Incorporating Adjuvants with Captan to Manage Common Apple Diseases

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Abstract

Captan has become an increasingly important fungicide in the management of common apple diseases such as apple scab (*Venturia inaequalis*) and bitter rot (*Colletotrichum* spp.) due to the low risk of fungicide resistance evolving in either pathogen population to this product. Restrictions on the amount of captan that can be applied per season limits the amount and the number of applications a grower may use, resulting in control failures during high disease pressure years. This 3-year field study evaluated how adjuvants combined with captan affected the incidence and severity

of apple scab and bitter rot on two different apple cultivars. Results showed that Li700 plus captan and Bond Max plus captan reduced disease incidence of apple scab and bitter rot in years with moderate to high disease pressure by increasing the coverage and retention of captan. The addition of these adjuvants also resulted in possible yield losses due to russetting caused by phytotoxicity. The overall benefits of incorporating adjuvants with captan based on this study could reduce disease incidence while potentially saving a grower up to \$5,329 ha⁻¹ due to fungicide reduction.

Apple scab, caused by the fungus *Venturia inaequalis*, and bitter rot, caused by the fungi *Colletotrichum* spp., are economically important diseases of apple trees (*Malus domestica*) in regions that experience cool, wet springs and warm, wet summers (Sutton 1990a, b). Fungicides are currently the most relied upon method of control of these pathogens (Gianessi and Reigner 2005). There are a variety of fungicides registered to control apple scab and bitter rot, including methyl benzimidazole carbamates (MBC), demethylation inhibitors (DMI), quinone outside inhibitors (QoI), and succinate dehydrogenase inhibitors (SDHI) (Köller et al. 1997; McKay et al. 2011; Szkolnik and Gilpatrick 1969). However, the extended and exclusive use of many of these fungicides resulted in resistant strains of *V. inaequalis* (Chapman et al. 2011; Lesniak et al. 2011) and *Colletotrichum* spp. (Jones et al. 1996) within years of their respective release. As a consequence of increasingly resistant populations, these fungicides no longer provide adequate control of pathogens, which has led to the greater reliance on the use of protectant fungicides, such as captan or mancozeb (Richmond et al. 1967; Turechek 2004).

Captan disrupts multiple cellular division pathways of the fungus, and consequently has a very low risk of developing fungicide resistance (Richmond et al. 1967; Rosenberger 2013; Turechek 2004). This makes captan an important option in the management of fungal diseases on apples, although there are several drawbacks that reduce its efficacy. When suspended in alkaline tank water (pH > 7), captan has a half-life of 20 min, meaning it could degrade significantly before applications are made (Frank et al. 1985; Gradis and Sutton 1981). Captan also cannot persist on plant surfaces if greater than one inch of rain occurs within 24 h after application, leaving the leaves and fruit unprotected during high infection periods (Smith and MacHardy 1984). Furthermore, thorough coverage of the plant surface is required in order for maximum efficacy of a protectant fungicide like captan (Köller et al. 2005). Unfortunately, apple fruit are moderately difficult to wet because of their waxy cuticles, which often results in poor deposition and coverage of captan (Gaskin et al. 2005). Lastly, the United States Environmental Protection Agency (U.S. EPA) has classified captan as a group B2 carcinogen, or a potential human carcinogen (EPA 1999). As a result, there are restrictions on captan applications that limit growers to 44.5 kg per hectare per season (Beckerman et al. 2015;

Cooley et al. 2013). For greater disease control, a rate of 5.7 kg per hectare of captan is recommended, which limits growers to approximately eight applications of captan per season. However, the successful management of apple scab and bitter rot in years with high disease pressure may require up to 14 applications of fungicide. To remain within label limitations, growers must either lower rates of captan or make fewer applications of the fungicide. Reducing the rate or extending the interval often results in management failures of apple scab and bitter rot, which can lead to yield loss (Beckerman et al. 2015).

One potential solution for improving captan persistence is by utilizing adjuvants. As defined in the American Society for Testing and Materials (ASTM), adjuvants are “materials that are added to a tank mix to aid or modify the action of an agrichemical, or physical characteristics of the mixture” (ASTM 1999). Adjuvants have been found to increase the spread, retention, penetration, and spray efficacy of materials being applied to plant surfaces (Gent et al. 2003; Percich and Nickelson 1982; Steurbaut 1993; Thompson et al. 1996). Adjuvants may also correct issues with mixing and application by affecting the drift, pH, or foaming of the tank water (Bakke 2007). A goal of modern integrated pest management is to reduce pesticide inputs while maintaining commercially acceptable levels of control. The addition of adjuvants to fungicides may help achieve this goal and can be readily adopted and implemented by growers.

Very few publications explore combinations of fungicides and adjuvants in field environments (Foy 1993; Gent et al. 2003; Steurbaut 1993). This is an issue as there are thousands of adjuvants available and little understanding of how they will interact with captan. Ultimately, this results in grower reluctance toward the addition of adjuvants to their management strategies. The objectives for this study were to identify beneficial adjuvant combinations with captan to reduce incidence and severity of apple scab and bitter rot with the lowest rate of captan, thereby improving growers’ disease management and profit margins without increasing costs.

Materials and Methods

Orchard site. In the summers of 2013, 2014, and 2015, studies were conducted to evaluate the effect of adjuvants when combined with captan to manage apple scab and bitter rot throughout the growing season. These experiments were executed in field plots at Meigs Farm, at the Throckmorton Purdue Agricultural Centers (TPAC) in Lafayette, IN. The orchard consisted of 16-year-old cvs. Golden Delicious and Honeycrisp apple trees grafted on M.7 rootstocks planted in Toronto-Millbrook complex soil. Golden Delicious trees were planted 6.1 m apart with 6.1 m between each row in a 0.5 ha field containing 130 trees. Honeycrisp trees were planted 3 m apart with 3.7 m between each row in a 0.2 ha field containing 104 trees. All trees were infected with naturally occurring inoculum of each disease; losses in this plot have exceeded 80% in untreated controls (Abbott and

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Beckerman 2013a, b, 2014a, b, 2015). The orchard was not irrigated. Trees were pruned before bud break each year. In 2013, apples were treated with the insecticides Imidan (Gowan Company, Yuma, AZ) at a rate of 0.14 kg per hectare and Altacor (DuPont, Wilmington, DE) at a rate of 0.28 kg per hectare according to Midwest Tree Fruit Spray Guide guidelines (Midwest Fruit Working Group 2013). In 2015, apples were treated with the insecticide Confirm (Gowan Company, Yuma, AZ) at a rate of 1.4 kg per hectare according to Midwest Tree Fruit Spray Guide guidelines (Midwest Fruit Working Group 2015).

Experimental design. In 2013, the Honeycrisp plot was arranged in a completely randomized design of 10 treatments containing uneven replications of four trees. In 2014 and 2015, the trees in the Honeycrisp plot design were arranged as a randomized complete block design of 10 treatments containing three replications of three trees. In 2013, 2014, and 2015, the design of the trees in the Golden Delicious plot was a randomized complete block design of 10 treatments containing three replications of four trees.

Treatment applications. Treatments in this study included no treatment (control), captan (Captan 80WDG; Arysta LifeScience, Cary, NC), Li700 (Loveland Products, Inc., Loveland, CO), Bond Max (Loveland Products, Inc., Loveland, CO), Attach (Loveland Products, Inc., Loveland, CO), Latron B-1956 (J.R. Simplot Company, Boise, IA), Li700 plus captan, Bond Max plus captan, Attach plus captan, and Latron B-1956 plus captan (Table 1). Adjuvants were selected based upon differing chemical properties. Treatments were applied to trees with an air blast sprayer (John Bean DP10P 50P) with ceramic whirl plate and disc nozzles (John Bean/Durand-Wayland, Inc., La Grange, GA) on flip over bodies that produced a solid cone spray pattern. Treatments were applied at 8.9 kph at 1,724 to 2,068 kPa (935.2 liters/ha rate) every 10 to 14 days beginning at 24 May in 2013, 30 April in 2014, 23 April in 2015, and ending at harvest. In 2013, Honeycrisp trees received eight applications made on 24 May; 4, 17, 28 June; 11, 23 July; and 6 and 16 August. Golden Delicious trees received 11 applications made on 24 May; 4, 17, 28 June; 11, 23 July; 6, 16, 30 August; and 13 and 25 September. In 2014, Honeycrisp trees received 10 applications made on 30 April; 12, 22 May; 5, 18 June; 2, 14, 25 July; and 8 and 19 August. Golden Delicious trees received 12 applications made on 30 April; 12, 22 May; 5, 18 June; 2, 14, 25 July; 8, 19 August; and 2 and 16 September. In 2015, Honeycrisp and Golden Delicious trees both received 11 applications made on 23 April; 6, 19, 29 May; 9, 23 June; 2, 16, 30 July; and 11 and 24 August. After 24 August 2015, no further applications were made to Golden Delicious because the trees did not produce apples.

Adjuvant effect on the water droplet. In 2015, water sensitive spray cards (Syngenta, Greensboro, NC) were placed in a single tree for each treatment approximately 1.5 m from the ground before treatment applications were made. After applications were made, the cards were measured to assess the effect of adjuvants on the water droplet. Percent droplet area on the card was analyzed using ASSESS 2.0 (Lamari 2008) by measuring the darker area that indicated water presence on the sensitive card and dividing by total area of the card.

Disease assessment. For all years, apples from only the inner trees of each replicate were scored for disease assessment to avoid fruit that may have been exposed to overlapping treatments that could result in possible biased phytotoxicity scoring. In all years, fruit of each

cultivar were scored for incidence and severity of apple scab, bitter rot, and phytotoxicity.

In 2013, Honeycrisp apples were scored on 22 August by arbitrarily selecting five branches from the two inner trees in each replicate. Disease and phytotoxicity incidence were recorded by counting the total number of infected apples. Golden Delicious apples were scored on 30 September by arbitrarily selecting five branches from the two inner trees in each replicate. Disease and phytotoxicity incidence was scored by recording the number of infected/blemished apples out of the total number of fruit on the branch.

In 2014 and 2015, Honeycrisp apples were scored on 24 August and 8 September, respectively, by arbitrarily selecting 10 branches from the inner tree in each replicate. In 2014, Golden Delicious apples were scored on 23 September by arbitrarily selecting five branches from the two inner trees in each replicate. In 2015, no scores for Golden Delicious apples were recorded as no apples were produced due to biennial bearing. For both years and cultivars, disease and phytotoxicity incidence were scored by recording the number of infected/blemished apples out of the total number of fruit on the branch. Disease and phytotoxicity severity were measured the same in 2013, 2014, and 2015, by estimating the surface area of the infection/blemish using the template published by Croxall et al. (1952).

Statistical analysis. For all years, apple scab incidence and severity, bitter rot incidence and severity, and phytotoxicity incidence and severity scores were averaged within treatments, subject to arcsine transformation. Then comparisons across all treatments were analyzed with a one-way ANOVA using a generalized linear model procedure (PROC GLM) of SAS v9.3 (SAS Institute, Cary, NC). If comparisons across all treatments were significant at $P = 0.05$, then individual treatments were grouped according to Fisher's protected LSD test at $P = 0.05$, using SAS v9.3. These groupings are shown in Figure 1. In 2014, apple scab severity data for Honeycrisp were not included in statistical analysis due to an abundance of zero variances. As there was no phytotoxicity in the captan-only and untreated control treatments in either cultivar in all years of this study, these treatments were not included in statistical analysis in order for data to meet the homogeneity of variance assumption.

Economic analysis. To quantify the hypothetical benefits and costs of managing apple scab and bitter rot using adjuvants with captan for fresh market apples, the authors used an adjusted formula that was based on a formula published by Brown and Keane (1997), where expected return using captan only was actual yield (100% minus disease incidence in captan-only treatment) multiplied by potential earnings per hectare. Similarly, expected return using adjuvants combined with captan was actual yield (100% minus disease incidence in adjuvant/captan treatment) multiplied by potential earnings per hectare. The cost and losses variable was phytotoxicity incidence in the adjuvant/captan treatment multiplied by potential earnings plus the material costs of applying the adjuvant. In order to estimate the potential earnings, we assumed that the gross value of fresh market apples in Indiana was \$22,163 ha⁻¹ (USDA-NASS 2014).

Results

Effect of adjuvants on apple scab management. Apple scab incidence and severity varied considerably among the years of the trial.

Table 1. List of materials used in this study to manage apple scab and bitter rot

Trade name	Active ingredients	Concentration per 379 liters	Manufacturer	Classification
Captan 80WDG	Captan: N-Trichloromethylthio-4-cyclohexene-1,2-dicarboximide	1.1 kg	Arysta LifeScience	Multisite fungicide
Li700	Phosphatidylcholine, methylacetic acid, and alkyl polyoxyethylene ether	0.30 liters	Loveland Products, Inc.	Adjuvant: acidifier, penetrant, drift reduction
Bond Max	Alcohol ethoxylate, 1,2-propanediol, and synthetic latex	0.44 liters	Loveland Products, Inc.	Adjuvant: spreader-sticker, deposition aid
Attach	Pinene (terpene) polymers, petrolatum, (p-Dodecylphenyl), omega-hydroxypoly (oxyethylene)	0.30 liters	Loveland Products, Inc.	Adjuvant: spreader-sticker
Latron B-1956	Modified phthalic glycerol alkyl resin	0.30 liters	J.R. Simplot Company	Adjuvant: spreader-sticker

In 2013, low apple scab incidence was observed in the untreated control. As a result, in this year, no significant reduction of apple scab incidence was observed between treatments in either cultivar when adjuvants were combined with captan ($P = 0.4174$). In 2014, apple scab infections were observed resulting in 100% apple scab incidence in the untreated control on Golden Delicious apples. In this year, Golden Delicious, Li700 plus captan, Bond Max plus captan, and Latron B-1956 plus captan reduced incidence and severity of apple scab ($P < 0.0001$, $P = 0.0002$, Fig. 1A and B). Due to inherent resistance of Honeycrisp to apple scab, apple scab incidence between treatments was too low to draw significant comparisons among adjuvant/captan combinations and captan ($P = 0.1344$). A similar result was also recorded in Honeycrisp apples in 2015 ($P = 0.8368$). In 2015, no Golden Delicious apples were produced due to biennial bearing and no data were recorded for that year.

Effect of adjuvants on bitter rot management. Bitter rot incidence and severity varied considerably among the years of the trial. In 2013, low incidence (1.5%) of bitter rot was observed in the untreated control in Honeycrisp apples. As a result, no adjuvants combined with captan reduced the incidence of bitter rot compared with captan alone in either cultivar ($P = 0.2765$, $P = 0.2368$). In 2014, greater bitter rot incidence was recorded in the untreated control in Honeycrisp (43.1%), while bitter rot incidence in the captan only treatment was low (8.3%). Li700 plus captan, Bond Max plus captan, and Attach plus captan lowered bitter rot incidence further than captan alone (1.5, 2.7, and 5.6%), but this was not a statistically significant effect compared with captan alone treatments ($P = 0.5332$). In 2015, greater bitter rot incidence was observed in both the untreated control and captan-only treatments (52.3 and 24.5%). In this year, Li700 plus captan and Bond Max plus captan significantly reduced the incidence of bitter rot compared with captan alone ($P = 0.0006$, Fig. 1C). All adjuvant and captan combinations significantly reduced the severity of bitter rot compared with captan alone ($P = 0.0382$, Fig. 1D).

Phytotoxicity incidence and severity. Among all years of this study, the greatest incidence and severity of phytotoxicity was observed in 2013. In all years, Golden Delicious apples were observed to be more susceptible to phytotoxicity than Honeycrisp apples. In 2013, Attach plus captan, and Latron B-1965 plus captan had significantly greater incidences and severity of phytotoxicity in Golden Delicious than other adjuvant and adjuvant plus captan combinations ($P = 0.0332$, $P = 0.0229$, Supplementary Table S1). In 2014, the use of Li700 plus captan, Bond Max plus captan, and Latron B-1956 plus captan resulted in significantly greater incidence and severity of phytotoxicity on Golden Delicious apples than other adjuvant and adjuvant plus captan combinations ($P < 0.0001$, $P < 0.0001$, Fig. 1A, Supplementary Table S2). In Honeycrisp, Bond Max plus captan significantly increased the incidence and severity of phytotoxicity, and Latron B-1956 plus captan had significantly greater incidence of phytotoxicity than other adjuvant and adjuvant plus captan combinations ($P = 0.0002$, $P = 0.001$). In 2015, applications of Attach plus captan had a significantly greater incidence of phytotoxicity while Bond Max plus captan had a significantly greater severity of phytotoxicity than other adjuvant and adjuvant plus captan combinations ($P = 0.0466$, $P = 0.0205$, Supplementary Table S3).

Discussion

Fungicides play a critical role in apple disease management. However, issues of fungicide resistance have resulted in many growers relying on captan for season-long disease control. Unfortunately, growers using captan generally reach the maximum limit of per hectare use and require additional protection. In this three-year study, we identified that certain adjuvants have the potential to improve the efficacy of captan for the management of apple scab and bitter rot while using reduced rates of fungicides (2.7 kg/ha compared with 5.7 kg/ha, or approximately 50% reduction in fungicide). Neither captan nor adjuvants applied alone in these conditions were comparable to captan mixed with

Fig. 1. Effect of adjuvants on apple scab (*V. inaequalis*) **A**, incidence and **B**, severity on Golden Delicious apples (2014), and bitter rot (*Colletotrichum* spp.) **C**, incidence and **D**, severity on Honeycrisp apples (2015) at Meig's Farm, at the Throckmorton Purdue Agricultural Center in Lafayette, IN. *Treatment had significant incidence of phytotoxicity. Data were subject to arcsin transformation prior to statistical analysis using the statistical software SAS 9.3. All data are displayed as back-transformed means.

Li700 or BondMax, suggesting that the enhanced management was due to the improved coverage of the fungicide by the addition of certain adjuvants.

Visual inspection of water sensitive spray cards suggested that Li700 and Latron B-1956 increased the coverage of the water droplet (Fig. 2). Using ASSESS 2.0 (Lamari 2008), we found that a spray containing only captan covered 27% of the water sensitive card surface, where Li700 plus captan resulted in 92% and Latron B-1956 plus captan resulted in 71% coverage of the card surface (Fig. 2). Both adjuvants are composed of chemical components that increase the spread of water droplets by reducing the surface tension, which resulted in increased coverage of captan (Hazen 2000). An even deposition of the active ingredients on plant surfaces is among the most important factors determining the efficacy of fungicide applications (Balardin et al. 2010; Holloway 1993; Wagner et al. 2003). Unfortunately, apple fruit are moderately difficult to wet because of their waxy cuticles, often resulting in poor deposition (Gaskin et al. 2005). Effective use of a protectant fungicide like captan requires thorough coverage of the plant surface in order to obtain optimal disease management (Köller et al. 2005).

Both Li700 and Latron B-1956 potentially improved captan coverage, but only the addition of Li700 consistently resulted in less disease. This may be due to the differences in the chemical composition of Li700 and Latron B-1956. Where the polyoxyethylene in Li700 reduces surface tension much like many surfactants that have long chains of hydrophobic carbons (Hazen 2000), the compacted hydrophobic portion of the modified phthalic molecules in Latron B-1956 may act more like organosilicone surfactants, or superspreaders (Ananthapadmanabhan et al. 1990). This means that the addition of Latron B-1956 may cause excessive spreading, resulting in unexpected run-off of fungicides, resulting in decreased efficacy (Hess 1999; Holloway 1994).

Finally, Li700 is an acidifier, which may have resulted in differences between it and Latron B-1956. The addition of Li700 would reduce the pH of the basic tank water and possibly prevent alkaline hydrolysis of captan which could prevent the breakdown of the active ingredient into less efficacious compounds (Somerville et al. 2012; Wolfe et al. 1976). The addition of Li700 to captan could have implications to growers in places like Indiana, who generally only have the option of using water with a pH of 8.0 and higher.

Compared with Li700 and Latron B-1956, the other adjuvants used in this study, Bond Max and Attach, did not dramatically increase the water droplet coverage according to visual inspection of the water

sensitive spray cards (Fig. 2). While both Bond Max and Attach have surfactant qualities due to the alcohol ethoxylated and oxyethylene present in their chemistry (Hazen 2000), these adjuvants also have sticking qualities due to the latex (Bond Max) and pinene (Attach) found in their chemistry (Hazen 2000). These sticking qualities may counteract the spreading and result in reduced droplet coverage. This was observed by visually inspecting the water sensitive spray cards where Bond Max resulted in 47% and Attach resulted in 27% coverage of the water sensitive spray card (Fig. 2). However, the increased “stickiness” of the water droplets could have improved disease management by increasing the retention of captan (Gaskin et al. 2014; Hazen 2000). This factor is important in apple disease management as a certain amount of captan residue is required to remain on the plant surface to ensure greater control for the entire interval between applications (Frank et al. 1985). Although both adjuvants may have improved the retention of captan, only Bond Max improved disease management. This is likely because latex-based stickers improve retention significantly better than pinene-based stickers (Gaskin and Steele 2009; Gaskin et al. 2014).

While the addition of certain adjuvants improved disease management on susceptible cultivars in years with moderate to high disease incidence, there were differences among years in this study. Adjuvant effects on incidence of apple scab and bitter rot were highly dependent upon conducive environmental conditions for disease and susceptibility of the cultivar. In 2014, there was a cool and wet spring followed by a moderately warm and wet summer (Supplementary Fig. 1B). These conditions may have contributed to a greater disease incidence in Golden Delicious and allowed for more detectable separation of the treatments. In 2014 and 2015, the spring and summer had both moderate temperatures and rainfall, which could have contributed to greater bitter rot incidence than prior years. However, statistical separation between captan only and captan plus adjuvant treatments was only observed in 2015. This is likely because 2015 had record-breaking rainfall in Indiana and the amount or frequency could have washed off captan, resulting in a more detectable difference between captan only and captan plus adjuvant treatments.

Overall, these results support a previous study where adjuvant efficacy in laboratory and field experiments showed that there were differences in adjuvants between controlled and field environments, with the latter showing fewer significant effects (Gent et al. 2003). The authors hypothesized that lack of significance in the field experiments was due to a low disease incidence (Gent et al. 2003).

Fig. 2. Water sensitive spray cards showing the effect of adjuvants on water droplets after various treatments were applied using an air blast sprayer. The blue coloration indicates water coming into contact with the card. Treatments are **A**, control (H_2O) = 13% coverage; **B**, Li700 = 68% coverage; **C**, Bond Max = 27% coverage; **D**, Attach = 16% coverage; **E**, Latron B-1956 = 74% coverage; **F**, captan = 27% coverage; **G**, Li700 + captan = 92% coverage; **H**, Bond Max + captan = 47% coverage; **I**, Attach + captan = 27% coverage; and **J**, Latron B-1956 + captan = 71% coverage. Droplet coverage was assessed using APS Assess (Lamari 2008).

Furthermore, it was noted by Steurbaut (1993) that there are several factors that could reduce the efficacy of adjuvants in the field, including harsher environments caused by wind and rain that can increase wash-off and increased canopy density that can decrease deposition. This may explain why certain adjuvants like Attach and Latron B-1956 were not as effective in this study.

The variation in adjuvant effects on disease management among the years highlights the difficulty in making practical interpretations from this research. In many cases, growers are reluctant to use adjuvants because any contribution to disease management might be offset from losses due to phytotoxicity. In 2013, there was an increased incidence of phytotoxicity, which could have been due to an early season application of dodine (Kirby and Bennett 1967). In following years, significant incidences of phytotoxicity were observed when Li700 or Bond Max was combined with captan (Fig. 3). This was not surprising as Li700 is classified as a penetrant, increasing infiltration of pesticides into the plant cell (Hazen 2000), and Bond Max contains long carbon-chained alcohols, which improve the absorption of pesticides into plant cells (Gent et al. 2003; Hess and Foy 2000). It should be noted that captan has been reported to show phytotoxic effect on apples when formulations include oils or other fungicides that increase infiltration and when weather conditions, such as high humidity and extended leaf wetness, occur during and after application (Creasy 1980; Rosenberger 2014). The addition of adjuvants to captan could mimic these conditions by prolonging the persistence of captan on the leaf and increasing the infiltration, resulting in damage. Moreover, the rates of adjuvants applied could also have some correlation with phytotoxicity. It should be noted that the rates of adjuvants applied in this study may be higher than what most growers would use, so the incidence and severity of phytotoxicity reported may be greater than typical as well.

The addition of Li700 and Bond Max to captan may still be beneficial to growers despite the potential for phytotoxicity. To demonstrate the potential value of incorporating these adjuvants with captan, we quantified the hypothetical benefits and costs of managing apple scab and bitter rot for fresh market apples using a concept published by Brown and Keane (1997). We focused on Li700 and Bond Max, which we identified to be the most promising adjuvants to include in the economic analysis.

Using the formula previously described in the methods section, the economic advantage of adding Li700 or Bond Max to captan in 2014 was \$4,667 { $[\$19,726 - [\$13,983 + (\$12 + \$1,064)]]$ } or \$3,083 { $[\$18,128 - [\$13,983 + (\$20 + 1,042)]]$ }, respectively, per hectare. And in 2015, the addition of Li700 or Bond Max to captan resulted in an economic benefit of \$5,329 { $[\$22,163 - [\$16,733 + (\$12 + \$89)]]$ }, or \$4,213 { $[\$21,277 - [\$16,733 + (\$20 + \$311)]]$ }, respectively, per hectare. These values assumed that all apples were equally valued, which is not the case as certain cultivars are more highly

valued than others, nor does this analysis does not take into account differences in fruit class. Finally, this analysis is also based upon using a rate of adjuvants that may be higher than most growers would use, so actual disease management, costs, and losses due to phytotoxicity might differ in real world applications.

In addition to potential savings of up to \$5,329 ha⁻¹, the incorporation of adjuvants could also reduce the amount of captan needed for adequate disease management throughout the season. This is important as label restrictions on captan limit growers to 44.5 kg per hectare per season, or eight applications at the recommended rate of 5.7 kg per hectare per application. But in favorable disease years, management of apple scab and bitter rot may require up to 14 applications at that rate. In order to remain within label limitations, growers must decide between lower rates of captan or fewer applications of the fungicide, potentially resulting in disease management failures. This study found that greater disease control was achieved by combining adjuvants with 11 to 12 applications of captan at a 2.7 kg per hectare rate, resulting in 29.9 to 32.6 kg per hectare of captan applied per season, thus significantly reducing the disease incidence of both apple scab and bitter rot without exceeding label limitations of captan.

In this study, we achieved greater disease management using reduced rates of captan through the use of adjuvants. Overall results showed that certain adjuvants have the potential to improve captan-based disease management compared with captan alone when conditions are favorable for disease and the host is susceptible. Although the results varied yearly, this study highlights the importance of using adjuvants to improve disease management while reducing rates of fungicide. This research also emphasizes the need for more practical studies like this one to better understand the role of adjuvants-fungicide combinations in the field environments, to reduce pesticide inputs, and improve growers' bottom lines.

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Fig. 3. Example of captan-adjuvant phytotoxicity on Golden Delicious apples.

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