Prot.* 51:11-14 (in Japanese).

Uhm, J. Y. 1998. Current practice of chemical control against apple diseases and its improvement in Korea. In: *Proceedings of the International Symposium on Recent Technology of Chemical Control of Plant Diseases*, pp. 19-49. Korean Society of Plant Pathology, Daegu, Korea.