Research on spray and atomiser fungicide application systems for use on plum pack lines

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INTRODUCTION

When this study commenced in 2010, Rovral Aquaflo, with the active ingredient Iprodione, was registered as a postharvest fungicide atomiser application for plums in SA. The basics of the atomiser system in use were derived from research done by Taylor, Dodd and Chambers (1992). Although decay control was fairly good, residues on fruit were sometimes inconsistent. This resulted in storage decay if residues were too low; and rejections of consignments of export plums if residues were too high. In an endeavour to improve efficacy of the atomiser system used in the industry, it was decided to evaluate electrostatic spray technology, similar to that introduced for pre-harvest table grape sprays. The intention was to modify or develop application methods and guidelines in an iterative process, until more efficient decay control could be realiSed for plums.

The objective of this research was therefore, to develop alternative post-harvest fungicide application options for use on plum pack-lines, with the specific aims to reduce and achieve more consistent residues, and to improve decay control. While it is common knowledge that fungicide dip applications are more effective than atomisers in controlling decay (Taylor, Dodd and Chambers, 1992), it was more appropriate - from a practical point of view - to focus on systems easy to use on pack lines.

MATERIALS AND METHODS

Background

The standard postharvest fungicide application for plums in SA, in 2010, involved use of atomisers to deliver a relatively high concentration of Iprodione (5600 ppm) at low volume (1.1 ml/kg fruit). En-route over the pack line, fruit was rotated under the atomiser heads on rollers.

Experimental process

To ensure the presence of decay, export quality plums sourced from commercial pack houses at optimum harvest maturity were inoculated with spores of *Botrytis cinerea*. Attempts were made to procure fruit not treated with pre-harvest fungicides. Postharvest fungicides were applied to fruit passed under the application systems on rotating rollers. The plums were cold stored, using the simulated cultivar specific export storage regime. To establish decay control efficacy, fruit was examined at the end of storage, which was typically around five weeks. Non-inoculated fruit was used to determine fungicide coverage and residues at time of treatment.

Inoculation procedure

Five cartons of plums, each comprising a replicate with a single tray (33-39 plums) were used per application treatment. The plums were wounded with a sterile needle (2 x 2 mm) and inoculated with *Botrytis cinerea* spore suspensions of 10,000 spores/ml. The various fungicide application treatments were applied after an incubation period of 3 hours at 20°C. Control fruit were wounded and inoculated, but treated with water.

Efficacy of fungicide application systems

Examining fruit for coverage by the solutions helped with assessment of the overall efficacy of the fungicide application treatments. The residues achieved and the decay control efficacy are described below:

Assessment of fungicide coverage at time of treatment:

Twelve fruit per replicate were randomly selected from the pack line, after applying SARDI fluorescent pigment (Furness, 2000) through the application system. Assessments were done at the Department of Plant Pathology at the University of Stellenbosch,

using a deposition assessment protocol of fluorometry, digital macro-photography and image analyses. Foreground elements were quantitatively calculated in percentage coverage of spray cover; and for qualitative analysis a statistical indication of spray deposition quality was calculated. In some instances, water-sensitive paper was also used to obtain a visual of deposition quantity and pattern.

Residue analysis on fruit immediately after treatment:

Fungicide residues were determined on three replicates of 20 fruit each per treatment, by Hearshaw and Kinnes Analytical Laboratory. Residue results are presented as averages.

Decay control efficacy after storage was established by determination of:

- Decay incidence - by counting the number of infected fruit and expressing this as a percentage of the total number of inoculated fruit examined.
- Decay severity - by measuring the size of the lesions and expressing this as an average lesion size for all fruit per replicate, in millimetres.
- Sporulation index - by multiplying the incidence of decay by the sporulation rating and expressing this as a percentage of the maximum if all fruit exhibited severe sporulation.

The sporulation classification was as follows:
no sporulation = 0, s
light sporulation = 1,
medium sporulation = 2
and severe sporulation = 3.

Fungicide application systems evaluated

The fungicide application systems tested were selected on an iterative basis, as follows:

- Standard atomiser (STD-Atom) and Electrostatic spray (ESS).
- Standard atomiser (STD-Atom) and High volume spray (HV-Spray).
- Standard atomiser (STD-Atom) and High volume spray (HV-Spray) and High volume atomiser (HV-Atom).

RESULTS AND DISCUSSION

Standard atomiser and Electrostatic spray fungicide application systems.

On Laetitia plums (Table 1), Iprodione was applied on a roller system using a STD-Atom at a spray volume of 1.1 ml/kg fruit, while 4.6 ml/kg of fruit was used for the ESS, as this was the lowest rate possible with the system. A good description of

Table 1: *Postharvest decay control using standard atomiser (STD-Atom) and electrostatic spray (ESS) systems to apply Iprodione to Leatitia plums, which were inoculated with* Botrytis cinerea *spores, prior to treatment and examined after simulated export storage.*

Application System	Fungicide	Fungicide Concentration (ppm)	Fungicide Volume (ml/kg fruit)	Iprodione Residue (ppm)	Parameters[2]		
					Decay Incidence (%)	Decay Severity (mm)	Sporulation Index (%)[4]
Control[3]	Water	0 - Control	1.1	0.2	86.5a	25.1a	15.1a
STD-Atom	Iprodione	5600	1.1	1.9	71.7a	22.5a	10.0a
ESS	Iprodione	5600	4.6	6.3	23.7b	8.4b	3.1b
Prob.>F[1]					***	***	**

[1] *One-way ANOVA table where NS, *, **, and *** represent non-significant or significant at the 5%, 1% or 0.1% level, respectively.*
[2] *Values in the same Decay Parameter column followed by different letters indicate significant differences (P<0.05) according to the LSD test.*
[3] *Control was water applied through a standard atomiser system.*
[4] *Sporulation index: No sporulation = 0, slight sporulation = 1, medium sporulation = 2, and severe sporulation = 3*

Table 2: *Postharvest decay control using standard atomiser (STD-Atom) and electrostatic spray (ESS) systems to apply Iprodione to Southern Belle plums, which were inoculated with* Botrytis cinerea *spores prior to treatment and examined after simulated export storage.*

Application System	Fungicide	Fungicide Concentration (ppm)	Fungicide Volume (ml/kg fruit)	Iprodione Residue (ppm)	Parameters[2]		
					Decay Incidence (%)	Decay Severity (mm)	Sporulation Index (%)[4]
Control	Water[3]	0 - Control	4.6	0.0	99.2a	60.0a	98.4a
STD-Atom	Iprodione	5600	4.6	3.1	97.2a	50.6b	96.1ab
ESS	Iprodione	5600	4.6	2.6	99.2a	49.6b	91.4b
Prob.>F[1]					NS	***	*

[1-4] *For definition see Table1*

electrostatic technology was recently published by Patel et al. (2015).

The quantitative spray coverage on Laetitia plums was significantly better with the ESS than the STD-Atom, with a fluorescence of 1.0 % and 0.4 %, respectively. By contrast, the qualitative spray deposit achieved using the ESS was inferior due to high variance (data not shown). Traces of Iprodione occurred on the control fruit probably due to orchard sprays (Table 1). Average Iprodione residues of 1.9 ppm and 6.3 ppm were obtained using the STD-Atom and ESS systems, respectively. The residue achieved with the ESS system, was more than double the permissible limit of 3 ppm and this was ascribed to better quantitative spray coverage. No significant differences in decay inhibition occurred between the Control and the STD-Atom treatments, while the ESS exhibited significantly less decay than both these treatments.

To compare these application systems properly, it was necessary to affect better quantitative fungicide coverage with the STD-Atom and reduce residues deposited on fruit with the ESS. To achieve this, the volume of fungicide delivered by STD-Atom was increased from 1.1 to 4.6 ml/kg fruit, and the atomiser heads on the ESS were raised from 650 to 900 mm above the rollers.

Trials were continued on Southern Belle plums (Table 2). Coverage analysis revealed that the changes made had the desired effect, since the quantitative spray deposition on fruit treated with the STD-Atom increased to 1.1 % fluorescence, and reduced to 0.4 % on fruit treated with the ESS (data not shown). As a result, Iprodione residues on fruit treated with the two applicators were similar, at 3.1 ppm for the STD-Atom and 2.6 ppm for the ESS. Under these conditions, the STD-Atom gave superior quantitative but inferior qualitative coverage than the ESS. Decay control by either system was not good on Southern Belle. However, for decay severity and sporulation, the ESS gave better inhibition of decay than the STD-Atom, compared to the Control. No significant differences in decay occurred between the application systems. Similar to the test on Laetitia (Table 1), the STD-Atom gave inadequate control of *Botrytis* decay using Iprodione. Whether or not this was due in part to *Botrytis* resistance to Iprodione was not established.

Since the ESS did not significantly improve decay control compared to the STD-Atom adapted to deliver high fungicide volume; and because similar residues on fruit were achieved, it was decided to proceed by testing a HV-Spray applicator system against the ESS.

Standard atomiser and High volume spray fungicide application systems

Following promising pilot trials in the laboratory with high volume sprays, it was decided to design and build a system for evaluation in a commercial pack line. A HV-Spray applicator was manufactured by Vizier Systems (Pty) Ltd. It consisted of a 3 bar 0.55 kW electric motor and pump with a 150 mesh filter.

Table 3: *Postharvest decay control using standard atomiser (STD-Atom) and high volume spray (HV-Spray) systems on Southern Belle plums, which were inoculated with* Botrytis cinerea *spores prior to treatment and examined after simulated export storage.*

Application System	Fungicide	Fungicide Concentration (ppm)	Fungicide Volume (ml/kg fruit)	Iprodione Residue (ppm)	Parameters[2]		
					Decay Incidence (%)	Decay Severity (mm)	Sporulation Index (%)[4]
STD-Atom	Water[3]	0 - Control	1.1	0.0	97.6a	31.1a	48.1a
STD-Atom	Iprodione	5600	1.1	0.3	89.2ab	25.3ab	20.7b
HV-Spray	Iprodione	500	Run Off	2.0	72.0c	17.6c	10.7b
HV-Spray	Iprodione	250	Run Off	0.9	79.1bc	19.9cb	8.0b
Prob.>F[1]					***	***	***

[1-4] *For definition see Table1*

An Enviroguard 110-LD-04 spray nozzle was used and the application rate was 1.31 L/min at a pressure of 2 bars. This ensured the fruit was fully covered with fungicide. Excess fungicide was recirculated by catching it in a chute. From the chute the fungicide drained into a holding tank from where it was pumped via a filter into the nozzle. An Exair Super 450 mm air knife was used to assist in drying the fruit after application.

Pack line testing of the HV-Spray system was done using 500 ppm and 250 ppm Iprodione compared to 5600 ppm with the STD-Atom as industry reference (Table 3). Average Iprodione residues of 2.0 ppm were obtained with the HV-Spray at 500 ppm fungicide concentration, while the HV-Spray at 250 ppm gave a residue of 0.9 ppm. For some unknown reason the STD-Atom gave a low residue of 0.3 ppm.

Decay incidence and severity were reduced with the HV-Spray at both Iprodione concentrations, compared to the STD-Atom (Table 3). The reduction was significant for the 500 ppm treatment. Compared to the Control, sporulation was significantly reduced by the HV-Spray at both concentrations of Iprodione and also by the STD-Atom treatment.

These results indicated that the HV-Spray at 500 ppm Iprodione concentration should give better decay control than the STD-Atom system used commercially. As with the previous tests, the STD-Atom with Iprodione had limited effect on Botrytis decay inhibition. The principle behind the concept of the HV-Spray was to increase the volume of product applied to the fruit, to improve coverage and enable use of lower fungicide concentrations. While this was achieved, the fruit was still very wet after treatment, despite using an air knife and fans to dry it. In addition to this drawback, pack house managers expressed concern about the HV-Spray system, because the fungicide in the recirculation system became dirty very quickly, so that a host of associated problems were anticipated. Consequently, it was felt that a cost effective alternative to the HV-Spray may be to simply increase the volume of the fungicide applied with the STD-Atom; and to adjust the fungicide concentration to attain residue results similar to the HV-Spray system. The advantage of this would be continued use of current atomiser systems in pack houses, without the need to change to expensive, new systems. Therefore, it was decided to test standard atomisers with adjusted fungicide volumes and concentrations as the final phase of this research.

Standard atomiser and high-volume spray; and High volume atomiser fungicide application systems.

The standard volume of 1.1 ml Iprodione per kg fruit for atomisers, was compared to volumes of 2 ml/kg and 3 ml/kg at concentrations of 5600 and 2250 ppm for each volume tested (Table

Table 4: *Postharvest decay control using standard atomiser (STD-Atom), high volume spray (HV-Spray) and atomiser modified to deliver high volumes (HV-Atom), to apply Iprodione and Fludioxonil to Songold, Laetitia and Angeleno plums. These were inoculated with* Botrytis cinerea *spores prior to treatment and examined after simulated export storage.*

Cultivar (FACTOR A)	Application System (FACTOR A)	Fungicide	Fungicide Concentration (ppm)	Fungicide Volume (ml/kg fruit)	Iprodione Residue (ppm)	Parameters[2]		
						Decay Incidence (%)	Decay Severity (mm)	Sporulation Index (%)[4]
Songold	Control[5]	Water	0	1.1	0.48	100.0a	37.9a	33.9a
	HV-Spray	Iprodione	500	Run off	0.81	100.0a	35.7ab	26.3abc
	STD-Atom	Iprodione[5]	5600	1.1	1.92	100.0a	37.3a	23.8abc
	STD-Atom	Iprodione	2250	1.1	0.80	100.0a	35.1ab	27.4ab
	HV-Atom	Iprodione	5600	2.0	1.76	98.9a	36.0ab	27.6ab
	HV-Atom	Iprodione	2250	2.0	2.86	100.0a	37.0a	20.2bc
	HV-Atom	Iprodione	5600	3.0	4.57	98.9a	33.4b	25.6abc
	HV-Atom	Iprodione	2250	3.0	5.19	100.0a	32.8bc	14.5c
	STD-Atom	Fludioxonil	1909	1.2	0.54	91.8b	29.6c	0.0d
Laetitia	Control[5]	Water	0	1.1	0.86	100.0a	34.3a	13.5a
	HV-Spray	Iprodione	500	Run off	0.80	100.0a	29.2bc	9.7a
	STD-Atom	Iprodione[5]	5600	1.1	3.34	97.9a	27.8bc	6.8ab
	STD-Atom	Iprodione	2250	1.1	0.21	100.0a	25.6cd	7.6ab
	HV-Atom	Iprodione	5600	2.0	2.45	98.2a	31.3ab	7.2ab
	HV-Atom	Iprodione	2250	2.0	2.87	98.9a	29.4bc	9.7a
	HV-Atom	Iprodione	5600	3.0	3.10	100.0a	29.7abc	9.2a
	HV-Atom	Iprodione	2250	3.0	3.79	95.7a	26.5cd	5.8ab
	STD-Atom	Fludioxonil	1909	1.2	0.50	66.7b	22.1d	0.3b
Angeleno	Control[5]	Water	0	1.1	0.11	98.9ab	32.7a	3.0a
	HV-Spray	Iprodione	500	Run off	0.50	97.1abc	27.8a	2.2a
	STD-Atom	Iprodione[5]	5600	1.1	1.64	99.1ab	32.0a	3.5a
	STD-Atom	Iprodione	2250	1.1	1.32	95.0abc	34.5a	2.3a
	HV-Atom	Iprodione	5600	2.0	3.12	100.0a	20.3a	7.0a
	HV-Atom	Iprodione	2250	2.0	2.23	93.3abc	29.2a	3.9a
	HV-Atom	Iprodione	5600	3.0	3.30	96.5abc	30.3a	1.5a
	HV-Atom	Iprodione	2250	3.0	2.25	93.1bc	33.1a	3.8a
	STD-Atom	Fludioxonil	1909	1.2	0.50	91.3c	22.8a	0.0a
Prob>F[1]				Factor A		***	***	***
				Factor B		***	***	***
				AXB		***	*	***

[1] *Two-way ANOVA table, where Factor A represents (Application Treatment) and Factor B (Cultivar). Non-significant (NS), significant for P<0.05(*), P<0.01(**) or P<0.001 (***).*

[2] *Only non-pooled data is shown because interactions were significant across all Decay Parameters. Values in same Decay Parameter column per Cultivar followed by different letters indicate significant differences (P<0.05), according to the LSD test.*

[4] *Sporulation Index: No sporulation = 0, slight sporulation = 1, medium sporulation = 2* | [5] *STD-Atom at 5600 ppm and 1.1 ml/kg fruit represented Industry Reference.*

4). Across the three cultivars used for testing, in five of the nine possible Iprodione treatment permutations in this trial, the higher concentration of 5600 ppm resulted in higher residues on the fruit. Generally, the increase in the volume of fungicide also increased the Iprodione residue on the fruit, but to the extent that it may lead to residues higher than the MRL of 3.0 ppm. Consequently, an increased volume of Iprodione applied through standard atomisers could not be recommended, even at 2500 ppm.

Fludioxonil, the active ingredient in the fungicides Scholar and Teacher, was included as a treatment applied through STD-Atom (Table 4). Fludioxonil reduced decay incidence, lesion size and sporulation significantly compared to the control, as well as most of the Iprodione treatments. In addition, at an average of 0.5 ppm, Fludioxonil residues were consistently well below the residue limit of 5 ppm. This treatment consistently reduced decay incidence, severity and sporulation across cultivars without exceeding the residue limit, making it the obvious choice for commercial control of *Botrytis* decay. Further research to establish broad spectrum decay control was suggested

Conclusions

Research conducted from 2010 to 2014, suggested that inhibition of *Botrytis* decay on plums, using standard atomisers to deliver 5600 ppm Iprodione at a volume of 1.1 L/Ton fruit was probably insufficient for fruit intended for export by sea. It must be stated that these were rigorous tests - more severe than commercial conditions - because fruit was inoculated with very high spore loads before treatment with fungicides. An electrostatic spray system was evaluated, but did not improve decay control compared to the standard atomisers adapted to deliver high fungicide volumes. Consequently, a high volume spray system was tested. While this system gave significantly improved inhibition of *Botrytis* decay, it was unfortunately non-viable commercially, because fruit was unacceptably wet after treatment. In addition, pack house managers expressed concern because the solution in the recirculation system became dirty quickly, and it was anticipated that this could lead to a number of problems. In an attempt to achieve decay control similar to the high volume spray, but without the drawbacks, the standard atomisers used in industry were evaluated using different volumes and concentrations of Iprodione. While success was achieved in the sense that residues and associated decay control were improved, the risk of exceeding the residue limits for Iprodione applied at higher than 1.1 mg/kg fruit, was too high to allow commercial recommendation. It was found that Fludioxonil, applied as per label, using the standard atomiser at an application rate of 10 ml/100 L water on 1000 kg fruit gave better control of *Botrytis* decay, with residues well within the 5 ppm limit for plums. This equates to 8.8 ml per 100 L water at a volume of 1.2 L/Ton of fruit.

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