Development of a 15-day Interval Spraying Program for Controlling Major Apple Diseases

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A fungicidal spray program for effective control of three major apple diseases in Korea (white rot, bitter rot, and *Marssonina* blotch) was developed. This was based on our previous studies showing that application of ergosterol biosynthesis inhibitors (EBIs) in early or mid-August can eradicate white rot infection in fruit and that some protective fungicides show after-infection activity against white rot. The basic spray program focused on control of white rot, the main target disease, and the fungicides were sprayed at 15-day intervals from petal fall to late August using fungicides that show after-infection and EBI activity. The basic spray program was modified over 4 successive years to improve control efficacy against bitter rot and *Marssonina* blotch, which sometimes cause as much damage as white rot. Modifications to the regime were made every year by replacing one fungicide in the basic program at a specific spraying time. Substitution of only one fungicide in the spray program, even early in the growing season, greatly influenced the final disease incidence at harvest. Applying this principle, a moderately efficient spray program for cv. Fuji that increased the spray interval from 10 to 15 days and thus reduced the number of sprays required per crop season was developed.

Keywords : bitter rot, *Marssonina* blotch, spraying program for apple, white rot

In Korea, disease can substantially reduce the quality and yield of apple, and is often severe because of frequent rain during the growing season (especially from mid- or late June through July). Although 33 parasitic diseases have been described on apple in Korea (KSPP, 2004), ten diseases are commonly found in almost all orchards and sometimes even in moderately well-managed orchards (Uhm, 1998). Seven of these diseases (white rot, bitter rot, *Marssonina* blotch, *Alternaria* blotch, sooty blotch, flyspeck, and rust) should be controlled with fungicides.

For controlling these diseases, farmers spray with fungicides 14-16 times, or even more than 20 times, during a single cropping season (Uhm, 1998).

Among the seven diseases that should be controlled by fungicides, white rot caused by *Botryosphaeria dothidea* (Moug) Ces. & De Not. is the most serious (Uhm, 1998; Lee et al., 2006) because cv. Fuji is highly susceptible to the disease and constitutes more than 70% of the apples produced in Korea. Although almost two-thirds of the fungicides sprayed in apple orchards are aimed at controlling white rot, the disease still causes considerable damage every year (Uhm, 1998). Therefore, control of white rot was of prime importance in the early stages of our work to develop fungicidal spray programs for apple. In developing a program to fight the seven common diseases that need to be controlled by fungicides, we considered white rot to be the main target, and the other diseases to be simultaneously controlled by modifying the white rot spray program. Fortunately, because the infection periods of these diseases (except rust) nearly overlap, simultaneous control of the diseases was considered possible (Uhm, 2005).

Because the pycnidiospores of the white rot fungus are dispersed to apples whenever it rains during the growing season (Sutton, 1981; Hayashi, 1984; Kim et al., 1995; Ogata, 1997) and because apple fruits are close to the inoculum source, control of the disease is very difficult using only protectant fungicides. In the screening of systemic fungicides that can cure the infection, encouraging results were obtained: application of EBIs (ergosterol biosynthesis inhibitors), especially tebuconazole, in early or mid-August greatly reduced the incidence of infection and the development of white rot, regardless of the infection time (Kim and Uhm, 2002).

In a further effort to select protective fungicides for control of white rot, after-infection fungicidal activity (i.e., reduction in infection frequency or disease incidence in previously infected fruit) was confirmed using folpet, azoxystrobin, iminoctadine-triacetate, and propineb (Lee et al., 2007). Moreover, the after-infection activities of the fungicides became more conspicuous when the fungi-

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cides were alternated (Lee et al., 2007). Combining these two facts, that application of EBIs in early or mid-August can cure fruit infected by white rot and that some protective fungicides show after-infection activity against white rot, we attempted to develop an effective spray program for controlling white rot and other diseases.

The conventional spray programs that have been developed by apple producers and pesticide companies recommend 16 sprays at 10-day intervals from late March to mid-September. In this study, however, we describe a new spray program that begins in late March, ends in late August, and is carried out at 15-day intervals. Reducing the spraying season and increasing the time between sprays reduces the number of applications per season from 16 to 9.

Materials and Methods

Orchard characteristics and chemical application. The experiments were conducted over 5 years (1999-2003) and involved cv. Fuji on M.26 rootstock in a commercial orchard near Daegu, Korea. The trees were spaced at 4×6 m and were 12 years old in 1999. The commercial orchard was located in a favorable area for disease development because it was surrounded by high hills, houses, and dense apple trees that obstruct airflow. Almost all trees were severely infected with *B. dothidea* and had numerous warts on their branches and even on small twigs. The orchard was managed using common methods: the grass was mown four times a year, and the trees were fertilized in early March with a multicomponent fertilizer for apple (N:P:K =12:6:8, KG Chemical Co. Ltd., Gyunggi, Korea) at 500 kg/ha.

Fungicides. The fungicides used and their abbreviations are given in Table 1.

Application of fungicides and control of insect pests.

Because the orchard was well isolated from other orchards, Lepidoptera could be controlled using a pheromone that disrupts their mating (Shin-Etsu Chemical Co. Ltd., Tokyo, Japan), while aphids and mites were controlled with pesticide spraying when required. The fungicides were applied to runoff with a single-nozzle spray gun at 3.5 MPa.

Disease incidence and infection frequency. Disease incidence of white rot and bitter rot was determined by counting the diseased fruits on each tree at weekly intervals from mid-August to harvest in late October or early November. At harvest, the total number of fruits on each tree was counted, and disease incidence was calculated as the percentage of diseased fruit per tree. To detect latent infection by white rot, 100 symptom-free fruit at harvest were placed on a styrofoam egg carton in a cardboard box, incubated at 25°C, and examined weekly for disease symptoms. The incidence of latent infection was calculated as the percentage of these initially symptom-free fruit that developed disease during a 4-week incubation. Infection frequencies were calculated by combining the disease incidences until harvest and the latent infection frequencies (Kim and Uhm, 2002). To determine the incidence of *Marssonina* blotch, ten small shoots, 1.0-1.5 m above the soil surface, were selected in each tree during early July, when shoot growth had nearly terminated and the symptoms of blotch had not yet appeared (Uhm, 1998). The selected shoots were marked with a ribbon, and the incidence of diseased leaves on the selected shoots was

Table 1. Details of fungicides used in this experiment

Common name	Commercial name	a.i. (%)	Formulation ^a	Abbreviation
Iminoctadine-triacetate	Befran	25	SL	Ita
Mancozeb+myclobutanil	Systhane M	65+2	WP	SYM
Propineb	Antracol	70	WP	Pro
Folpet	Folpet	50	WP	Fol
Azoxystrobin	Amistar	10	WP	Azx
Kresoxim-methyl	Hebichi	42	SC	Krx
Tebuconazole	Silbacur	20	SC	Teb
Iminoctadine-triacetate+Difenoconazole	Smazinwang	15+3	SC	SAM
Dithianon	Delan	43	SC	Dit
Metiram	Polyram	55	WG	Met
Fluazinam	Frownicide	50	WP	Flz
Chlorothalonil	Daconil	75	WP	Chl
Captan	Captan	50	WP	Cap
Thiram	Sulmanae	80	WP	Thi

^aSL=soluble concentrate, WP=wettable powder, SC=suspension concentrate, WG=water dispersible granule

Table 2. Fungicidal spray sequence and possible target diseases for developing the basic spray program in 1999

Cover spray	Date Sprayed	Spray programs			Possible target Diseases
		99-1	99-2	99-3	
1	20 Apr	Ita	Ita	Ita	MC ^a , VC ^b , AB ^c
2	12 May	SYM	SYM	SYM	Rust, AB, BR ^d
3	28 May	Pro	Azx	Azx	WR ^e , BR, AB, SB ^f
4	12 Jun	Fol	Pro	Fol	WR, BR, AB, MB ^g
5	26 Jun	Ita	Ita	Ita	WR, MB, BR
6	11 Jul	Azx	Azx	Fol	WR, BR, MB
7	26 Jul	Ita	Ita	Ita	WR, BR, MB
8	10 Aug	Teb	Teb	Teb	WR, MB
9	24 Aug	SAM	SAM	SAM	MB, WR

^aMoldy core; ^bValsa canker; ^cAlternaria blotch; ^dBitter rot; ^ewhite rot; ^fSooty blotch; ^gMarssonina blotch

determined in mid-September. However, in the experiments after 1999, only defoliation frequency was determined because most diseased leaves that had been infected in the early growing season had abscised from the trees. In addition, some leaves with lesions, mostly spots, were maintained on the tree but were ignored because they do not affect fruit quality.

Development of the basic spray program in 1999. On the basis of our two previous studies showing that white rot infection on fruit can be cured by application of EBIs in early or mid-August (Kim and Uhm, 2002) and that several protective fungicides also have after-infection activity against white rot (Lee et al., 2007), three spraying programs were developed (Table 2). For the first cover spray (at the pink stage), iminoctadine-triacetate, a wide-spectrum fungicide, was used to control *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 and bitter rot. From the third cover spray until the final cover spray in late August, fungicides were scheduled at 15-day intervals. After late August, infection by white rot is rare (Ogata, 1997), and the infection risk by bitter rot is also small (Ijima, 1999). During the high-risk period for infection by white rot (from the fourth cover spray in late May to early August), four fungicides with after-infection activity (folpet, iminoctadine-triacetate, azoxystrobin, and propineb) were used in various schedules in the three programs (Table 2). In all three programs, five fungicides are required to cover the high-risk period but only four fungicides were available in 1999; therefore, azoxystrobin or iminoctadine-triacetate, which are much more effective than the other two fungicides (Lee et al.,

2007), were used twice (Table 2). In mid-August, tebuconazole, which has high curative efficacy against white rot, was scheduled. For the last cover spray in late August, Samzinwang (Kyungnong Co. Ltd.), a combined formula of difenocoazole and iminoctadine-triacetate, was used to control *Marssonina* blotch and white rot. Each spray program was applied to six randomized trees, and the incidences of major diseases were determined by the methods described above.

Improvements to spray programs from 2000 to 2003. Because the basic spraying program focused on the control of white rot, it required modifications to control bitter rot and *Marssonina* blotch, which sometimes cause as much damage as white rot. Because epidemics of apple diseases vary greatly among years, research to improve the spray program was continued over 4 years to increase the chances that the program would be useful during most years. The spraying program was modified each year by replacing one fungicide at a specific time in the basic program, and thus the modified programs differed by only one fungicide. The details of the modified spray programs (which fungicides were included or excluded) are provided in the Results and Discussion.

The modified spraying programs were applied to the orchard together with the basic program, and the incidence of major diseases (white rot, bitter rot, and *Marssonina* blotch) was determined as described above. Because the modified spraying programs differed by only one fungicide, we could attribute differences in disease control to the contribution of the substituted fungicide. Within any 1 year (1999-2002), fungicides to be used in the basic program for the next year were selected based on the contribution of each substituted fungicide to disease control in the current year. To determine the severity of diseases in each year, fungicides were completely excluded from the third cover spray in the plot with the untreated control containing six trees. Different trees were assigned to this untreated control each year to avoid any possible hazard from excluding the fungicides.

Design of experiments and analyses of data. All of the experiments in this study were designed as randomized complete blocks with three replicates and two adjacent trees per replicate. Data were analyzed with an analysis of variance (ANOVA). If an ANOVA was significant, the means were separated with Duncan's multiple range test (SAS Institute, Cary, NC, USA).

Results and Discussion

Control of major apple diseases with the basic spraying

Table 3. Control of apple diseases by different spray programs with 15-day spray interval from petal fall to late August (1999)

Spray programs ^a	Incidence (%)						
	White rot		Bitter Rot	Sooty, Flyspeck ^d	Alternaria blotch	Marssonina blotch	
	disease ^b	infection ^c				disease	defoliation
99-1	0.0 b ^c	4.8 b	0.3 a	0.2	0.2	11.2 a	5.2 a
99-2	5.3 a	23.2 a	0.7 a	0.0	0.0	9.8 a	0.7 b
99-3	3.2 a	19.2 a	0.0 a	0.1	0.4	7.6 a	1.3 b
Untreated	66.3 c	92.6 c	4.8 b	100	5.3	100 b	88.9 c

^aRefer to Table 2 for fungicides sequence of each program.

^bDisease incidence is the % of fruit with symptoms until harvest. ^cInfection 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.

^dIn most case sooty blotch and flyspecks concur on same fruit.

^eWithin a line, means followed by the same letter are not significantly different at the 5% level by DMRT

program in 1999. In the plot not treated with fungicides in 1999, about two-thirds of the apples had white rot symptoms at harvest, and nearly all fruit were infected (Table 3). The incidences of bitter rot and *Alternaria* blotch were low. Active rust lesions were not detected in mid-September, but leaf spot lesions cured using 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 nearly all leaves and with substantial subsequent defoliation in mid-September (Table 3). Sooty blotch and flyspeck disease were also found on all of the fruit in the untreated plot (Table 3).

In spite of severe white rot in the untreated plot, the three spray programs controlled the disease effectively, and program 99-1 was especially effective (Table 3). White rot disease incidence and infection frequency differed between treatments 99-1 and 99-2, and between 99-1 and 99-3, but the cause of the difference was unclear because of multiple differences among the spray programs (Table 2). The incidences of bitter rot and *Alternaria* blotch were very low, even in the untreated plot, and their incidence in the fungicide-treated plots was negligible (Table 3). Sooty blotch and flyspeck were severe in the untreated plot, but were almost completely controlled in all of the fungicide-treated plots (Table 3). Although *Marssonina* blotch was severe in the untreated plot, it was effectively controlled by the three spraying programs; incidence on leaves with symptoms in mid-September did not differ among the programs but defoliation frequency was lower in 99-2 and 99-3 than in 99-1 (Table 3). In spite of the slightly lower control efficacy of 99-1 against *Marssonina* blotch, this was selected as the basic program for further modification in subsequent years because it provided excellent control of the primary target, white rot.

Control of apple diseases by modified spraying programs in 2000. Experiments to improve program 99-1 were conducted over 4 consecutive years (2000-2003). The

severity of each disease varied greatly by year. Note that the fungicides sprayed before flowering and petal fall were not changed during 2000 or thereafter because their contribution to the control of the major diseases was small.

In 2000, the basic program used in 1999 (99-1) was changed in one of two ways: iminoctadine-triacetate, which had been used twice in program 99-1, was replaced with either dithianon or fluazinam (Table 4). The incidence of white rot in the untreated plot was less than 12%, and no difference was observed in the incidence of white rot among the three spraying programs (Table 4). The incidence of bitter rot, however, which had been a minor disease on cv. Fuji, increased considerably in the untreated plot (Table 4). Control of bitter rot by the three programs was low and was significantly lower with program 00-2 than with the

Table 4. Effect of modification of spray program on the control of apple white rot, bitter rot and *Marssonina* blotch (2000)

Cover sprays	Date Sprayed	Spray programs and disease incidence (%)			
		99-1 (basic ^a)	00-1	00-2	Untreated
1	4 Apr	Ita	Ita	Ita	Ita
2	2 May	SYM	SYM	SYM	SYM
3	23 May	Pro	Pro	Pro	–
4	8 Jun	Fol	Fol	Fol	–
5	25 Jun	Ita	Dit	Flz	–
6	10 Jul	Azx	Azx	Azx	–
7	25 Jul	Ita	Ita	Ita	–
8	17 Aug	Teb	Teb	Teb	–
9	28 Aug	SAM	SAM	SAM	–
White rot		0.0 a ^b	1.0 a	0.0 a	11.8 b
Bitter rot		2.9 a	2.9 a	5.5 b	12.2 c
Marssonina blotch		1.2 b	0.9 b	0.8 b	46.8 a

^aBasic program for 2000 was selected among the programs of the previous year on the basis of control efficacies against white rot.

^bWithin a line, means followed by the same letter are not significantly different at the 5% level by DMRT

other two programs (Table 4). Despite the high incidence of *Marssonina* blotch in the untreated plot (Table 4), this disease was adequately and equally controlled by all three programs (Table 4).

In selecting the basic spraying program for 2001, we excluded program 00-2 because it provided poor control of bitter rot. A slight difference in the control efficacies against white rot and *Marssonina* blotch was detected between program 99-1 and 00-1, but the differences were not significant (Table 4). However, 00-1, in which iminoctadine-triacetate was replaced by dithianon in the sixth cover spray of 99-1, was selected as the basic program for 2001 to avoid repeated use of iminoctadine-triacetate.

Control of apple diseases by modified spraying programs in 2001. In 2001, seven modified spraying programs were designed by replacing one chemical in the basic program (00-1): in five of the programs, propineb was replaced by either thiram, azoxystrobin, captan, fluazinam, or metiram, and in two of the programs, folpet was replaced by either metiram or fluazinam (Table 5).

In the untreated plot, the incidences of white rot and defoliation by *Marssonina* blotch were high enough to allow evaluation of the spray program, but the incidence of bitter rot was too low (Table 5). Single changes of fungicide in the basic program (00-1) greatly affected control of white rot and *Marssonina* blotch in 2001. Substitution of azoxystrobin for propineb in the third cover spray (26 May, program 01-2) completely suppressed white rot, while the use of thiram at the same time (program 01-1) reduced disease control. Use of thiram also reduced the control of *Marssonina* blotch. Substitution of captan, fluazinam, or

metiram for propineb did not affect control of white rot, but substitution with captan or metiram reduced the control of *Marssonina* blotch (Table 5).

When folpet was replaced with metiram (01-6) or fluazinam (01-7) in the fourth cover spray, the contribution of fluazinam to the control of white rot was significantly greater than that of metiram and was also greater than that of folpet, but not significantly so. The three fungicides used in the fourth cover spray did not affect the control of bitter rot or *Marssonina* blotch (Table 5).

The data thus far had shown that the selection of fungicides in the third cover spray around late May greatly affected the control of white rot and *Marssonina* blotch. Why control of white rot was so influenced by different fungicides applied in late May was difficult to explain because the large-scale dispersal of pycnidiospores, the main inoculum source of the disease, does not begin until later in the season (Kim et al., 1995; Ogata, 1997) and the infection frequency in late May is not high (Ogata, 1997; Kim, 2000). Moreover, any possible infections resulting from inadequate properties of the chemicals applied in late May might be overcome by the subsequent fungicides, such as folpet and iminoctadine-triacetate, which have after-infection activity against white rot (Lee et al., 2007; Uhm, 1998). Explaining how fungicides applied at such an early stage of growth could influence the final control efficacy of a spray program was also difficult because secondary infection from diseased fruit is not possible in white rot (Hayashi, 1984). However, in the case of *Marssonina* blotch, control by fungicides applied early in the growing season might be very important because the primary infections originating from overwintered inoculum sources might

Table 5. Effect of modification of spray program on the control of apple white rot, bitter rot and *Marssonina* blotch (2001)

Cover Spray	Date sprayed	Fungicide spray programs and disease incidence (%)								Untreated
		00-1 Basic ^a	01-1	01-2	01-3	01-4	01-5	01-6	01-7	
1	13, Apr	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita
2	5, May	SYM	SYM	SYM	SYM	SYM	SYM	SYM	SYM	SYM
3	26, May	Pro	Thi	Azx	Cap	Flz	Met	Pro	Pro	–
4	9, Jun	Fol	Fol	Fol	Fol	Fol	Fol	Met	Flz	–
5	25, Jun	Dit	Dit	Dit	Dit	Dit	Dit	Dit	Dit	–
6	10, Jul	Azx	Azx	Azx	Azx	Azx	Azx	Azx	Azx	–
7	25, Jul	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita	–
8	10, Aug	Teb	Teb	Teb	Teb	Teb	Teb	Teb	Teb	–
9	25, Aug	SAM	SAM	SAM	SAM	SAM	SAM	SAM	SAM	–
White rot		3.2 bc ^b	5.5 d	0.0 a	1.4 ba	1.7 ba	2.0 ba	4.6 dc	1.8 ba	23.6 e
Bitter rot		1.1 a	2.1 a	1.6 a	0.5 a	1.5 a	0.4 a	1.2 a	0.7 a	8.0 b
<i>Marssonina</i> Blotch		1.8 a	10.6 d	2.4 ba	5.8 bc	3.6b ac	6.3 c	2.3 a	1.8 a	19.0 e

^aBasic program for 2001 was selected among the programs of the previous year mainly on the basis of control efficacies of major diseases and of rationality of spray program.

^bWithin a line, means followed by the same letter are not significantly different at the 5% level by DMRT

Table 6. Effect of modification of spray program on the control of apple white rot, bitter rot and Marssonina blotch (2002)

Cover spray	Date sprayed	Fungicide spray programs and disease incidence (%)							
		02-0 Basic ^a	02-1	02-2	02-3	02-4	02-5	02-6	Untreated
1	4 Apr	Ita	Ita	Ita	Ita	Ita	Ita	Ita	Ita
2	2 May	SYM	SYM	SYM	SYM	SYM	SYM	SYM	SYM
3	23 May	Azx	Azx	Azx	Azx	Azx	Azx	Azx	–
4	8 Jun	Flz	Flz	Flz	Flz	Flz	Flz	Flz	–
5	25 Jun	Dit	Trx	Met	Chl	Dit	Dit	Dit	–
6	10 Jul	Fol	Fol	Fol	Fol	Trx	Met	Chl	–
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	–
White rot		2.1 ba ^b	3.0 b	1.2 a	5.4 c	2.2 ba	2.8 ba	2.1 ba	34.7 d
Bitter rot		2.1 ba	1.0 a	1.2 a	0.9 a	1.0 a	3.1 b	1.2 b	12.9 c
Marssonina blotch		2.4 ba	4.1 bd	7.6 d	6.3 dc	0.2 a	6.8 d	2.7 ba	24.5 e

^aBasic program for 2002 was designed on the basis of contribution of fungicides of 5th and 6th cover spray on the control of white rot, bitter rot and Marssonina blotch in the experiment of previous year

^bWithin a line, means followed by the same letter are not significantly different at the 5% level by DMRT

occur early, and secondary infection can result from the spores produced on the primary infection lesions.

Based on these results, a basic program for 2002 was prepared with the fungicide that contributed most to the control of white rot or *Marssonina* blotch at each spraying time; azoxystrobin, fluazinam, and dithianon were selected for the third, fourth, and fifth cover spray, respectively, and folpet was selected for the sixth cover spray, to avoid repeated use of azoxystrobin.

Control of apple diseases by modified spraying programs in 2002. For the experiment in 2002, the basic spraying program (02-B) was modified in six ways, focusing on the control of bitter rot using fungicides known to be highly effective against this disease. Trifloxystrobin, metiram, or chlorothalonil was substituted for dithianon at the fifth cover spray and for folpet at the sixth cover spray. In 2002, the incidence of the three major diseases in the untreated plot was higher than in the previous year (Table 6). The results of replacing dithianon with the three other fungicides for the fifth cover spray were complex. Some fungicides contributed more than dithianon to the control of some diseases but less than dithianon to the control of other diseases. In no case was the contribution of the substitute invariably higher than that of dithianon for the control of the three diseases (Table 6). Therefore, dithianon was considered the most suitable chemical for the fifth cover spray.

When the three chemicals were substituted for folpet in the sixth cover spray, the final control efficacies against the three diseases were quite different from those obtained using the three chemicals in the fifth cover spray. The contribution of trifloxystrobin to control of bitter rot and

Marssonina blotch was greater than that of folpet, but the contributions of trifloxystrobin and folpet for control of white rot were similar (Table 6). Chlorothalonil, which contributed little to white rot control when used in the fifth cover spray, contributed substantially to white rot control when used in the sixth cover spray (Table 6). Moreover, the use of chlorothalonil in the sixth cover spray tended to reduce *Marssonina* blotch, although not significantly. The use of metiram in the sixth rather than in the fifth cover spray resulted in more bitter rot but did not change the incidence of the other diseases (Table 6).

These results once again demonstrated that a change of one fungicide in a spraying program can bring about a great difference in the final control of major diseases, and that the contribution of each fungicide to the control of a specific disease is greatly affected by the timing of application.

On the basis of the contribution of the fungicides in the fifth and sixth cover sprays to the control of the three major diseases, we decided to maintain dithianon in the fifth cover spray and to substitute trifloxystrobin for folpet in the sixth cover spray for the basic program in 2003.

Control of apple diseases by modified spraying programs in 2003. By 2002, our experiments had identified the basic framework for the spraying program that could reasonably control the major apple diseases on cv. Fuji. In 2003, trials were conducted to solve a few remaining secondary problems. Because azoxystrobin causes severe phytotoxicity on cultivars bred with cv. MacIntosh as one parent, we developed another spray program in which azoxystrobin was replaced with kresoxim-methyl, which is also a strobilulin fungicide but does not cause phytotoxicity

in orchards containing azoxystrobin-sensitive cultivars.

Dithianon performed well repeatedly for the control of the three major diseases (Tables 5, 6) but also but caused skin irritation to some workers. Therefore, we intended to developed a special spraying program in which dithianon was replaced by other fungicide. Metiram which had been tested in 2002, but was abandoned because of its low contribution to control of *Marssonina* blotch was tested again (Table 7).

As repeatedly revealed during this study, the control efficiencies of a spraying program were often largely affected by changing only one chemical. Therefore, we considered that the contribution of metiram to the control of *Marssonina* blotch might increase if azoxystrobin were replaced by kresoxim-methyl in the third cover spray.

Tebuconazole had been consistently used in the eighth cover spray throughout this study on the basis of our previous finding that tebuconazole, when applied in early or mid-August, can cure fruit infected with white rot regardless of infection time. However, bitertanol is less expensive than tebuconazole and provides similar control of white rot (Kim and Uhm, 2002); therefore, we tried substituting tebuconazole with bitertanol.

In 2003, rain was frequent from May to August (1031 mm in 58 days), and incidences of the three major diseases in the untreated plot were very high (Table 8). In particular, *Marssonina* blotch was so severe that nearly all of the trees

were defoliated by mid-September (Table 7).

When azoxystrobin was replaced by kresoxim-methyl in the basic program, control of white rot and *Marssonina* blotch was not significantly affected, but the control of bitter rot increased significantly (Table 7). Therefore, kresoxim-methyl might well be substituted for azoxystrobin in mixed cultivar orchards. Control of white rot and *Marssonina* blotch in program 03-2 (in which kresoxim-methyl was used in the third cover spray and metiram was substituted for dithianon in the fifth cover spray) was still significantly lower than with the basic program, but control of bitter rot was similar to that in the basic program (Table 7). Therefore, in the case of severe skin irritation by dithianon, metiram can be used, although a risk of slight damage by white rot and *Marssonina* blotch exists. We are still looking for other substitutes for dithianon.

When bitertanol replaced tebuconazole in the basic program, control of white rot and bitter rot remained the same, but control of *Marssonina* blotch was reduced (Table 8). This indicated that tebuconazole plays a very important role not only in the control of white rot but also in the control of *Marssonina* blotch, and that bitertanol cannot replace tebuconazole.

During these studies to develop an efficient spraying program for apple, we found that substitution of only one fungicide in the spray program, even early in the growing season, can greatly influence the final disease incidence at harvest. Applying this finding, we developed a moderately efficient spraying program for cv. Fuji, in which the program increased the spray interval from 10 to 15 days and thus reduced the number of sprayings required per crop season. Although this program has been adopted by most apple growers in Korea, room for improvement may still exist.

Table 7. 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 Basic ^a	03-1	03-2	03-3	Untreated
1	12 Apr	Ita	Ita	Ita	Ita	Ita
2	3 May	SYM	SYM	SYM	SYM	SYM
3	24 May	Azx	Krx	Krx	Azx	—
4	9 Jun	Flz	Flz	Flz	Flz	—
5	25 Jun	Dit	Dit	Met	Dit	—
6	14 Jul	Trx	Trx	Trx	Trx	—
7	25 Jul	Ita	Ita	Ita	Ita	—
8	5 Aug	Teb	Teb	Teb	Bit	—
9	22 Aug	SAM	SAM	SAM	SAM	—
White rot		0.0 a ^b	1.1 ba	2.3 b	2.5 b	31.8 d
Bitter rot		2.8 bc	1.2 a	1.9 ba	3.4 c	17.2 d
<i>Marssonina</i> Blotch		0.0 a	0.0 a	7.3 c	28.8 d	96.5 d

^aBasic program for 2003 was designed on the basis of contribution of fungicides of 5th and 6th cover spray on the control of white rot, bitter rot and *Marssonina* blotch in the experiment of previous year

^bWithin a line, means followed by the same letter are not significantly different at the 5% level by DMRT

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