The effect of rainfall on copper spray residues on kiwifruit foliage, fruit and canes

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Abstract Copper sprays are known to have protectant activity against the bacterial disease *Pseudomonas syringae* pv. *actinidiae* (Psa), but their longevity on kiwifruit vines was unknown. Commercial copper sprays were applied using a moving head tracksprayer to the fruit, foliage and canes of Hayward kiwifruit after which simulated rain was applied in incremental amounts up to 100 mm. The copper sprays were moderately resistant to rain wash-off on leaves with at least 25 mm of rain required to remove 50% of the initial residues. Copper sprays applied to both kiwifruit canes and fruit were highly resistant to rain wash-off with up to 100% of the initial spray deposits still present after 50 mm of rain. Up to four sequential copper sprays on fruit are unlikely to exceed maximum residue limits for fruit even in the absence of rain.

Keywords copper sprays, residues, rain resistance, kiwifruit.

INTRODUCTION

The infection of kiwifruit by *Pseudomonas syringae* pv. *actinidiae* (Psa) occurs via airborne bacteria and infects through natural apertures (e.g. stomata) and wounds on leaves and vines. Control of this bacterial disease is difficult and options are limited. These options consist mainly of reducing inoculum through good orchard hygiene and protecting the plant during the main infection periods in spring and autumn (Vanneste et al. 2011). The risk of infection can be reduced by the use of protectant copper sprays (KVH 2012), but their longevity on kiwifruit was unknown. Copper residues have shown good longevity and resistance to rain wash-off on species such as citrus and field bean, but this was not found to be correlated with the availability of much lower concentrations of free Cu^{2+} ions, which were toxic to *P. syringae* (Menkissoglu & Lindow 1991). Overuse of copper sprays can lead to development of copper-resistant bacterial strains and increase the risk of phytotoxic damage to fruit and foliage (L.G. Hawes, HortEvaluation Ltd, unpublished data). In addition, excessive use of copper may result in unacceptable residues in fruit thereby creating market access issues.

The studies reported here were the first investigations into copper residue longevity on kiwifruit vines as a result of sprays applied to control Psa. They were undertaken to determine how rainfall affects residues: (1) on fruit after single and multiple applications of commercial copper sprays, (2) on upper and lower leaf surfaces after a single dilute spray application and (3) similarly on young replacement and aged canes.

MATERIALS AND METHODS

Fruit and foliage were sampled in March/April from Hayward blocks that had received no copper sprays during that season (S. Max, Zespri, personal communication). Foliage was harvested on the day of the trial, and fruit was sampled, stored at 4°C and used within 24 h. All plant material was handled with gloves. Dormant canes, both old and replacement (young) wood, were sampled in June from similar blocks, stored at 4°C and used within 4 days.

In preparation for spraying, fruit samples (100 replicates per treatment) were mounted upside down on nails such that they were not touching or vertically shaded by each other. Leaves were mounted on chicken wire mesh supports at 45 degree angles, with either the adaxial or abaxial surface facing upwards (50 replicates of each per treatment). Canes (50 replicates per treatment) were trimmed to 40 cm lengths and balanced and secured across packing trays, such that they were not touching or shaded by each other.

Chemicals used were Nordox 75WG (750 g/kg cuprous oxide, Gro-Chem), Kocide Opti (300 g/kg copper hydroxide, Du Pont), Champ DP (375 g/kg copper hydroxide, Nufarm) and Bordeaux (10.8.1000) mix, at varying copper rates as prescribed commercially (Table 1). Sprays were also applied, to fruit only, at four times the recommended rate to simulate the maximum residues from four consecutive spray applications. Treatments were applied as specified (S. Max, Zespri, personal communication) in dilute volumes without adjuvants; for fruit and foliage, and also for Bordeaux mix applied to canes, this was at 2000 litres/ha, and for all other cane applications it was 600 litres/ha. Sprays were applied at ambient temperature using a calibrated moving head tracksprayer with nozzles mounted 1.5 m above the targets to ensure droplets were at maximum velocity at impact, to best approximate an airblast application. The 2000 litres/ha treatments were applied through a twin-cap nozzle containing two 8004EVS nozzles (Spraying Systems Co.) at 150 kPa pressure. The 600 litres/ha treatments were applied with two TX12 nozzles (Spraying Systems Co.) mounted 50 cm apart at 250 kPa.

Sprayed fruit and canes were left to dry overnight under cover in ambient conditions, while sprayed leaves were left for only 2 h to dry. Some slight leaf curling occurred during this time and any leaves exhibiting this were flattened and secured with clothes pegs prior to rain being applied. Rain was applied through a calibrated overhead sprinkler system (Spinnet™ bridgeless micro-sprinklers, 3 m apart, 1.5 m above target, producing an even distribution of large rain-like droplets over a flat distribution of 3.5 m radius) to targets at 10 mm/h, which equates to a moderately heavy rain event (Keeney & Valcore 1996), for varying time intervals up to 10 h. Rain intensity was determined empirically with measuring cylinders and funnels adjacent to the spray targets.

Fruit and leaves were left to dry for 24 h and 12 h respectively, then bagged and frozen. Leaves were visibly assessed for spray coverage prior to sampling. Unsprayed blank tissues and sprayed tissues that received no rain were also sampled. Each sample, containing either 20 replicate fruit or 10 replicate leaves, was analysed for copper residues (R J Hill Laboratories) as per standard Zespri protocols. Post-rain residue data were compared with copper deposits on fruit and foliage that had received no rain to determine maximum residues (as ppm of fresh weight) remaining after the nominated rain events. No statistical tests were possible as replicate tissues were bulked for a single residue analysis for each treatment, tissue, rainfall combination.

Canes were left to dry for 24 h and then the centre section of each cane was sub-divided into two 15 cm samples that were placed in separate re-sealable plastic bags (10 replicates per bag). Samples were weighed and washed in 1% nitric acid for 30 min, then filtered through a Millipore AP25 glass fibre filter and analysed for copper (R J Hill Laboratories). Unsprayed blank canes and sprayed canes that received no rain were also sampled and processed similarly. Copper residues were determined as ppm of wet cane weight after correction for unsprayed blanks. The mean water content of canes was determined as 49% (CV=4.4%). Post-rain residue data were compared with copper deposits on canes that had received no rain to determine maximum residues remaining after the nominated rain events. The duplicate analysis of each bulked sample was used to confirm the reproducibility of residue results but no statistical tests were possible.

RESULTS AND DISCUSSION

Fruit residues

Copper residues on Hayward fruit were highly resistant to rain wash-off, with residues of all three formulations declining little with up to 50 mm rain (Table 1). A maximum of 30% of applied copper was removed with 25 mm rain and 35% with 50 mm (Table 2). Amounts of spray retained were similar for all three commercial formulations, with zero rain residues generally reflecting the different rates of copper applied (Table 1). Kocide Opti residues declined least as a percentage of original deposits (Table 2) but the difference in rainfastness between formulations is probably not of practical significance. Similar results were obtained using Hort16A fruit (data not presented).

The application of four times the recommended rates of copper did not result in an equivalent increase in residues on fruit. These were in the range of 5-10 ppm in the absence of rain (Table 1). In the EU maximum residue limits for copper are ca 20 ppm, and so all fruit treatments had a considerable safety margin.

Leaf residues

As seen on fruit, the rain-free residues on foliage generally reflected the different rates of copper applied in each spray (Table 1), with the exception

Table 1 Copper residues (ppm) from commercial sprays remaining on Hayward fruit, leaves and canes after increasing rain events.

		Cu	Total rain applied (mm)			
Target	Product	kg/ha	0	25	50	100
Fruit	Nordox	0.83	3.3	3.4	3.0	-
	Kocide Opti	0.39	1.8	1.9	1.6	-
	Champ	0.79	3.7	2.9	2.6	-
Fruit (× 4 rate)	Nordox	3.3	9.6	7.4	7.2	-
	Kocide Opti	1.6	5.0	5.1	5.1	-
	Champ	3.2	10.3	7.1	6.7	-
Fruit blank	-	-	*0.9*	-	-	-
Leaf adaxial	Nordox	0.83	86	47	36	-
	Kocide Opti	0.39	39	19	11	-
	Champ	0.79	66	34	28	-
Leaf abaxial	Nordox	0.83	169	83	57	-
	Kocide Opti	0.39	56	29	22	-
	Champ	0.79	112	71	64	-
Leaf blank	-	-	*3.0*	-	-	-
Cane – young	Nordox	0.83	4.7	6.2	6.0	5.4
	Kocide Opti	0.39	3.7	2.8	3.1	3.1
	Bordeaux	8.0	47	28	55	44
Young cane blank	-	-	*0.5*	-	-	-
Cane – old	Nordox	0.83	5.0	8.8	4.2	6.2
	Kocide Opti	0.39	3.9	5.1	5.4	4.9
	Bordeaux	8.0	39	26	34	39
Old cane blank	-	-	*2.2*	-	-	-

of Nordox on the abaxial surface. The residues on leaves were far higher than on fruit due to the large capture area of foliage proportional to leaf weight. Surface residues on fruit are diluted by their large mass.

Spray residues were consistently higher on the abaxial (lower) surface relative to the adaxial (upper) surface (Table 1). This was due to run-off of dilute sprays from the moderately easy-to-wet adaxial surface (Gaskin et al. 2005) compared to the large volume-holding capacity of the hairy abaxial leaf surface. Residue wash-off rates were generally similar on both surfaces (Table 2), but the abaxial surface is less exposed to rain wash-off in an orchard environment. The hairs also appeared to protect residues more than on the hairless adaxial surface; accumulation of blue copper spray residues at the leaf margins was less visible on the abaxial than on the adaxial leaf after 25 mm of rain.

The copper sprays were similarly all moderately resistant to rain wash-off from leaves, but less so than on fruit, with at least 25 mm of rain required to remove 50% of the initial residues on leaves (Table 2). A total of 50 mm of rain removed approximately 60-70% of initial copper deposits. Results similar to those reported here for Hayward foliage were also obtained on Hort16A (data not presented).

The total copper deposits on navel orange and bean leaves treated with copper hydroxide have been shown to decrease over time under field conditions, with a half-life of approximately 40 days (Menkissoglu & Lindow 1991), and precipitation did not increase the rate of loss of these residues. The concentration of soluble complexed copper, which had no significant toxicity towards *P. syringae*, increased for up to 30 days following spray application and comprised up to 25% of total copper on these leaves. The

Table 2 Copper residues (as % of initial spray deposits) from commercial sprays remaining on Hayward fruit, leaves and canes after increasing rain events.

Target	Product	Cu kg/ha	Total rain applied (mm) 0	25	50	100
Fruit	Nordox	0.83	100	103	91	-
	Kocide Opti	0.39	100	106	89	-
	Champ	0.79	100	78	70	-
Fruit (x 4 rate)	Nordox	3.3	100	77	75	-
	Kocide Opti	1.6	100	102	102	-
	Champ	3.2	100	70	65	-
Leaf adaxial	Nordox	0.83	100	55	42	-
	Kocide Opti	0.39	100	49	28	-
	Champ	0.79	100	52	42	-
Leaf abaxial	Nordox	0.83	100	49	34	-
	Kocide Opti	0.39	100	52	39	-
	Champ	0.79	100	63	57	-
Cane young	Nordox	0.83	100	138	132	119
	Kocide Opti	0.39	100	72	72	82
	Bordeaux	8.0	100	59	118	93
Cane old	Nordox	0.83	100	238	71	145
	Kocide Opti	0.39	100	174	189	161
	Bordeaux	8.0	100	68	87	99

free Cu^{2+} ion concentration (toxic), which killed *P. syringae* at very low doses, increased with time to a maximum at 10-20 days following application and was up to 10,000 times lower than dissolved (nontoxic) copper concentrations (Menkissoglu & Lindow 1991). These authors also found no relationship between the total amount of copper deposits and the amount of free Cu^{2+} ions on leaves of their two host species. The concentration of free Cu^{2+} ions that will kill Psa on kiwifruit leaves and how total copper deposits relate to these ions is still not understood.

Dormant cane residues

Background copper levels on replacement canes were relatively low because they had never been sprayed with copper (Table 1). In contrast, old canes had received high doses of copper sulphate (24 kg/ha), applied to drop leaves, the previous season(s) and this resulted in highly variable background copper levels on these canes.

There were no large differences in wash-off between young (current season) canes and old (2-year fruiting) canes, although both showed some quite large variations in residues with successive rain events. Copper sprays applied to both young and old canes were highly resistant to rain wash-off (Table 1). After 100 mm of rain more than 80% of initial deposits were still present (Table 2). While Bordeaux mix was applied at 10-20 times the rate of Nordox and Kocide Opti, the rainfastness of all formulations was similar.

CONCLUSION

Commercial copper sprays were moderately resistant to rain wash-off on leaves with at least 25 mm of rain required to remove 50% of the initial deposits. Copper sprays applied to both kiwifruit canes and fruit were highly resistant to rain wash-off with up to 100% of the initial spray deposits still present after 50 mm of rain. Up to four sequential copper sprays on fruit will be unlikely to exceed maximum residue limits for fruit even in the absence of rain. The efficacies of the products tested at the residue levels detected here are unknown because the concentration of total copper, and production of free Cu^{2+} ions, required to control Psa on kiwifruit vines is still to be clarified.

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