Scientia Horticulturae xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Elimination of summer fungicide sprays for apple scab (*Venturia inaequalis*) management in Uruguay

Sandra Alaniz[a,*], Carolina Leoni[b], Oscar Bentancur[c], Pedro Mondino[a]

[a] *Departamento de Protección Vegetal, Facultad de Agronomía, Universidad de la República, Garzón 780, 12900 Montevideo, Uruguay*
[b] *Sección Protección Vegetal, Programa Nacional de Investigación en Producción Frutícola, Instituto Nacional de Investigación Agropecuaria (INIA Las Brujas), Ruta 48, Km 10, Rincón del Colorado, Canelones 90200, Uruguay*
[c] *Departamento de Biometría, Estadística y Computación, Facultad de Agronomía, Universidad de la República, Garzón 780, 12900 Montevideo, Uruguay*

ARTICLE INFO

Article history:
Received 24 May 2013
Received in revised form 23 October 2013
Accepted 13 November 2013

Keywords:
Apple disease
Summer fungicide remove
Integrate disease management

ABSTRACT

Apple scab caused by *Venturia inaequalis* is the most important disease of apple in Uruguay. Under conventional management an average of 14–16 fungicide sprays are used each season to control this disease. In this work, the elimination of fungicide sprays for apple scab control after mid-December was evaluated during two seasons in three commercial apple orchards planted with cultivars of Red Delicious, the main apple produced in Uruguay. This finding was based on the ontogenic resistance which implies that the susceptibility to apple scab of leaves and fruits decreases with the ageing of the tissues. Increments of scabbed leaves happened during the summer and fall in all orchards evaluated, but this increase happened in both treatments, with or without fungicide applications during the summer. Instead, none of the orchards evaluated showed increases of apple scab lesions on fruit after December 15th. This finding suggests that it is feasible to reduce up to 30% of fungicide sprays to control apple scab in apple fruit that are harvested from January (like cultivars of Gala) to March (like cultivars of Red Delicious) in Uruguay.

1. Introduction

Apple scab caused by *Venturia inaequalis* (Cke.) during the winters is a severe worldwide disease of apples (*Malus domestica* Borkh.). Fruit and all green tissues are susceptible to the disease and are infected throughout the growing season from green-tip to leaf fall (MacHardy, 1996; Mondino and Alaniz, 2009; Bowen et al., 2011). Apple scab management is based mainly on fungicide sprays; each year high amounts of fungicide per hectare are applied, which entails environmental and health risks (Gadoury et al., 1989; Carisse and Jobin, 2012). Additionally, problems of resistance in *V. inaequalis* populations to some active ingredients commonly used for apple scab management, such as sterol demethylation inhibitors, dodine or QoI, have been reported (Köller et al., 1997, 1999, 2004; Köller and Wilcox, 2001; Jobin and Carisse, 2007).

Integrated Fruit Productions Programs encourage the reduction of fungicide sprays to control apple scab (Cooley and Autio, 1997). One strategy is based on the reduction or elimination of the fungicide sprays during the summer. This strategy takes in consideration, the differences in susceptibility to apple scab that decreases with the ageing of fruit and leaf tissues. This age-related resistance is called "ontogenic resistance" (MacHardy, 1996). In expanding leaves, the incubation period is approximately two months, and the leaves older than seventeen days do not develop lesions (Biehn et al., 1966; MacHardy, 1996; MacHardy et al., 2001). In accordance, in fruits the wetness period required for infection increased with their age (Schwabe, 1982; Tomerlin and Jones, 1983; MacHardy, 1996; Xu and Robinson, 2005). Schwabe et al. (1984) observed that ten weeks after full bloom and at 15 °C, the fruit requires at least 24 h of wetness to be infected; moreover, a dry interruption of only one hour significantly reduced the amount of infection. The summer conditions, with short "fruit wetness" periods and fruits and leaves in their adult stage, drastically reduce the risk of secondary apple scab infections. Also, high temperatures during the day can contribute to limit the periods of infections, as *V. inaequalis* development is inhibited with temperatures higher than 25 °C (MacHardy, 1996). Hence, the fungicide applications used to control apple scab during the summer could be reduced or eliminated.

In Uruguay, apple scab is the most important disease of apple orchards. Under conventional management an average of 14–16 fungicide sprays are used each season to control this disease. A farmer with an orchard of 10 ha applies around 800 kg of fungicide (mainly dithiocarbamates and demethylation inhibitor fungicides) per season (Mondino et al., 2003). Approximately 50% of the apple orchards planted in Uruguay are cultivars of Red Delicious that are harvested at the end of summer (March), 20% cultivars of Gala that are harvested at mid-summer (mid-January to mid-February) and

* Corresponding author.
E-mail address: salaniz@fagro.edu.uy (S. Alaniz).

0304-4238/$ – see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.scienta.2013.11.016

Table 1
Characteristics of the three apple orchards planted with cultivars of Red Delicious evaluated.

Orchard	Locality	Cultivar/rootstock	Year of plantation	Space between rows and between trees	Size (m^2)	Number of fungicide sprays per summer in standard management	
						2008/09	2009/10
1	Melilla	Red chief/seed	1996	5 × 2.5	6500	4	–
2	Las Brujas	Red spur/seed	1989	5 × 2.5	7000	2	4
3	Rincón de Melilla	Red standard/seed	1985	6 × 3	10,000	5	4

the remaining 30% mainly Cripps Pink, Fuji and Granny Smith cultivars that are harvested in the fall. Based on previous analysis, it might be possible to eliminate fungicide sprays for apple scab management from mid-December in cultivars of Red Delicious and Gala and eliminate summer fungicide spray in cultivars harvested in the fall. Thus, the objective of this work was to evaluate the effect of fungicide spray elimination from mid-December to apple scab control in Red Delicious apples in Uruguay.

2. Materials and methods

2.1. Apple scab assessment in the field

Three commercial apple orchards planted with cultivars of Red Delicious located in the south-central region of Uruguay, the main apple production area, were selected for the experiments. Orchards selected had different apple scab incidence in fruit and leaves at mid-December, and during the spring, they were managed by the farmers according to Integrated Fruit Productions Programs of Uruguay (Scatoni et al., 2004). Orchard descriptions are presented in Table 1.

Over two consecutive seasons, 2008/09 and 2009/10, from December 15th to harvest, fungicide sprays were eliminated in one half of the orchard (the same half in both seasons), and the second half received fungicide sprays until harvest according farmer's apple scab management based on Integrated Fruit Productions Programs of Uruguay.

Apple scab incidence was assessed on leaves and fruits on mid-December and at harvest. The leaves were additionally assessed at leaf fall (end-May) and fruits were scored for apple scab lesions at mid-summer (end-January). On leaves, apple scab incidence was determined on 20 terminal shoots on 10 trees per treatment (with or without summer fungicide spray). The trees were randomly selected and the terminal shoots were collected from the bottom, the centre and the top of the trees and evaluated in the laboratory. Each shoot had an average of 10–12 leaves. On fruits, apple scab incidence was determined from 25 fruits per tree on 20 trees per treatment in the orchard. The trees and fruits were randomly selected in each orchard and the border trees were not included in the evaluations. A leaf or a fruit was considered as infected if at least one visible scab lesion was present. Leaf and fruit scab incidence was estimated as percentage of leaves and fruits diseases.

The data were analysed with GLIMMIX procedure using the Poisson distributions of the variable and the logarithm as link function. The treatments with 0.0% of apple scab incidence were not included in the analysis. The statistical analysis was conducted in SAS program (SAS 9.1 Institute Inc., Cary, NC, USA).

Additionally, temperature and rainfall data were obtained from a local weather station located within 12 km from the commercial orchards evaluated.

2.2. Apple scab assessment on storage fruits

In addition, 600 fruits in 2008/09 and 900 fruits in 2009/10 with no visible lesions of apple scab were selected from each treatment and stored on regular atmosphere (0 °C). Incidence of scabbed fruits was evaluated in a sample of 300 fruits after three and six months of storage in 2008/09 and after three, six and eight months of storage in 2009/10. A fruit was considered infected if at least one visible scab lesion was present in the fruit. Fruit incidence was estimated as percentage of scabbed fruits.

3. Results

3.1. Apple scab assessment in the field

Values of apple scab incidence in all commercial orchards evaluated during both seasons are given in Figs. 1 and 2. No significant differences ($P > 0.05$) were found for apple scab incidence on leaves during the summer on sprayed or un-sprayed sections of the orchards in both seasons, except in orchard 1 (Table 2). Differences ($P < 0.05$) were found among evaluation time in all orchards and both seasons, except in the orchard 3, season 2009/10 (Table 2). The apple scab incidence on leaves at mid-December was between 3.10% (orchard 3, season 2008/09) and 0.00% (orchard 3, season 2009/10). The incidence of this disease increased during the summer and at harvest the values reached between 0.19% (orchard 1, season 2008/09) and 11.56% (orchard 3, season 2009/10). During the autumn the incidence of apple scab continued to increase and at leaf fall was between 1.53% (orchard 1, season 2008/09) and 39.13% (orchard 2, season 2009/10) (Fig. 1).

For fruits, statistical analysis showed that there were no significant differences ($P > 0.05$) in apple scab incidence between treatments and evaluation time in all orchards and in both seasons (Table 2). The orchards with the lowest value of incidence were orchard 1 season 2008/09 and orchard 3 season 2009/10, in both cases apple scab incidence remained always in 0.00%. The orchard with highest incidence was the orchard 3 season 2008/09, when

Table 2
Analysis with GLIMMIX procedure for the treatment effect (with or without summer fungicide applications) and evaluation time (mid-December, mid-summer, harvest and leaf fall) on apple scab incidence assessed on leaves and fruits in three apple orchards planted with cultivars of Red Delicious during two season (2008/09 and 2009/10).

Orchard	Effect	P-value	
		2008/09	2009/10
Leaves			
1	Treatment	0.0112	–
	Evaluation time	0.008	–
2	Treatment	0.2725	0.0803
	Evaluation time	0.003	0.0026
3	Treatment	0.1437	0.2551
	Evaluation time	0.2349	0.0195
Fruits			
1	Treatment	na[a]	–
	Evaluation time	na[a]	–
2	Treatment	0.4834	0.2321
	Evaluation time	0.858	0.913
3	Treatment	0.8088	na[a]
	Evaluation time	0.1042	na[a]

[a] na: not analysed.

Please cite this article in press as: Alaniz, S., et al., Elimination of summer fungicide sprays for apple scab (*Venturia inaequalis*) management in Uruguay. Sci. Hortic. (2013), http://dx.doi.org/10.1016/j.scienta.2013.11.016

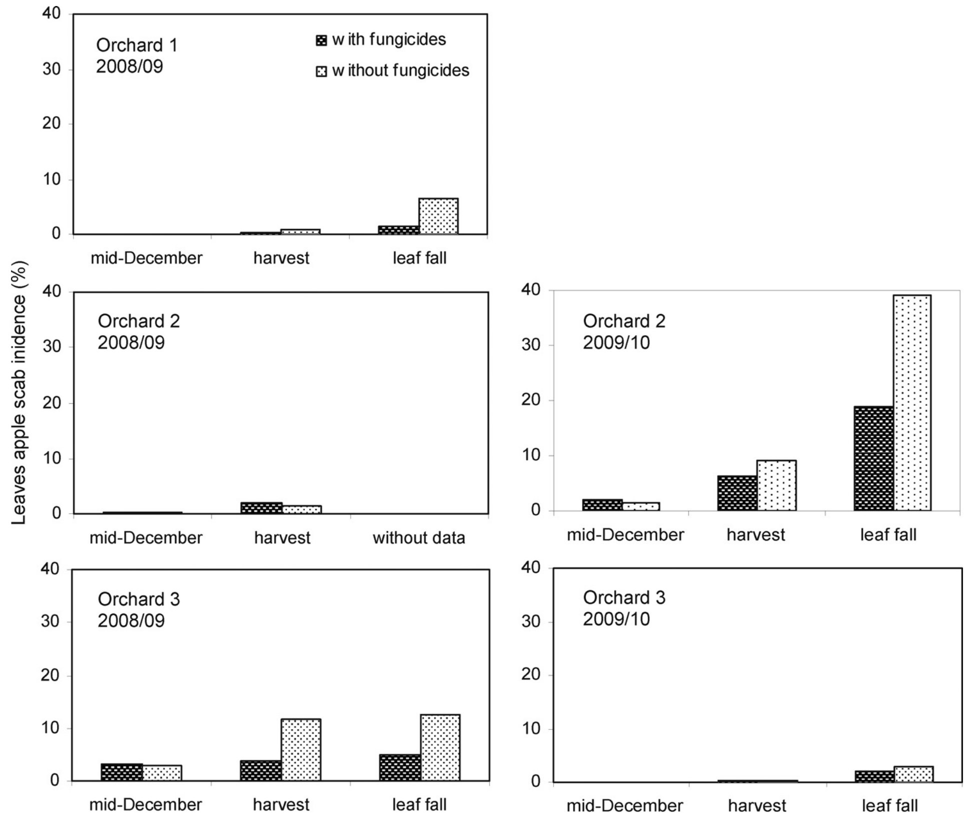

Fig. 1. Apple scab incidence assessed on leaves in three apple orchards planted with cultivars of Red Delicious during two seasons (2008/09 and 2009/10).

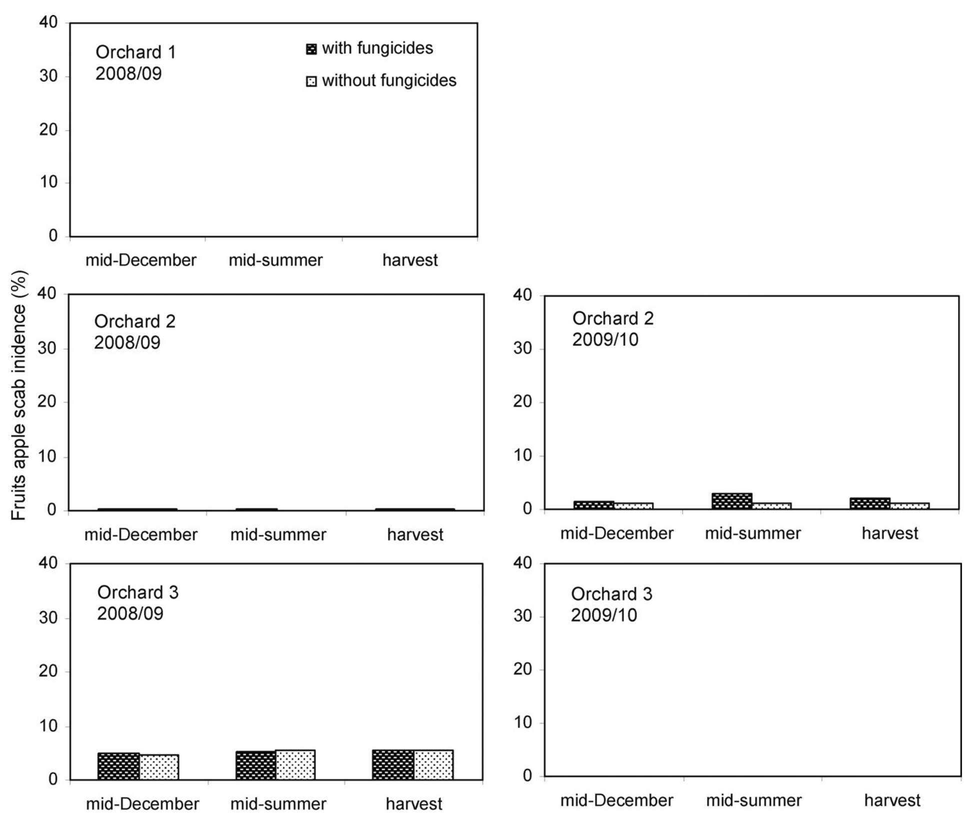

Fig. 2. Apple scab incidence assessed on fruits in three apple orchards planted with cultivars of Red Delicious during two seasons (2008/09 and 2009/10).

Table 3
Temperature and rainfall data registered in a local weather station located within 12 km from the commercial orchards evaluated during two seasons (2008/09 and 2009/10).

Weather events	Season							
	2008/09				2009/10			
	Dec.	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.
Accumulated rainfall (mm)	45	125	87	536	146	34	133	20
No. of rainfall events	5	7	10	17	10	7	14	5
No. of rainfall events over 10 mm	2	2	3	11	4	2	6	1
Average temperature (°C)	20.2	22.1	21.2	20.8	20.5	22.9	21.5	20.6
Average maximum temperature (°C)	26.3	27.9	26.7	25.4	25.6	29.5	27.0	26.6

apple scab incidence was 4.80 and 4.60% with and without fungicide spray respectively in mid-December, and 5.60 and 5.40% with and without fungicide spray respectively at harvest (Fig. 2).

Conducive weather conditions for apple scab were present in both summer seasons. Abundant precipitations were registered with a minimum of 5 rainfall events in each month and at least 1 of them was over 10 mm. Average monthly temperature were around of 22 °C (Table 3). From 2 to 5 treatments with captan were applied from December 15th in the treatments with summer fungicide spray (Table 1).

3.2. Apple scab assessment on storage fruits

No apple scab lesions were observed in any of the fruits harvested from summer sprayed or un-sprayed orchards in the three orchards evaluated during the two seasons and stored on regular atmosphere during three, six or eight months.

4. Discussion

Apple scab has been widely studied worldwide; however, in most areas where apple is produced, the management of this disease requires large amounts of fungicide applications from green-tip to harvest (Gadoury et al., 1989; Mondino et al., 2003; Carisse and Jobin, 2012). Traditionally, epidemiological studies have been focused on primary infections because apple scab development depends mainly on infections generated from ascospores (MacHardy, 1996). Nevertheless, during the last years more attention has been placed in secondary infections (Holb et al., 2005; Holb, 2008; Carisse et al., 2009; Carisse and Jobin, 2012).

In this work, fungicide elimination to control secondary infection of apple scab during the summer in commercial apple orchards planted with cultivars of Red Delicious was evaluated. Increases in apple scab on leaves were observed in all orchards evaluated, but this increase happened regardless of fungicide treatments. The ontogenic resistance proposed by MacHardy (1996) prevents the development of new infections in adult leaves; however, the presence of young leaves during the summer can host new infections caused by conidia. Rainfalls during both seasons were relatively abundant and conducted the development of secondary cycles in young leaves. This increase in scab leaf infections also shows that the summer fungicide sprays carried out by the farmers, were not properly performed to avoid the increase of scabbed leaves. In Uruguay, primary apple scab in spring is managed with protectant fungicide applications performed according to weather forecasts based on the probability of rainfall; and curative fungicide applications based on Mill's apple scab infection table (Mills and LaPlane, 1951). The conditions for ascospore infections are provided to the farmers by the warning system of the Plant Protection Service of the Ministry of Agriculture and Fisheries of Uruguay. The end of ascospore discharge finishes at the end of spring, so summer infections can only be caused by conidia from active scab lesions (MacHardy, 1996). During the summer, there is no warning systems for conidia infections and weather forecasts are quite inaccurate because summer rain events are difficult to predict. As a result, fungicide applications during the summer are not always timely made and in some cases are applied together with insecticide after the rain, based on insect risk damage.

The elimination of summer fungicides spray implies more scabbed leaves in the fall compared with orchard treated with fungicides; nevertheless, this increase does not involve a gradual build-up of *V. inaequalis* inoculum and a higher potential risk of this disease in the following years. An example of this is the orchard 3 in which the percentage of apple scab lesions in leaves and fruits in the fall of 2010 was lower than in the previous fall. Apple scab is a polycyclic disease and the success of the control is mainly based on the management of disease through the season and less in control of the initial inoculum.

Moreover, no increases of scabbed fruit during the summer were observed in the orchards evaluated and in both the seasons, the ontogenic resistance prevented the establishment of secondary cycles in fruit (Schwabe et al., 1984). Holb (2008) and Carisse and Jobin (2012) evaluated the removal of fungicide applications during the summer in Hungary and Canada, respectively. Contrary to our studies, they only could reduce the number of fungicide treatments because the high risks of increasing of the apple scab in fruit and leaves during the summer. The weather conditions in these countries are much more conducive to the development of apple scab. The number and quantity (mm) of rains during the experiment conducted in Canada were much more abundant than during the experiments conducted in Uruguay. As a result, the number of fungicide spray performed during the summer in the treatments with standard practices were between 7 and 11, more than double that in Uruguay (Carisse and Jobin, 2012).

Based on our results, the elimination of fungicide sprays to control apple scab from mid-December can be proposed for Uruguayan conditions. This strategy is suggested for apples that are harvested from January (like cultivars of Gala) to March (like cultivars of Red Delicious) and implies a reduction of up to 5 fungicides sprays (until 30% less fungicides/ha each season). This proposed management is in accordance with Integrated Fruit Production directives which aim among other aspects, the reduction in pesticide use is a desired output of the farming systems (Malavolta and Cross, 2009).

Uncited references Q3

MacHardy et al., 1993.

Acknowledgment

The authors are grateful to the farmers who provide the apple orchards where the experiments were performed.

Please cite this article in press as: Alaniz, S., et al., Elimination of summer fungicide sprays for apple scab (*Venturia inaequalis*) management in Uruguay. Sci. Hortic. (2013), http://dx.doi.org/10.1016/j.scienta.2013.11.016

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.scienta.2013.11.016.

References

Biehn, W.L., Williams, E.B., Kué, J., 1966. Resistance of mature leaves of *malus atrosanguinea* 804 to *Venturia inaequalis* and *Helminthosporium carbonum*. Phytopathology 6, 588–589.

Bowen, J.K., Mesarich, C.H., Bus, V.G., Beresford, R.M., Plummer, K.M., Templeton, M.D., 2011. *Venturia inaequalis*: the causal agent of apple scab. Mol. Plant Pathol. 12, 105–122.

Carisse, O., Meloche, C., Boivin, G., Jobin, T., 2009. Action thresholds for summer fungicide sprays and sequential classification of apple scab incidence. Plant Dis. 93, 490–498.

Carisse, O., Jobin, T., 2012. Managing summer apple scab epidemics using leaf scab incidence threshold values for fungicide sprays. Crop Prot. 35, 36–40.

Cooley, D.R., Autio, W.R., 1997. Disease-management components of advances integrated pest management in apple orchard. Agric. Ecosyst. Environ. 66, 31–40.

Gadoury, D.M., MacHardy, W.E., Rosenberger, D.M., 1989. Integration of pesticide application schedules for disease and insect control in apple orchards of the northeastern United States. Plant Dis. 73, 98–105.

Jobin, J., Carisse, O., 2007. Incidence of myclobutanil- and kresoxim-methyl-insensitive isolates of *Venturia inaequalis* in Quebec orchard. Plant Dis. 91, 1351–1358.

Holb, I.J., 2008. Timing of first and final sprays against apple scab combined with leaf removal and pruning in organic apple production. Crop Prot. 27, 814–822.

Holb, I.J., Heijne, B., Withagen, J.C.M., Gáll, J.M., Jeger, M.J., 2005. Analysis of summer epidemic progress of apple scab at different apple production systems in the Netherlands and Hungary. Phytopathology 95, 1001–1020.

Köller, W., Parker, D.M., Turechek, W.W., Avila-Adame, C., Cronshaw, K., 2004. A two-phase resistance response of *Venturia inaequalis* populations to the QoI fungicides kresoxim-methyl and tryfloxystrobin. Plant Dis. 88, 537–544.

Köller, W., Wilcox, W.F., 2001. Evidence for predisposition of fungicide-resistant isolates of *Venturia inaequalis* to a preferential selection for resistance to other fungicides. Phytopathology 91, 776–781.

Köller, W., Wilcox, W.F., Barnard, J., Jones, A.L., Braum, P.G., 1997. Detection and quantification of resistance of *Venturia inaequalis* populations to sterol demethylation inhibitors. Phytopathology 87, 184–190.

Köller, W., Wilcox, W.F., Jones, A.L., 1999. Quantification, persistence, and status of dodine resistance in New York and Michigan orchard populations of *Venturia inaequalis*. Plant Dis. 86, 66–70.

MacHardy, W.E., Gadoury, D.M., Rosenberger, D.A., 1993. Delaying the onset of fungicide programs for control of apple scab in orchard with low potential ascospore dose of *Venturia inaequalis*. Plant Dis. 77, 372–375.

MacHardy, W.E., 1996. Apple Scab: Biology, Epidemiology, and Management. APS Press, St. Paul, MN, USA, pp. 545.

MacHardy, W.E., Gadoury, D.M., Gessier, C., 2001. Parasitic and biological fitness of *Venturia inaequalis*: relationship to disease management strategies. Plant Dis. 85, 1036–1051.

Malavolta, C., Cross, J., 2009. Guidelines for Integrated Production of Pome Fruit, Technical Guideline III, 47., 4th ed. Bulletin OILB srop, 2008.

Mills, W.D., LaPlane, A.A., 1951. Disease and insect in the orchard. Cornell University Extension Bulletin, pp. 100, 630.

Mondino, P., Alaniz, S., Leoni, C., 2003. Racionalización y Reducción del uso de Fungicidas en el Control de la Sarna del Manzano Ocacionada por Venturia Inaequalis. In: Producción Integrada en Uruguay: claves de un sistema amigable con el medio ambiente que permite obtener frutas y hortalizas de alta calidad, PREDEG/GTZ, Montevideo, Uruguay, 258, pp. 119–121.

Mondino, P., Alaniz, S., 2009. Bowen Manejo Integrado de la Sarna del Manzano. In: Stadnik, M. (Ed.), Manejo Integrado de Doencas da Macieira, 227, 1st ed. CCA-UFSC, Florianopolis, Brasil, pp. 35–44.

Scatoni, B., Mondino, P., Leoni, C., Nuñez, S., Buschiazzo, M., Merino, N., De Lucca, R., Moizo, A., Ferrando, N., Telis, V., 2004. Programa de Producción Integrada Frutícola, Directivas Zona Sur-Uruguay. Facultad de Agronomía., pp. 46.

Schwabe, W.F., 1982. Wetting and temperature requirements for infection of mature apples by *Venturia inaequalis* in South Africa. Ann. Appl. Biol. 100, 415–423.

Schwabe, W.F., Jones, A.L., Jonker, J.P., 1984. Changes in the susceptibility of developing apple fruit to *Venturia inaequalis*. Phytopathology 74, 118–121.

Tomerlin, J.R., Jones, A.L., 1983. Development of apple scab on fruit in the orchard and during cold storage. Plant Dis. 67, 147–150.

Xu, X.M., Robinson, J., 2005. Modelling the effect of wetness duration and fruit maturity on infection of apple fruit of Cox's orange pippin and two clones of Gala by *Venturia inaequalis*. Plant Pathol. 54, 347–356.