FINAL REPORT

An investigation on head rot disease of broccoli crops grown for processing

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Client: Horticulture Australia Ltd

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This report is published by Horticulture Australia Limited, to pass on information concerning horticultural research and development undertaken for the processing vegetable industry in Tasmania.

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Media Summary

In recent years, the production of broccoli produced for processing into frozen vegetable products has increased rapidly. Although head rot disease has been identified by the processors to be a major constraint to processing broccoli production in Tasmania, little is known of the primary causal organisms or pre-disposing factors. This project was therefore aimed at gaining a better understanding of the primary causal organisms, or factors that predispose broccoli to head rot.

This two-year project was funded by McCain Foods (Aust.) Pty Ltd, Simplot Australia Pty Ltd and Nufarm Australia Ltd, with matching funds from Horticulture Australia Limited. The major findings of the four areas of studies examined in this project are summarized as follows:

1. Etiology of head rot

- The potential of bacteria to cause rot on non-wounded heads is determined by two key characteristics, the presence of pectolytic activity and biosurfactant activity. On plants that have thick, waxy surfaces, like broccoli, the water soaking properties of biosurfactant-producing bacteria, help provide entry through natural openings. In addition, as the broccoli head increases in maturity, the partial opening of sepals increases, thereby making them vulnerable to bacterial and fungal invasion.

- In this study, fluorescent pseudomonads were the most common microbes isolated from water soaked and soft head rot lesions. The fluorescent pseudomonads were subsequently identified as *Psuedomonas fluorescens, P. marginalis*, and *P. tolassi.* The pectolytic positive and high biosurfactant producing *P. marginalis* was the most virulent bacteria, capable of causing rot on undamaged heads under humid conditions and without continuous wetting. Other bacteria types require damaged and/or continuous wetting of heads to cause rot.

- Fungi isolated from head rot include *Alternaria*, *Botrytis*, *Cladosporium*, *Fusarium compactum* and *Sclerotinia sclerotiorum*. The most common fungal rots were *Botrytis* and *Sclerotinia*. Fungi such as *Sclerotinia, Botrytis* and *Fusarium* did not appear to require damage for invasion. *Alternaria,* however, can only infect damaged and continuously wet florets, and therefore is likely to be a secondary invader.

2. Surfactant activity of agricultural chemicals

- All of the insecticides commonly used in broccoli crops showed none or very mild surfactant activity. Therefore, a wetting agent was often applied with the insecticide in order to improve wetting and uptake on waxy plant surfaces. Activator and Agral are commonly used in pesticide applications for insect or disease control in horticultural crops in Tasmania.

- At the beginning of this study in 2002, many growers were found to apply these adjuvants at the maximum rates recommended with insecticides on broccoli crops. However, as a result of findings in this study that high rates of these adjuvants may pre-dispose the wet florets to severe head rot, lower rates are recommended for use instead. The minimum rates recommended on labels were shown to be as effective in wetting the florets as higher rates of the adjuvants, with lower risks of bacterial invasion.

Media Summary (Cont.)

3. Bacterial control

- This study showed that all the copper-based products were less effective in the complete inhibition of very high populations of bacteria (in excess of 10^6 – 10^{10} cfu/mL). At the lower bacteria levels of 10^4 cfu/mL and below, complete bacteria inhibition was achieved with the copper treatments. Therefore, copper products are most effective when used as crop protectants to reduce initial bacterial population levels on plant surfaces, thus preventing diseases. They are likely to be less effective when used on a severely infected crop that already has a very high bacteria population.

- Unlike copper products, general disinfectants such as Sporekill and Path-X were shown to be highly effective in eradicating high populations of bacteria. The disinfectants, however, have no residual activities, and hence offer no prolonged protection from bacteria re-colonisation. The use of Sporekill at 0.1%, however, generally increases the incidence of black spots on matured heads, and requires further studies on its effects on plants before commercial use at the late crop stage.

- The frequent use of copper sprays can result in the prevalence of copper tolerant bacteria strains. However, the resistance development by the copper tolerant bacteria strains appears to be quantitative, whereby increasing the toxicity or the availability of free copper ions may still effectively control the copper resistant strains. Improved toxicity and efficacy could be achieved in part with new and better formulations of copper products. Alternatively, copper toxicity may be enhanced with the use of additives that enhance the solubility and uptake of copper ions or that interfere with the bacteria resistance mechanisms.

4. Black spots

- If severe, black spots affect the appearance of the broccoli heads, reducing their quality, as well as increasing the risk of secondary rot after harvest and storage. Black spots appeared to be associated with cell necrosis on the sepals of florets, and were not necessarily related to the bacterial head rot. This symptom increased with head maturity. In our field observations, nutrient deficiency, frost damage, and a prolonged period of wetness on florets tended to increase the incidence of black spots.

- In the presence of frequent frost conditions, copper treatments may have increased the incidence of black spots on the sepals of florets on maturing heads in a field trial. This study also indicated a possible link in concentrations of copper products in spray mixture, whereby higher copper product concentrations with low spray water volume of 210 L/ha tended to increase black spot incidence compared to a high volume spray of 400 L/ha. The pH of different copper products also appeared to be related to the incidence of black spots. No increase in black spot incidence was noted with the alkaline Champ DP, while the slightly acidic Cuprofix MZ tended to cause high incidence of black spots.

- In 2003, the use of the disinfectant Sporekill in mixtures with copper sprays also tended to increase black spot incidence, compared to copper sprays only. This may be related to increased wetting with Sporekill or other possible adverse effects on plant cells on sepals of florets. Therefore, although Sporekill and other disinfectants are highly effective in eradicating or reducing bacteria populations, further investigation is recommended to understand its impact on black spots.

Technical Summary

In recent years, the production of broccoli produced for processing into frozen vegetable products has increased rapidly. Although head rot disease has been identified by the processors to be a major constraint to processing broccoli production in Tasmania, little is known of the primary causal organisms or pre-disposing factors. This project was therefore aimed at gaining a better understanding of the primary causal organisms, or factors that predispose broccoli to head rot.

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1. Etiology of head rot:

- The potential of bacteria to cause rot on non-wounded heads is determined by two key characteristics, the presence of pectolytic activity and biosurfactant activity. On plants that have thick, waxy surfaces, like broccoli, the water soaking properties of biosurfactant-producing bacteria, help provide entry through natural openings. In addition, as the broccoli head increases in maturity, the partial opening of sepals increases, thereby making them vulnerable to bacterial and fungal invasion.

- In this study, fluorescent pseudomonads were the most common microbes isolated from water soaked and soft head rot lesions. The fluorescent pseudomonads were subsequently identified as *Psuedomonas fluorescens, P. marginalis*, and *P. tolassi.* The pectolytic positive and high biosurfactant producing *P. marginalis* was the most virulent bacteria, capable of causing rot on undamaged heads under humid conditions and without continuous wetting. Other bacteria types require damaged and/or continuous wetting of heads to cause rot.

- Fungi isolated from head rot include *Alternaria*, *Botrytis*, *Cladosporium*, *Fusarium compactum* and *Sclerotinia sclerotiorum*. The most common fungal rots were *Botrytis* and *Sclerotinia*. Fungi such as *Sclerotinia, Botrytis* and *Fusarium* did not appear to require damage for invasion. *Alternaria,* however, can only infect damaged and continuously wet florets, and is therefore likely to be a secondary invader.

2. Surfactant activity of agricultural chemicals:

- All of the insecticides commonly used in broccoli crops showed none or very mild surfactant activity. Therefore, a wetting agent was often applied with the insecticide in order to improve wetting and uptake on waxy plant surfaces. Activator and Agral are commonly used in pesticide applications for insect or disease control in horticultural crops in Tasmania.

- At the beginning of this study in 2002, many growers were found to apply these adjuvants at the maximum rates recommended with insecticides on broccoli crops. However, as a result of findings in this study that high rates of these adjuvants may pre-dispose the wet florets to severe head rot, lower rates are recommended for use instead. The minimum rates recommended on labels were shown to be as effective in wetting the florets as higher rates of the adjuvants, with lower risks of bacterial invasion.

Technical Summary (Cont.)

- Most copper products have little or no surfactant activity, and did not wet the florets or pre-dispose heads to head rot. Moderate surfactant activities recorded with Bravo and Tri-Base Blue are expected to be similar to the minimum rates of spray adjuvants, and are unlikely to have any adverse impact. Some dry copper hydroxide products were shown to increase surface tension between water droplets and the surface of the florets, making the surface even more water repellent.

3. Bacterial control

- An excess of copper ions can be damaging to plant tissues. Therefore, copper products formulated for agricultural use are almost insoluble in water at approximately pH 7.0. Copper sprays applied on to plants exist mainly as insoluble deposits of copper salts. Under moist conditions, carbon dioxide, plant and microbial exudates form weak organic acids in water on the plant surface, hence reducing plant surface pH. A small quantity of free copper ions (Cu^{2+}) is released from the insoluble copper deposits into this film of water. Cu^{2+} is toxic to fungal spores or bacterial cells.

- This study showed that all of the copper-based products were less effective in the complete inhibition of very high populations of bacteria (in excess of 10^6 – 10^{10} cfu/mL). Even though at 10^6 cfu/mL, the copper products Champ DP, Cuprofix MZ, and Tri-Base Blue did reduce the final population to approximately 1% of the initial population, the remaining 10^4 cfu/mL was still considered to be relatively high. At the lower bacteria levels of 10^4 cfu/mL and below, complete bacteria inhibition by Champ DP, Cuprofix MZ, and Tri-Base Blue was recorded.

- The reduced effectiveness of the copper products at very high bacteria levels may be associated to the proportion of free copper ions in solution and at equilibrium, bacterial cell population, and uptake by the bacteria. Therefore, copper products are most effective when used as crop protectants to reduce initial bacterial population levels on plant surfaces, thus preventing diseases. They are likely to be less effective when used on a severely infected crop that already has a very high bacteria population.

- General disinfectants, including those recommended for use to disinfect dam or washing water, such as Sporekill and Path-X, may be useful for drastic reduction of bacterial populations to low levels that can then be effectively controlled by copper based products. Unlike copper products, these disinfectants were shown to be highly effective in eradicating high populations of bacteria.

- The disinfectants, however, have no residual activities, and hence offer no prolonged protection from bacteria re-colonisation. Therefore, these disinfectants should be considered for use only as in additive to copper products, rather than as replacement products. The use of Sporekill at 0.1%, however, generally increased the incidence of black spots on matured heads, and requires further studies on its effects on plants before commercial use at the late crop stage.

- The frequent use of copper sprays can result in the prevalence of copper tolerant bacteria strains. One of the two strains of *P. marginalis* used in this study appeared to be more tolerant to copper than the other. The copper tolerant isolate came from a crop that had been sprayed with copper, while the more copper sensitive isolate was from an untreated crop.

Technical Summary (Cont.)

The resistance development by the copper tolerant bacteria strains appears to be quantitative, rather than a qualitative resistance to copper, whereby increasing the toxicity or the availability of free copper ions may still effectively control the copper resistant strains. Improved toxicity and efficacy could be achieved in part with new and better formulations of copper products. As an alternative, copper toxicity may be enhanced with the use of additives that enhance the solubility and uptake of copper ions, or that interfere with the bacteria resistance mechanisms.

4. Black spots

- If severe, black spots affect the appearance of the broccoli heads, reducing their quality, as well as increase the risk of secondary rot after harvest and storage. Black spots appeared to be associated with cell necrosis on the sepals of florets, and were not necessarily related to the bacterial head rot. This symptom increased with head maturity. In our field observations, nutrient deficiency, frost damage, and a prolonged period of wetness on florets tended to increase the incidence of black spots.

- In the presence of frequent frost conditions, copper treatments may increase the incidence of black spots on the sepals of florets on maturing heads in a field trial. The labels of many copper products have crop damage warnings that they should not be applied to cabbage crops if frost is likely. Similar warnings should also apply to their use on broccoli crops, particularly close to harvest, when the matured heads are most prone to damage.

- This study also indicated a possible link in concentrations of copper products in spray mixture, whereby higher copper product concentrations with low spray water volume of 210 L/ha tended to increase black spot incidence compared to a high spray water volume of 400 L/ha.

- The pH of different copper products also appeared to be related to the incidence of black spots. No increase in black spot incidence was noted with the alkaline Champ DP, while the slightly acidic Cuprofix MZ tended to cause high incidence of black spots.

- In both 2002 and 2003, whole crops have been observed to develop a purplish discoloration on the sepals of the florets. While some of these purplish spots might have developed into black spots most eventually disappeared. This general discolouration in the whole crop is believed to be due to a physiological response to poor translocation of nutrients under very cold conditions, or in a nutrient deficient crop.

- In 2003, the use of the disinfectant Sporekill in mixtures with copper sprays also tended to increase black spot incidence, compared to copper sprays only. This may be related to increased wetting with Sporekill or other possible adverse effects on plant cells on sepals of florets. Therefore, although Sporekill and other disinfectants are highly effective in eradicating or reducing bacteria populations, further investigation is recommended to understand its impact on black spots.

Technology Transfer

- Regular updates were given to R & D managers of the processing companies as findings became available during the project.

- A research meeting was held with staff from McCain Foods and Simplot, an Industry Development Officer and consultants, to present and discuss outcomes of the project studies, on 28th June 2002, at Serve-Ag Research, Devonport, Tasmania.

- Project outcomes were presented at Tasmanian vegetable extension days held at Devonport on 14th August 2002 and 5th September 2003. These were well attended by Tasmanian growers, industry representatives and researchers.

- A poster was presented at the International Plant Pathology Congress that was held at Christchurch, New Zealand on 3 - 7 February 2003. Copies of the poster were provided to Horticulture Australia and voluntary contributors.

Recommendations

- At the late crop stage when heads are maturing, use minimum label rates for spray adjuvants to minimize risk of damage to the florets by wetting agents.

- Copper products should be used primarily as crop protectants to reduce initial bacterial population levels on plant surfaces, thus preventing diseases.

- For head rot control in crops that are already infected, the addition of a disinfectant to copper sprays may assist in reducing bacterial populations to low levels that can then be effectively controlled by copper based products. The disinfectants, however, have no residual activities, and should be considered for use only as additives to copper products, rather than as replacement products. However, avoid the use of a disinfectant close to harvest, until safe lower rates that do not cause black spots can be recommended.

- Use of a high volume spray is preferable to a low volume spray for improved coverage and reducing the toxic effects of concentrated copper in a low volume spray.

- Crop damage warnings should be on the label, copper should not be applied on broccoli crops if frost is likely and close to harvest when the matured heads are most prone to blemishes or black spots.

General Discussions

Head rot epidemiology

The potential of bacteria to cause rots on non-wounded heads is determined by two key characteristics: the presence of pectolytic activity and biosurfactant activity (Hildebrand 1989). The pectolytic fluorescent pseudomonads are important bacterial pathogens, causing soft rots on a diverse group of vegetables (Liao & Wells 1987). On plants that have thick, waxy surfaces, like broccoli, the water soaking properties of biosurfactant-producing bacteria, help provide entry through natural openings (Hildebrand 1989). Biosurfactants released by some fluorescent pseudomonads may also enable surfactant deficient strains to colonise the water soaked areas even though physical injury of tissues is not evident (Wimalajeewa *et al*. 1987, Hildebrand 1989).

Stomata, and sepals of florets that do not overlap completely to close the reproductive parts of the flower, help provide small openings for surfactant-mediated entry by bacteria and fungal pathogens. As the broccoli head increases in maturity, the partial opening of sepals increases, thereby making them vulnerable to bacterial and fungal invasion. In this study, a higher incidence of bacterial head rot, as well as fungal rot by *Sclerotinia*, *Botrytis* and *Fusarium,* was noted on matured heads. Less mature heads harvested for the fresh market rarely get infected by bacteria or fungal pathogens. Low susceptibility of young heads may partly be associated with the presence of high levels of glucosinates in plant tissues (J. Kirkegaard, CSIRO, per. comm.). These observations suggest that bacterial and fungal head rot may be managed with head maturity and early harvest timing, particularly in the presence of prolonged wet field conditions.

Surfactant activities of agricultural chemicals

All of the insecticides commonly used in broccoli crops showed none or very mild surfactant activity. Therefore, a wetting agent is often applied with the insecticide in order to improve wetting and uptake on waxy plant surfaces. Activator and Agral are commonly used in pesticide applications for insect or disease control in horticultural crops in Tasmania. At the beginning of this study in 2002, many growers were known to apply these adjuvants at the maximum rates recommended with insecticides on broccoli crops. However, as a result of findings in this study, high rates of these adjuvants may pre-dispose the wet florets to severe head rot and lower rates are recommended for use instead. The minimum rates recommended on labels were shown to be as effective in wetting the florets as higher rates of the adjuvants, with lower risks to bacterial invasion.

Most copper products have little or no surfactant activity, and do not wet the florets or pre-dispose heads to head rot. Moderate surfactant activities recorded with Bravo and Tri-Base Blue are expected to be similar to the minimum rates of spray adjuvants, and unlikely to have any adverse impact. Excessive metallic copper ions, however, may have phytotoxic effects on plant tissues and cause burning or blemishes similar to black spots on sepals of florets.

General Discussions (Cont.)

Bacterial control

An excess of copper ions is damaging to plant tissues. As a result of the phytotoxic effects, copper products formulated for agricultural use are almost insoluble in water at approximately pH 7.0. Copper sprays applied to plants exist mainly as insoluble deposits of copper salts (Menkissoglu & Lindow 1991). These products are designed to release a small, but constant, supply of free copper ions whenever the plant surface is wet.

Under moist conditions, carbon dioxide, and plant and microbial exudates, form weak organic acids in water on the plant surface, hence reducing plant surface pH. A small quantity of free copper ions (Cu^{2+}) is released from the insoluble copper deposits into this film of water (Arman & Wain 1958, Lee *et al*. 1993). Any fungal spores or bacterial cells that come in contact with this moisture will absorb the free copper ions. Once absorbed, the free copper ions will disrupt cellular enzyme systems.

If too many copper ions are released at one time, phytotoxicity and damage to the florets and foliage can occur. The phytotoxicity symptoms include burning of leaves, and black spots or blemishes on florets. Factors that can result in excessive release of free copper ions are; the spray mixture is too acidic (less than pH 6.0 to 6.5), copper formulations are contaminated with soluble copper compounds, or formulations that release too many copper ions. This study also indicated a possible link in concentrations of copper products in spray mixture volumes. Higher copper product concentrations with low spray water volumes of 210 L/ha tended to increase black spot incidence compared to high spray water volumes of 400 L/ha. Furthermore, as mentioned in the previous sub-heading, low pH of resulting copper spray mixture may also contribute to phytotoxicity.

Particle sizes of a copper product have been shown to affect their efficacy (Torgeson *et al*. 1967). Formulations with smaller particles produce improvements in disease control through better coverage, rain-fastness, longevity of the product, and release of copper ions on plant surfaces. The smaller the particle size, the greater the number of particles per gram, and therefore the greater the release of copper ions for antibacterial activity. Smaller particles give superior coverage and improved efficacy in disease control. Tri-Base Blue and Champ DP are examples of copper products that are made of ultra-fine particles of less than 1 micron. New copper product formulations such as these have enabled the use of lower rates of metallic copper for disease control, thereby reducing the potential environmental risk. In this study, although Champ DP appeared to be less effective than Tri-Base Blue in inhibiting *P. marginalis* in an *in-vitro* test, it appeared to be more effective in reducing black spots and bacterial head rot in a field trial. These differences in efficacies suggest the complex interacting factors between copper type, particle size, pH, toxicity and other formulation properties. According to Scheck & Pscheidt (1998), the amount of free copper ions in solution is the only predictor of formulation efficacy, which could not be estimated from the metallic copper content of a product.

This study showed that all the copper-based products were less effective in the complete inhibition of very high populations of bacteria (in excess of 10^6 – 10^{10} cfu/mL). Even though at 10^6 cfu/mL, Champ DP, Cuprofix MZ, and Tri-Base Blue did reduce the final population to approximately 1% of the initial population, the remaining 10^4 cfu/mL was still considered to be relatively high. At the lower bacteria levels of 10^4 cfu/mL and below, complete bacterial inhibition by Champ DP, Cuprofix MZ, and Tri-Base Blue were recorded.

General Discussions (Cont.)

The reduced effectiveness of the copper products at very high bacterial levels may be associated with the proportion of free copper ions in solution and at equilibrium, bacterial cell population, and uptake by the bacteria. Therefore, copper products are believed to be most effective when used as crop protectants to reduce initial bacterial population levels on plant surfaces, thus preventing diseases. It is likely to be less effective when used on a severely infected crop that already has a very high bacterial population.

General disinfectants, including those recommended for use to disinfect dam or washing water, such as Sporekill and Path-X, may be useful for drastic reduction of bacterial populations to low levels that can then be effectively controlled by copper based products. Unlike copper products, these disinfectants were shown to be highly effective in eradicating high populations of bacteria. It should be noted however, that the disinfectants have no residual activities, and hence offer no prolonged protection from bacteria re-colonisation. Therefore, these disinfectants should be considered for use only as an additive to copper products, rather than as replacement products.

In recent studies conducted in Queensland, Martin & Hamilton (2003) showed that the reliance on copper sprays by pepper producers for bacterial spot of pepper has resulted in the prevalence of copper tolerant bacteria strains. In this study with *in-vitro* tests, one of the two strains of *P. marginalis* used appeared to be more tolerant to copper than the other. This difference in copper tolerance between the two *P. marginalis* isolates could be attributed to the origin of the isolates, where the copper tolerant isolate came from a crop that had been sprayed with copper, while the more copper sensitive isolate was from an untreated crop.

According to Cooksey (2002), the higher tolerance to copper ions may be partly related to the loss of toxicity when proteins produced by the copper resistant bacteria can bind with multiple copper ions. However, the resistant development by the copper tolerant bacteria strains appears to be quantitative, rather than a qualitative resistance to copper (Lee *et al*. 1993), whereby increasing the toxicity or the availability of free copper ions may still effectively control the copper resistant strains.

The use of increased rates of copper products is not an option due to the increased risk of phytotoxicity, and the general trend of reducing rather than increasing metallic copper rates. Improved toxicity and efficacy could be achieved in part with new and better formulations of copper products. As an alternative, copper toxicity may be enhanced with the use of additives that enhance the solubility and uptake of copper ions or that interfere with the resistance mechanisms. Additives that have shown enhancement of copper sensitivity include fungicides, ferric chloride, zinc chloride and aluminium nitrate (Cooksey 2002). Scheck *et al*. (1998) found that while all copper-based bactericides reduced the population size of copper-sensitive strains of *Pseudomonas syringae pv. syringae* by 50%, only cupric hydroxide mixed with mancozeb or ferric chloride reduced the population size of the copper-resistant strains by an equivalent amount.

The increased toxicity of mancozeb mixtures with copper based bacteriacides appears to be associated with the ability of the dithiocarbamate anion to chelate copper and transport cupric ions to copper susceptible sites within bacterial cells (Medhekar & Borapai 1981). Lee *et al*. (1993) showed that adding iron in the form of ferric chloride to cupric hydroxide resulted in increased toxicity to copper resistant strains of *Xanthomonas campestris pv juglandis*, on walnut. The ferric ion apparently has a direct physiological effect on *X. campestris pv juglandis*, resulting in an increased susceptibility to the toxic effect of cupric ion.

General Discussions (Cont.)

The addition of ferric chloride to cupric hydroxide also increases the availability of cupric ions on leaf surfaces by lowering the pH and through cation exchange between cupric ion and ferric ion. Unfortunately, in this study, we were not able to compare the treatment mixture of iron chelate + Champ DP against Champ DP alone, due to little or no head rot in the treatments.

Black spots

The small black spot was not necessarily related to the bacterial head rot. If severe, black spots may affect the appearance of the heads, thereby reducing their quality or make them unmarketable. In this study, when the black spots were kept moist under room temperature, about 20°C, bacterial decay was noted on the spots that may spread and cause head rot. Therefore, black spots may increase the risk of secondary rot by bacteria, thereby affecting the quality of affected heads after harvest and storage.

Black spots appeared to be associated with cell necrosis on the sepals of florets. This symptom increased with head maturity. In our field observations, nutrient deficiency, frost damage, and prolonged period of wetness on florets tended to increase black spot incidence. In the presence of frequent frost conditions in 2002, Kocide DF treatments consistently increased the incidence of black spots on the sepals of florets on maturing heads in a field trial. This increase in black spots appeared to be related to increased susceptibility to frost damage. The labels of many copper products have crop damage warnings that they should not be applied onto cabbage crops if frost is likely. Similar warnings should also apply on their use on broccoli crops, particularly close to harvest, when the matured heads are most prone to damage.

The pH of different copper products also appeared to be related to the incidence of black spots. The copper product Champ, which has a relatively high pH value, tended to cause lower black spot incidence, while copper products like Cuprofix MZ resulted in a high incidence of black spot.

In both 2002 and 2003, whole crops have been observed to develop a purplish discoloration on the sepals of the florets. While some of these purplish spots might have developed into black spots, most eventually disappeared. This general discolouration in the whole crop is believed to be due to a physiological response to poor translocation of nutrients under very cold conditions, or in a nutrient deficient crop.

In 2003, the use of the disinfectant Sporekill in mixtures with copper sprays also tended to increase black spot incidence, compared to copper sprays only. This may be related to increased wetting with Sporekill or other possible adverse effects on plant cells on sepals of florets. Therefore, although Sporekill and other disinfectants are highly effective in eradicating or reducing bacteria populations, further investigation is recommended to understand their impact on black spots.

Acknowledgments

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