Bagging Apple Fruit for Codling Moth Control in Western Montana

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ADDITIONAL INDEX WORDS. *Cydia pomonella*, integrated pest management, *Malus domestica*, urban agriculture

SUMMARY. Codling moth (*Cydia pomonella*) is a major insect pest of apple (*Malus domestica*). If unmanaged, then codling moth can infest nearly all apples in an orchard, where the flesh-tunneling larva leave frass-laden tracks in the fruit. Insecticide-based management requires accurate application timing (typically based on adult moth and/or degree-day monitoring) and multiple spray applications. Both the season-long commitment to codling moth monitoring and management and limited familiarity with insecticides, application tools, and proper application procedures can prevent a small-scale or backyard grower from effectively limiting fruit damage. In addition, an increasing segment of growers is interested in nonchemical alternatives. Bagging fruitlets early in the season could be a simple and effective method of codling moth management for this subset of growers. At our research orchard in Corvallis, MT, we tested a method combining fruit thinning and bagging using plastic bags the first season and nylon bags the second season. Plastic bags reduced the incidence of codling moth damage to fruit from 34% to 10%, but European earwig (*Forficula auricularia*) frass, which was found in more than 50% of plastic-bagged apples, made harvesting the fruit unappealing. We tested nylon fruit bags during the second year of the study. These bags did not significantly reduce the incidence of codling moth. Both the soluble solids content and titratable acidity were higher in unbagged fruit during the second year of the study, whereas color measurements indicated bagged fruit were greener on the shaded side of the fruit. Failure of the nylon bags may have been attributable to eggs laid before bagging, eggs laid or larva burrowing through bagging, or improper bag application methods. Further research could assess whole-tree bags, the addition of rubber bands or twist ties when applying nylon bags, pretreatment of fruit with horticulture oil, and/or dipping nylon bags in kaolin clay before application; however, these steps add time and increase costs, which may discourage the small-scale fruit grower. Overall, results indicate that fruit bagging holds promise for codling moth management; however, further work is needed to optimize the methodology.

Codling moth (*Cydia pomonella*) is a major insect pest of apple (*Malus domestica*) almost everywhere the fruit is grown. In Montana, frass-filled exit holes left by codling moth larva (strikes) were apparent on more than 50% of apple fruit in late summer (August or September) in some orchards west of the continental divide (Leisso et al., 2020). Management of this pest in commercial orchards requires tracking degree-days, monitoring codling moth life stages, and multiple insecticide applications (Jones et al., 2013; Murray and Alston, 2020). This level of attuned and season-long management may be excessive for small-scale, noncommercial growers who are typically not as well-versed as commercial fruit growers in safe and environmentally responsible insecticide

application, nor as familiar with the codling moth life cycle and appropriate insecticide timing. A simpler management method with potential appeal to small-scale or noncommercial growers combines fruit thinning and bagging early during the season to protect fruits from adults laying eggs on the fruit. Complete prevention of adults laying eggs on fruit is difficult because adults typically emerge near the time of full bloom;

therefore, other methods to reduce overall populations are advised (for example, removing and destroying fallen fruit, trunk banding) (Murray and Alston, 2020). Fruit bagging can reduce the need for spraying and result in a high percentage of undamaged fruit (Bentley and Viveros, 1992) and, in many cases, enhance other aspects of fruit quality (Buthelezi et al., 2021). Information is limited, however. A recent review of fruit bagging strategies called for more research because it discovered a dearth of published information pertaining to codling moth (Buthelezi et al., 2021). An extension guide by Alfuth (2019) indicates plastic bags can be effective but does not indicate the level of control. Bessin and Hartman (2019) combined Japanese apple bags or paper bags with dormant oil and two early-season insecticide applications to substantially reduce codling moth-damaged fruit (along with several diseases); however, avoiding spray applications altogether would be simpler and preferred by some backyard growers.

The objectives of this study were to evaluate fruit bagging as a strategy for mitigating codling moth damage and to determine the effects of bags on fruit quality. Because labor and time constraints are concerns for all fruit growers, we also report the time to thin and bag fruit according to each type of bag.

Materials and methods

For both years of the study, 17 trees in the middle row of a 38-tree ‘Cortland’ apple block at Montana State University Western Agricultural Research Center, Corvallis, MT (lat. 46°19′45.5 N, long. 114°5′7.4 W) were used. Fruit bagging dates and information are detailed in Table 1. We selected fruit on lower branches that did not require ladders to reach for crew safety reasons. Time spent bagging and thinning and bags remaining at harvest were recorded both years. Insecticides were not applied to the

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	g·L ⁻¹	0.1
2.54	inch(es)	cm	0.3937
0.0254	mil(s)	mm	39.3701
28.3495	oz	g	0.0353
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Table 1. Approximate apple fruit size, bagging dates, codling moth degree-days (CDD), estimated adult codling moth flight at bagging, time required to thin and bag fruit, and percent fruit damaged by codling moth according to bag type and year. The adult moth presence as indicated by biofix and the estimated proportion of adult emergence (flight) at the time of bagging implies that eggs may have been laid on fruit before bagging. Six fruit and 12 fruit per each of the 17 trees were bagged in 2019 and 2020, respectively. We also noted earwig frass in the fruit stem bowl in 2019.

	Plastic bags (2019)	Nylon bags (2020)
Fruit size at bagging	Diameter of ≈ 1.5 cm (0.59 inch)	Diameter of ≈ 1.5 cm
Bagging date	5 June 2019	1 June 2020
CDD since biofix on bagging date ^z	170	130
Estimated adult moth flight ^y	27%	20%
Thinning and bagging time per fruit	1 min and 33 s	1 min and 7 s

	Mean $\pm$ SE (%)		
Treatment	Fruit with at least one codling moth strike	Earwig frass in stem bowl	Fruit with at least one codling moth strike
Bagged	10.6 $\pm$ 3.7 b ^x	53.1 $\pm$ 7.4 ^w	18.3 $\pm$ 4.0
Unbagged	34.9 $\pm$ 9.8 a	Visual estimate: <5%	21.6 $\pm$ 2.7
P	0.0002	Not applicable	0.3312

^zBiofix defined as two moths caught two nights in a row in a codlemone lure (T3111; Trécé, Adair, OK) baited pheromone trap (Pherocon III Orange Delta Trap; Trécé). Biofix dates were 15 May 2019 and 15 May 2020. Codling moth degree-days are per USPEst.org using the online app model called "codling moth v2 (Knight 2007)" (Knight, 2014).

^yBased on Appendix 1, Table 6 in Beers et al. (1993).

^xMeans followed by a different letter in a column are statistically different according to Wald's chi-square test ($P < 0.05$).

^wNo statistics performed: very few unbagged fruits had earwig frass and no official count was performed.

bagging trial row; however, they were applied to adjacent rows both years.

In 2019, low-density polyethylene (plastic) bags measuring 6 1/2 $\times$ 5 7/8 inches (width $\times$ height) (Ziploc sandwich bags; SC Johnson, Racine, WI) were purchased (\$0.02 each retail cost at a local store) and prepared by cutting off the corners to prevent moisture buildup (Alfuth, 2019). The bagging treatment involved thinning six fruitlet clusters per tree to a single fruitlet that

had a diameter of ≈ 1.5 cm. A prepared plastic bag was slipped over each remaining fruitlet, sealed, and stapled on either side of the stem. For the control treatment, six additional fruit clusters were thinned and marked with flagging tape measuring 1 inch wide $\times$ 1 mil thick (green plastic flagging tape; Empire, Mukwongo, WI). The flagging tape length varied based on the amount needed to tie on a branch. Fruit were harvested on 2 Oct. 2019, after freezing temperatures (as low as 23 °F). Data collected for the bagged fruit included the presence of codling moth fruit strikes and the presence of european earwig (*Forficula auricularia*) frass, typically in the stem bowl (the indentation surrounding the fruit stem). The latter was unexpected but sufficiently common to warrant documentation. Because of heavy self-thinning and the loss of flagging tape for many thinned clusters, all unbagged fruit were counted and assessed for codling moth strikes as the control.

In 2020, we used nylon mesh bags to eliminate the problem of moisture collection and earwig issues observed during the plastic bag trial. Heavy-duty nylon bags (style #1040-heavy weave; Maggot Barriers, Gloucester, MA) were purchased (\$0.10 each retail price as purchased online). Bags were secured by gathering and tying the ends of the nylon tube-shaped bag around the stem (12 bags per tree). For the control

treatment, the remaining clusters on the tree were hand-thinned to one fruitlet per cluster. Because of forecasted frost, fruit were harvested on 30 Sept. 2020, and pooled into bins according to treatment. Forty fruit were selected at random from each bin to evaluate maturity. Fruit weight (grams) and surface color were recorded for all fruit. The peel color on red and green sides of the fruit were evaluated with a diffuse reflectance accessory (DRA) (Cary 60 DRA; Agilent Technologies, Santa Clara, CA) connected using a fiber-optic cable to a spectrophotometer (Cary 60 ultraviolet-Vis; Agilent Technologies) and recorded as lightness, chroma, and hue (Color App; Agilent Technologies). Then, 20 fruit for each treatment were cut in half for a starch-iodine test, which was performed and the results were rated according to the Cornell scale (from 1 to 8) (Blanpied and Silsby, 1992). Iodine-stained portions and cores were removed before fruit were processed in a juicer (model E-1188 Jack LaLanne's Power Juicer; Tristar Products, Fairfield, NJ). After juicing, a drop of juice from each fruit was analyzed to determine the soluble solids concentration (SSC) using a hand-held refractometer (model number HI96841; HANNA Instruments, Smithfield, RI); the pH and titratable acidity (TA) were assessed with a potentiometric titrator (model AT1102; Hach, Loveland, CO) equipped with

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an autosampler (AS1000; Hach) connected to a pH electrode (IntelliCAL PHC281 pH Ultra Refillable pH electrode; Hach). Juice samples were titrated to a pH of 8.2 with 0.25 M sodium hydroxide (NaOH). Results are expressed in grams of malic acid per liter of solution.

Data were analyzed with the SAS statistical package (version 9.4; SAS Institute, Cary, NC). Proportions of codling moth-damaged fruit were analyzed with PROC LOGISTIC, cumulative logit model, and Fisher's scoring optimization technique; the Wald chi-square is reported. Fruit weight, pH, TA, SSC, and color were analyzed with PROC GLM. Assumptions of normality were assessed using the Shapiro-Wilk test performed with PROC UNIVARIATE. When testing several transformations did not correct data to meet the assumption for normality, the nonparametric Kruskal-Wallis test was performed. Homogeneity of variance was tested using Levene's test. Tukey's post hoc test was used to establish the means separation when PROC GLM models were significant.

Results

In 2019, the cluster thinning and plastic bagging time required an average of 1 min and 33 s per fruit; however, in 2020, similar procedures with the nylon bags required 1 min and 7 s (Table 1). Plastic bagging reduced the incidence of codling moth from 35% of control fruit to 11%, but 53% of bagged fruit had earwig frass in the stem bowl (the indentation surrounding the fruit stem). There was no obvious damage from the earwigs. In 2020, the nylon bagging of the fruit did not reduce the incidence of codling moth strikes. Nylon bagging affected fruit quality; the SSC was lower, TA was lower, and the fruit peel color on the nonred side of fruit (sometimes called “background color”) was greener (Table 2).

In 2019, 20% of the plastic bags were lost before harvest (81 remaining out of 102 placed). In 2020, 30% of the nylon bags were lost before harvest (142 remaining out of 204 placed).

Pictures from both years of the study are available online for public use via figshare (Leisso, 2021).

Discussion

The time required to thin and bag fruit was substantial. It was estimated to be between 40 and 60 fruit/h. Neither plastic sandwich bags nor nylon bags were completely effective methods for controlling codling moth. During the present study, plastic bags reduced codling moth strikes, but nylon bags did not. This does not necessarily indicate that nylon bags are less effective than plastic bags because bag types were assessed during different years. The presence of earwig frass in more than 50% of plastic bags made harvesting unappealing, although earwigs rarely damage apple fruit (Orpet et al., 2019), and their populations will vary among orchards. The codling moth degree-days and estimated life stages at the date of bagging (Table 1) suggested that adults may have laid eggs on fruit before bagging. Avoiding codling moth egg-laying before bagging is difficult because adults typically begin emerging from pupae near the time of full bloom. Larvae also may have entered through slight gaps between the bag and fruit stem, or perhaps they burrowed their way through small holes in the nylon.

A previous study involving ‘Granny Smith’ apples thinned and paper-bagged at golf ball size showed a reduced incidence of codling moth infestation to 0.4% and 1.3% compared with 2.5% and 24.5% during the 2 years of the study; no difference in codling moth infestation was observed in fruit that were and were not thinned (Bentley and Viveros, 1992). Other apple insect control using bagging has been reviewed by Buthelezi et al., (2021).

Nylon bags affected fruit quality, as indicated by the SSC, TA, and background color. Bags could be removed several weeks before harvest to improve fruit color (Buthelezi et al., 2021). Neither bag type was salvageable for reuse during the following season; therefore, they are not suitable for growers interested in sustainability.

Conclusions

Enclosing ≈1.5-cm-diameter apple fruitlets in plastic bags reduced codling moth damage to fruit, but the presence of earwig frass and moisture in the bag (despite cutting corners off the bags) made harvest unappealing. During a

Table 2. Apple fruit quality for unbagged fruit versus fruit maintained in nylon bags through harvest in 2020. Results of the starch, soluble solids content (SSC), pH, and titratable acidity (TA) are reported for 20 fruit per treatment. The weight and color measurements of lightness, chroma, and hue are reported for 40 fruit. Fruit were selected at random from the harvest of the 17 trees included in the trial.

Mean ± SE											
Treatment	Starch (1–8 scale) ^z	Wt (g/fruit) ^y	SSC (%)	pH	TA (g·L ⁻¹) ^x	Lightness of red side (L*)	Chroma of red side (C*)	Hue angle of red side (h°)	Lightness of green side (L*)	Chroma of green side (C*)	Hue angle of green side (h°)
Unbagged	3.6 ± 0.3	150.6 ± 5.1	14.3 ± 0.1 a	3.35 ± 0.01	8.6 ± 0.3 a ^w	43.4 ± 0.7	32.2 ± 0.9 b	24.3 ± 1.1	63.7 ± 1.3 b ^v	33.2 ± 1.1 b	88.8 ± 3.5 b ^v
Bagged	3.6 ± 0.4	140.7 ± 6.3	13.8 ± 0.1 b	3.38 ± 0.01	7.8 ± 0.3 b	42.5 ± 1.0	37.2 ± 0.8 a	26.7 ± 1.7	74.7 ± 0.6 a	40.1 ± 0.7 a	107.7 ± 0.6 a
<i>P</i>	1.0000	0.2266	0.0327	0.0763	0.0450	0.4219	<0.0001	0.2208	<0.0001	<0.0001	<0.0001

^zStarch scale reported by Blaupied and Silsby (1992).

^y1 g = 0.0353 oz.

^xTitratable acidity in terms of malic acid; 1 g·L⁻¹ = 0.1%.

^wMeans followed by different letters in a column are statistically different according to Tukey's honestly significant difference ($P < 0.05$), except when the nonparametric Kruskal-Wallis test statistic was used.

^vNonparametric Kruskal-Wallis test statistic because of the lack of homogeneity of variance ($P < 0.05$).

separate study year, nylon bags did not reduce codling moth damage to fruit, and the point of failure is unclear. Possible explanations include eggs laid on fruit before bagging, larvae entering fruit in slight gaps between the bag and the stem, or eggs laid on top of bags and larvae burrowing their way through the knit of the nylon into the fruit. Future research could include spritzing the fruit with horticultural mineral oil before applying bags (to kill any eggs), adding twist ties or rubber bands to secure bags, or dipping nylon bags in a kaolin clay solution before applying them. Additionally, whole-tree bags could be assessed.

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