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Codling Moth Survival in Cherry: Effect of Cultivars and Fruit Maturity

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Abstract

The codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) is a quarantine pest for sweet cherries, *Prunus avium* (L.), exported to Japan. Development of rearing techniques for codling moth on cherries would improve the disinfestation methods and increase the understanding of the pest-host relationship. Hence, codling moth development from first instar to adult was studied in the laboratory on sets of immature and mature fruits of 'Bing', 'Cashmere', 'Chelan', 'Rainier', and 'Van' cultivars. Immature apples were used as controls. Larvae developing from cherries took significantly longer to become adults than those from apples. The highest adult emergence from infested cherries was from 'Chelan' with 16% from immature fruits and 8% from mature fruits, whereas emergence was < 6% from other cherry cultivars. Adult emergence from apples was 62 to 77%. Weight and fecundity of female adults from cherries were significantly less than those reared from apples. These results demonstrate that although codling moth can be reared from cherry under controlled laboratory conditions, host suitability of the fruit is poor, and postharvest disinfestation treatments for fruits intended for export need not be as severe as those for other quarantine pests.

Sweet cherries, *Prunus avium* (L.), shipped to Japan from the United States must be fumigated with methyl bromide to destroy possible infestation by the codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) (13, 16). Codling moth development in pome fruits and walnuts is well documented (3), but codling moth survival in cherries has been questioned (20). Furthermore, microscopic inspection of 6,400 cherries from 30 growing areas in Washington state found no codling moth (14). In more than 710 million cherries from western United States inspected between 1978 and 1996, regulatory officials found only eight codling moth larvae, all but one from California (20).

The development of postharvest quarantine treatments requires large numbers of insects (1, 8, 13). However, disinfestation procedures against codling moth in cherries would be impeded if relying on only field infested fruits. In spite of intensive orchard monitoring for pest management programs, no field populations of codling moth have been reported on cherries. Devising the methodology to rear this insect on cherries would greatly aid in testing and improving disinfestation techniques, and determining the preferred host would be the initial phase of this process. Furthermore, survival tests on codling moths should be conducted on typical commercial fruits to obtain inferences on codling moth biology under field conditions. Thus, the objective of this study was to evaluate a range of potential hosts by measuring codling moth survival from first instar to adult on immature and mature fruits of commercial cherry cultivars.

This study required using laboratory reared insects for several reasons. First, laboratory reared insects were convenient, readily available, and were of a known age group, whereas wild insects would have to be collected from different sources and these would have a range of physiological ages. Laboratory reared insects have been adapted to laboratory conditions, which would improve likelihood of successful

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development whereas wild strains may not do well under confined conditions (5, 11, 18). Codling moths from this laboratory colony have been used in large numbers (>30,000) for quarantine tests on cherries and have been accepted in other postharvest and physiological tests. Finally, laboratory reared insects have been exposed only to an artificial diet so that there is no selection preference for a particular fruit, such as wild moths reared from apple.

Materials and Methods

Cherry Cultivars. Fruits of five cherry cultivars ('Bing', 'Cashmere', 'Chelan', 'Rainier', and 'Van') were obtained from growers in the Yakima Valley and Lower Columbia River Basin in central Washington state. Immature and mature fruits of each cultivar were tested separately, except for immature 'Cashmere' which was not available. All cultivars have dark red skins except 'Rainier', which is golden skinned. 'Chelan' has the earliest ripening season, followed by 'Cashmere'; the remaining are harvested about the same time.

Test Insects. Codling moth eggs were obtained from a colony reared at the USDA-ARS Yakima Agricultural Research Laboratory and maintained on a soya-wheat germ-starch artificial diet (18) at ≃ 27°C, 40 to 50% RH, with a 16:8 hr light: dark photoperiod.

Fungicide Test. Previous observations revealed that postharvest fungal fruit diseases were detrimental to adult moth emergence from laboratory-infested cherries (Hansen, unpublished data). Fungal infections were from multiple species, likely including *Alternaria, Botrytis, Cladosporum, Penicillium,* and *Rhizopus* spp. (9, 17). These fungal infections were not identified because identification to species is difficult, requiring isolation of colonies and formation of particular diagnostic structures.

Because the fungal infections destroyed fruit integrity, eliminating disease would enhance codling moth development. Thus, the effect of Rovral® (Rhone-Poulenc Ag Co., Research Triangle Park, NC), iprodione: 3-(3,5-dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide, was examined to determine if the fungicide reduced fruit disease on cherries and if it affected codling moth survival. Immature 'Chelan' cherries, with and without fungicide ($n = 50$ for each of four replicates), were infested as described below. Adult emergence and time of first appearance of fungus was compared between those with and without fungicide. Untreated, uninfested immature cherries served as controls for the fungal test.

Treatment Procedures. To reduce fungal infections, all cherries to be infested were dipped in the fungicide Rovral® at 2.4 gm/ liter water, then air dried. Each cherry was infested by using a small brush to place a newly hatched larva near the stem end, then the infested fruit was contained in a tapered plastic cup (3 cm bottom dia, 4 cm top dia, 4 cm ht) with a plastic top and maintained in a 25°C rearing room. Uninfested cherries without fungicide were controls for fruit quality and were held in the same type of containers in the same rearing room. Immature apples (ca. 3 cm dia), organically-grown and not treated with fungicide, were used as controls for codling moth development and were similarly infested with one first instar per fruit and held in the same rearing room. A treatment consisted of a single cherry cultivar at the same maturity level, either immature straw color stage or fully mature. Each treatment replicate included 50 infested cherries with 25 infested apples and 10 uninfested cherries as the controls, and the treatments were replicated four times.

Data Collection. Cherries were observed weekly for larval viability, instar, condition of the fruit based on a visual inspection scale (from "0", with no damage, to "9", complete destruction), and the presence of fungal disease recorded for each observation. Excess fluids were drained off as necessary, because the cherries deteriorated from fungal disease. Missing larvae were assumed dead, which is standard procedure when evaluating quarantine treatments against the codling moth (8, 13). Corrugated cardboard squares were attached to the inner side of the lid tops to provide pupation sites for larvae emerging from apples and cherries. After pupation, fruits were removed from the containers and cardboard squares examined for moth emergence every other day. Newly emerged adults were killed by freezing, then weighed using a yearly calibrated C-31 Microbalance (Cahn Instruments, Inc., Cerritos, CA). Female specimens were held in 70% isopropanol until dissected under a stereomicroscope where ovarian development was assessed by using Ferro and Akre (6) as a guide to internal anatomy. Eggs (≥ 0.2 mm dia), which were clearly visible using the 30X power of the microscope, were counted within each moth.

Data Analysis. Data summary, statistical tests, and linear regressions were done using SAS (15). Nonlinear regressions were conducted by using TableCurve V.3 (12). Equality of two population regression coefficients was determined by using the t-test (21).

Results and Discussion

Fungicide Test. Adult codling moth emergence was significantly greater (t = 9.80, df = 3; P < 0.05) from Rovral® treated fruits (mean ± SEM % emergence/ rep = 16.0 ± 6.1%) than from nontreated cherries (mean ± SEM % emergence/ rep = 1.0 ± 0.6%). The mean (± SEM) duration of uninfested immature 'Chelan' cherries, without fungicide, was about 39 (± 5) days before first showing signs of disease. The fungicide significantly prolonged cherry quality (t = 8.23, df = 3; P < 0.01); infested immature cherries with fungicide lasted about 26 (± 1) days before disease, whereas those without fungicide went 16.6 (± 0.5) days. Thus, the fungicide had no net detrimental effect on larval development.

Time to Emergence. Larva took longer to develop from cherry cultivars than from apples, regardless of cherry maturity (Fig. 1). Adult moths emerged from apples as early as three weeks. Average time for first adult emergence among the cherry cultivars was the shortest for 'Rainier' mature cherries at about 35 days and, for most cultivars, moth development was significantly longer in each cultivar ripeness category than in the respective apple control. The delayed development in cherries suggests that cherries are less suitable than apples as a host for rearing codling moth larvae in the laboratory.

Adult Emergence. Adult emergence in the apple controls ranged from 62 to 77 % (Table 1), and no significant differences were found among the apple controls for the different cherry cultivars (F=1.65; df=5, 30; P>0.05). Among the cherry cultivars, 'Chelan' had the highest average rate of adult emergence: 16% from immature fruits, 8% from mature fruits (Table 1). The remaining cherries had < 6% with 'Bing' having the lowest rate of adult moth emergence: 1.6% from immature fruits, 1.0% from matuıe fruits. Some replicates had no adult emergence.

Adult weights and fecundity. Adult moths emerging from the control apples were always heavier than from the corresponding cherries (Fig. 2 & 3). Also, female adults were heavier than males. Females emerging from apple ranged in weight from 4.9 to 32.9 mg and from 5.2 to 26.7 mg for those emerging from cherries. Males emerging from apple ranged in weight from 5.3 to 22.7 mg and from 4.7 to 16.0 mg for those emerging from cherries. Differences between adult weights of moths reared from either a cherry cultivar or its apple control were significant for all studies except females in immature 'Bing' and males in immature 'Van' and mature 'Rainier'. The lack of a statistical differences between weights of males emerging from apples and immature 'Van' or mature 'Rainier' may be a mathematical artifact due to the disparity in the number of adult moths emerging from the fruits (from apples: n ≥ 40; from cherries: n = 1) to produce a sufficient test (21) .

The size differences in moths reared from different types of fruit suggest poorer development from cherries. The heaviest moths reared from a cherry cultivar came from immature 'Chelan' (Fig. 2 & 3),

Table 1. Mean (and SEM) of % adult codling moth emergence from larvae reared on individual cherries (4 replicates at 50 cherries per replicate).

		Cherry		Control[a]		Comparison[b]	
Cultivar	Ripeness	Mean	SEM	Mean	SEM	*t*	p[c]
Bing	Immature	1.6	0.6	66.0	5.6	27.43	**
	Mature	1.0	0.6	76.8	4.0	22.59	**
Cashmere	Mature	4.4	1.2	65.0	1.0	25.60	**
Chelan	Immature	16.0	6.0	63.2	8.0	4.50	ns
	Mature	8.0	1.0	62.0	2.4	24.00	**
Rainier	Immature	4.0	1.2	63.2	8.8	19.20	**
	Mature	4.0	1.2	62.0	3.5	20.21	**
Van	Immature	1.0	0.6	72.8	7.6	16.15	*
	Mature	5.6	2.2	72.0	2.8	21.33	**

[a]25 apples used per replicate.
[b]Wilcoxon rank sum test with df=6.
[c]Significance level: ns = not significant, * = $P<0.05$, ** = $P<0.01$.

which alone among all the cherries examined had a survival rate not different statistically from its control. Further evaluation is needed to determine why moths were so successful in 'Chelan'.

Adult moth weights from this study were lower than those observed in other studies. Wearing and Ferguson (19) reported that the average weight of adult females reared from 'Delicious' apples was 26.6 mg. Hathaway et al. (10) found that the average weight of adult female codling moths reared from immature apples was 29.1 mg. Geier (7) observed that the aver-

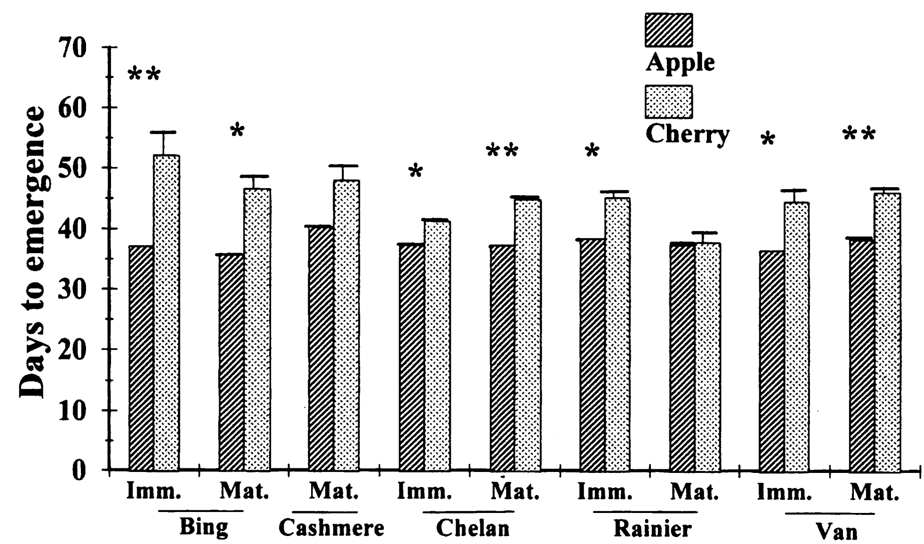

Figure 1. Mean (± SEM) number of days to codling moth adult emergence from immature and mature cherries of different cherry cultivars and their respective controls. Significance (*=$P<0.05$, **=$P<0.01$) between cherries and controls determined by Wilcoxon rank sum test for two samples.

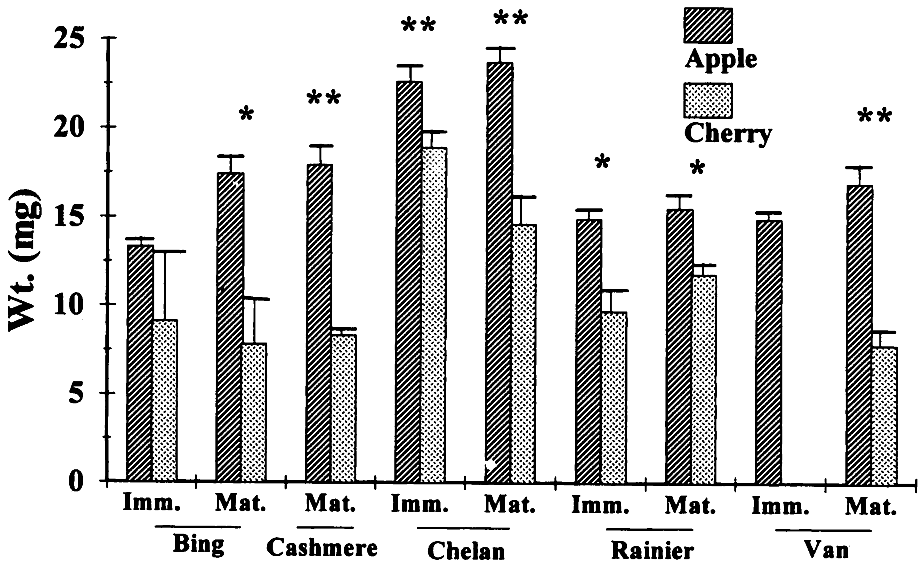

Figure 2. Mean (± SEM) weights (mg) of female codling moth adults emerging from immature and mature cherries of different cherry cultivars and their respective controls. Significance (*=P<0.05, **=P<0.01) between cherries and controls determined by Wilcoxon rank sum test for two samples.

age weight of newly emerged female moths ranged between 25 to 28 mg, depending on the seasonal generation.

Female adult moths from apples had more eggs than those from cherries for every study (Fig. 4). The number of eggs per female ranged from 0 to 136 for females emerging from apple and from 0 to 62 for females emerging from cherries, with females from immature 'Chelan' the most fecundate of the cherry-reared moths. Previously, Wearing and Ferguson (19) found the total number of eggs for moths reared from 'Delicious' apples ranged from 0 to 284. Geier (7) listed estimated or observed average egg production reported in a dozen studies to be from 5 to 80 eggs per female, depending on food supply, location and seasonal generation.

Correlation between adult female weight and the number of eggs could not be made for each cherry cultivar and maturity level because of the few moths that emerged, but the relationship was significant when all cherry data were pooled (r=0.556; df=39, P<0.01). For all apple data, female adult weight was highly correlated with number of eggs (r= 0.333, df=246, P<0.01). When the regression coefficient of the cherry correlations (β = 0.207) was compared to that of the apples (β = 0.068), no statistical difference was found (t = 1.658, df = 286; P>0.05). Earlier, Geier (7) found a positive correlation between adult female weight and the number of oocytes in the ovarioles. Cisneros and Barnes (4) also reported a similar relationship using pupal weight of females. Information from the current study suggests that oocyte reproduction is impeded when larvae develop in cherries, resulting in fewer eggs than when development is in apples.

Fungus Relationships. Most infested cherries were destroyed by various fungi, probably including *Alternaria, Botrytis, Cladosporum, Penicillium*, and *Rhizopus* spp., all common postharvest diseases of cherries (9, 17). Even with a fungicide, cultivars differed to time of first sign of

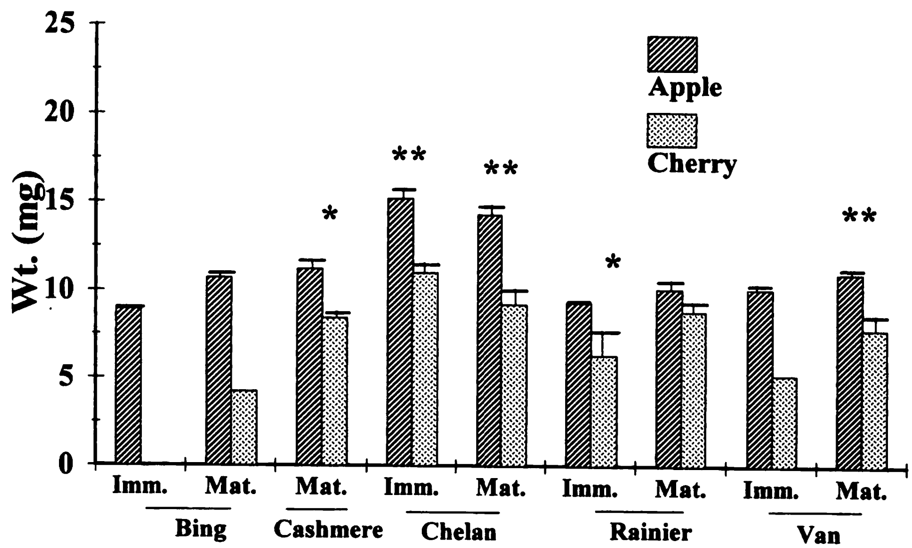

Figure 3. Mean (± SEM) weights (mg) of male codling moth adults emerging from immature and mature cherries of different cherry cultivars and their respective controls. Significance (*=P<0.05, **=P<0.01) between cherries and controls determined by Wilcoxon rank sum test for two samples.

fungus by level of maturity, cultivar, and whether infested or not (Fig. 5). In contrast, the time to the first fungal observation among the control apples was about 25 days, which was not significantly different among the studies (F=1.19; df=5, 30; P>0.05).

A descriptive model was developed by using nonlinear regression analysis of the average adult emergence with average days to first observation of fungus for each cultivar. An exponential equation,

$$y=a+b^{(-x/c)},$$

provided a good fit (r^2=0.890) where y is the percentage of adult emergence, x is days to first observation of disease, and the equation parameters (±SEM) are 2.18(±0.99) for a, 1.45 x 10^{-6} (±7.12 x 10^{-6}) for b, and -1.64 (±0.50) for c. According to this model, the rate of adult emergence remains about the same with the first fungal observation until day 22 when the rate of emergence increases greatly. That is, if an infested cherry can survive for more than 22 days, then the likelihood of codling moth survival increases greatly. However, maintaining infested cherries disease-free at room temperature for more than three weeks would be unusual.

Missing larvae. Although fruit were confined in enclosed containers, larvae were frequently not found in diseased fruits, where conditions became so severe that larval cadavers if encountered were often in an advanced state of decomposition. Furthermore, the numbers of larvae missing were significantly different among cultivars for each maturity level (immature fruits: F=13.77; df=3, 12; P<0.01; mature fruits: F=11.84; df=4, 15; P<0.01). Immature 'Bing' had the greatest proportion (51% overall) of missing larvae. 'Rainier' and 'Chelan' had the lowest percentage of missing larvae (< 20%) for both cherry maturity levels. The proportion of missing larvae, which ranged from 3 to 15%, were not significantly different among the apple controls.

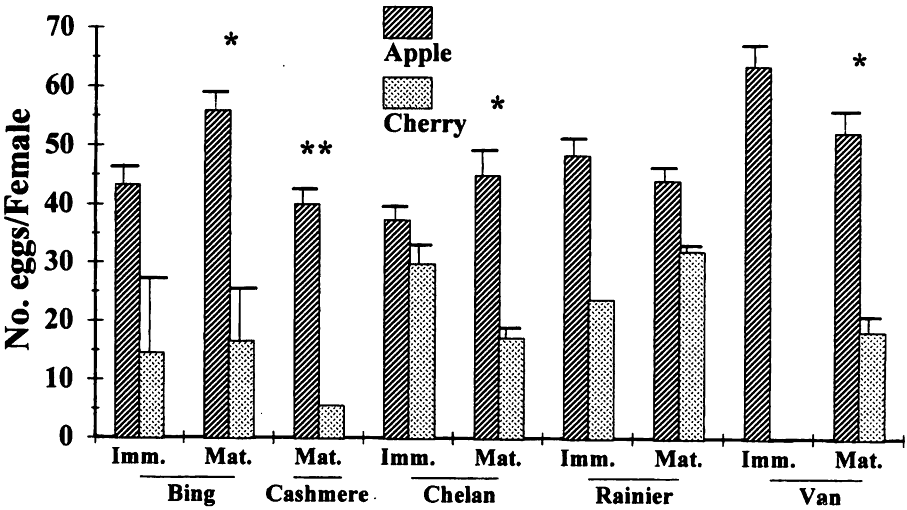

Figure 4. Mean (± SEM) number of eggs per female codling moth adults emerging from immature and mature cherries of different cherry cultivars and their respective controls. Significance (*=P<0.05, **=P<0.01) between cherries and controls determined by Wilcoxon rank sum test for two samples.

In an earlier study on codling moth infested cherry fruits, about half of the larvae were not found (Hansen, unpublished data). Fruit disease was suspected as the cause for missing larvae because of the prevalent rapid break down of the fruits. In this study, fungal infections were delayed by the use of Rovral®, resulting in fewer missing larvae and improved adult emergence. Because disease control is essential for rearing codling moth in cherry, other fungicides should be examined. However, some quarantine studies may be problematic because Japan prohibits fungicide application on imported cherries.

Conclusions.

The fungicide treatment prolonged the life of cherries long enough for codling moth development to be completed, but less than 6% of the first instars developed to adults in most cherry cultivars (Table 1). Furthermore, the female adults that did survive were smaller and less fecund than those that emerged from apples. Thus, cherries are a poor host for codling moth and these fruits should be handled differently than well-established codling moth hosts. For example, postharvest quarantine treatments need not be as intense as current treatments because even if infested, there will be high pest mortality. This is in keeping with Baker's (2) original concept of applying probit-9 security

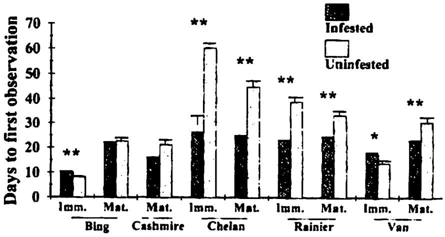

Figure 5. Mean (± SEM) number of days to first observation of fungal disease on immature and mature cherries of different cherry cultivars infested with codling moth and uninfested. Significance (*=P<0.05, **=P<0.01) between infested and uninfested cherries determined by Wilcoxon rank sum test for two samples.

(99.99683% mortality). Also. less severe treatments would result in higher quality fruits for export, which may lead to increase in market demand. Thus. the economic advantage of improved postharvest handling would be commercially beneficial to all parties.

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