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COMPARISON OF THE COSTS OF MATING DISRUPTION WITH TRADITIONAL INSECTICIDE APPLICATIONS FOR CONTROL OF CODLING MOTH IN APPLE ORCHARDS IN TURKEY

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Abstract

Mating disruption is an alternative control tactic that prevents male insects from finding females, resulting in lower pest density and less crop damage. However, the relatively high cost of mating disruption compared to the conventional chemical control may be an impediment to its adoption by growers worldwide. Therefore, this study aimed at comparing the costs of mating disruption with insecticides for control of codling moth, Cydia pomonella L., in apple orchards in Turkey in 2013 and 2014. Experimental orchards consisted of semi-dwarf 'Gala' and 'Fuji' apple cultivars. Codling moth populations, the number of insecticide applications and management costs varied between cultivars and years. When averaged over cultivars, mating disruption decreased the total number of sprays for apple pest complex by 40.70% and 56.60% in 2013 and 2014, respectively. All control costs related to the number of insecticide sprays, the application of pheromone dispensers, labour, machinery, fuel and other pheromone-based expenses such as pest monitoring were analyzed. Based on partial budgeting analysis, mating disruption treatments lowered insecticide and machinery costs but increased labour costs compared with conventional treatments. The cost of mating disruption ranged from $193.70 higher than the conventional treatment in cv. 'Gala' in 2013 to $ 96.00 less than the conventional treatment in cv. 'Fuji' in 2014. A break-even analysis showed that a price decrease of 22.22% and 70.37% for pheromone dispensers would be required to convince growers to use mating disruption in cvs. 'Gala' and 'Fuji' in 2013, respectively. However, the cost of mating disruption programme was similar or less than a conventional insecticide programme in 2014. The reduction of initial pest density, as well as the improvement of biological control, could lead to the development of more cost-effective and efficacious mating disruption programmes in subsequent years.

Key words*: Cydia pomonella L., chemical control, cost analysis, economics, pheromones.*

INTRODUCTION

Codling moth *(Cydia pomonella* L.) is a key deciduous fruit pest that poses a great economic threat to growers worldwide. Apart from apple, it also attacks pear, walnut, and quince (Witzgall, 2008). Damage is done by larvae, which feed on the fruit skin and bore deeply into the fruit. Larvae can cause up to 100% damage in untreated orchards (Elkins et al., 2005). Damaged apples are culled before packing, making it more challenging for growers to maintain profitability.

Codling moth management mainly relies on chemical control. Two to three cover sprays are commonly used to target hatching eggs and larvae of the first generation codling moth (Kovanci, 2015). In Turkey, growers begin to spray insecticides such as diflubenzuron, methoxyfenozide, novaluron or thiacloprid with an air-blast sprayer at 150 degree-days after the biofix in pheromone traps. Likewise, second generation codling moth larvae are also treated with at least two insecticide sprays at 800 degree-days.

However, the increasing resistance of codling moth populations to insecticides, coupled with adverse effects on beneficial insects, have led to control failures in the field (Reyes et al., 2007). In addition to high costs of chemicals, spraying equipment and gas, insecticide resistance has already increased control costs with traditional insecticide applications. Additional indirect costs of pesticide use on the human health and environment remain to be evaluated. Thus, there is a great need for alternatives to chemical control.

Mating disruption is an alternative control tactic that prevents male insects from finding females, resulting in lower pest density and less

crop damage (Cardé and Minks, 1995). In this technique, growers apply large quantities of pheromone dispensers to cause no or delayed mating by disrupting chemical communication in the orchard. Mating disruption has proven to be a viable alternative method to control key pests including the codling moth, Oriental fruit moth (*Grapholita molesta* Busck.) and pink bollworm (*Pectinophora gossypiella* Saunders) (Cardé and Minks, 1995).

Unlike chemical control, mating disruption has no known toxicity or adverse effects on natural enemies so far. Besides, it has the potential to reduce or eliminate the need for insecticide treatments. However, pheromone dispensers are more costly than insecticides. Placement of pheromone emitters is labour intensive since they must be hand-deployed high in the canopy in most orchards (Elkins and Shorey, 1998).

In this context, the paper presents a detailed cost analysis of mating disruption versus conventional chemical control in 2013 and 2014. The objective of this study was to determine if the adoption of mating disruption would be financially feasible for control of codling moth in apple orchards in Turkey.

MATERIALS AND METHODS

Data on codling moth population, insecticide and pheromone use and cullage rates were collected on two apple orchards in 2013 and 2014. The orchards were located in Deydinler village of Inegol town (40.03° N, 29.53' E) near Bursa, Northwestern Turkey. One orchard contained semi-dwarf cv. 'Gala trees' on M.9 rootstock, while the other orchard contained semi-dwarf cv. 'Fuji trees' grafted on M.26 rootstock. Trees were trained with the tall spindle at a spacing of 1.7 x 3.3 m, resulting in approximately 1750 trees per ha. Fuji trees had central leader training with 2 x 4.5 m spacing (1100 trees/ha).

Each orchard was 10-ha in size and allocated into two 5-ha plots for mating disruption and chemical control. Conventional insecticide plots were separated by at least 500 m from mating disruption plots.

In the chemical control plots, Fuji trees received a total of 5 and 6 applications for control of codling moth in 2013 and 2014, respectively, whereas Gala trees had only a total of 3 and 4 sprays. A total of two cover sprays were made with diflubenzuron (Dimilin 48 SC, Hektas, Turkey) at 20 ml/ 100 l water (300 ml/ha) against eggs and larvae of first generation codling moth on May and June in both years. Depending on years, one to four thiacloprid (Calypso 240 OD, Bayer, Turkey) at 40 ml/ 100 l water (400 ml/ha) and methoxyfenozide (Prodigy 240 SC, Dow Agro Sciences, Turkey) treatments at 60 ml/100 l water (400 ml/ha) were applied to control second generation codling moth in July and August in 2013 and 2014.

In mating disruption plots, thiacloprid was applied once to control codling moth in mid-May before pheromone application. Pheromone dispensers (Isomate C Plus®, Sumitomo, Turkey) were hung on trees by hand at 1000 dispensers/ha in early-June each year. Each dispenser was baited with 190 mg of codling moth pheromone containing (E, E) - 8, 10-Dodecadien-1-ol. Four pheromone traps (Pherocon CM, Trece, USA) were used for monitoring codling moth adults in each plot.

Points of indifference between mating disruption and insecticide sprays at different prices for pheromone dispensers were determined by break-even analysis. For this purpose, cullage records were obtained from growers in both years. Data was evaluated using t-tests at 95% confidence level (Williamson et al., 1996).

In order to predict percent damage by codling moth larvae, fruit assessments were made by picking 100 fruit randomly from each of the 10 trees per treatment. Fruits with stings, entries and live larvae were counted and analyzed by ANOVA. The presence of codling moth larvae was confirmed by cutting fruits.

The technique of partial budgeting was used to examine the cost differences between two management alternatives for codling moth. The US dollar ($) amounts were provided using an exchange rate of 1TL = 0.5$ at the time of the study. The price per unit of pheromone and insecticide materials were multiplied by their amount of use to calculate the final cost per ha.

In budget assumptions for machinery, predicted fuel and lubrication costs of a 60 h.p. tractor with an air-blast sprayer were at $ 2.00 per hour of operation. The same sprayer had estimated repair costs at $ 1.00 per hour. An

average spray may need 1 machine hour per ha. Hence, fuel and lube cost for spraying in insecticide plots were calculated as 1 hour x $2.00/hour x number of sprays. Similarly, one insecticide spray in mating disruption plots costs $ 2.00 (1 hour x $ 2.00/hour x 1 spray).

The labour for machinery and placing pheromone dispensers in the orchard were also calculated. Machine labour cost for insecticide sprays was calculated using the following formula, where the value 1.10 represents the need for 10% more man hours to refill or clean the sprayer (Williamson et al., 1996): Machine labour cost = Machine hours x 1.10 x $ 2.00/hour x number of sprays.

The labour for hanging pheromone dispensers at 1000 dispensers/ha by hand was estimated to cost $ 4.00 per hour. The installation takes about 5 hours per ha to complete. Thus, pheromone applications would cause an estimated increase of $ 20.00 in labor costs to deploy pheromone dispensers.

Each pheromone dispenser cost $ 0.27, with a total of $ 270.00 per ha. Other pheromone related expenses included monitoring of codling moth and other pests with pheromone traps or visual inspection. A pheromone trap package for codling moth costs $ 30 per ha. Fixed or overhead costs were considered unchanged between operations using mating disruption and conventional insecticide.

RESULTS AND DISCUSSIONS

Mean codling moth catch in pheromone traps averaged across cultivars in 2013 and 2014 in Bursa, Turkey is shown in Figure 1.

Codling moth populations were higher in 2014 than in 2013. Pheromone traps in mating disruption plots caught fewer moths compared with insecticide plots in both years.

Insecticide applications for all mite and insect pests of cv. 'Gala' and 'Fuji' apples in mating disruption and insecticide plots in 2013 and 2014 are given in Table 1.

'Fuji' cultivar required 1.5 to 2 times more insecticide applications than cv. Gala as this variety was more susceptible to aphids, spider mites and codling moth (Yiem 1993; Joshi et al., 2015). When averaged over cultivars, mating disruption decreased the total number of sprays for apple pest complex by 40.70% and 56.60% in 2013 and 2014, respectively.

Depending on the years and cultivars, a total of four to 10 sprays was eliminated in the mating disruption plots. Insecticide applications for codling moth were reduced from three to six in the conventional programme to one in the mating disruption programme.

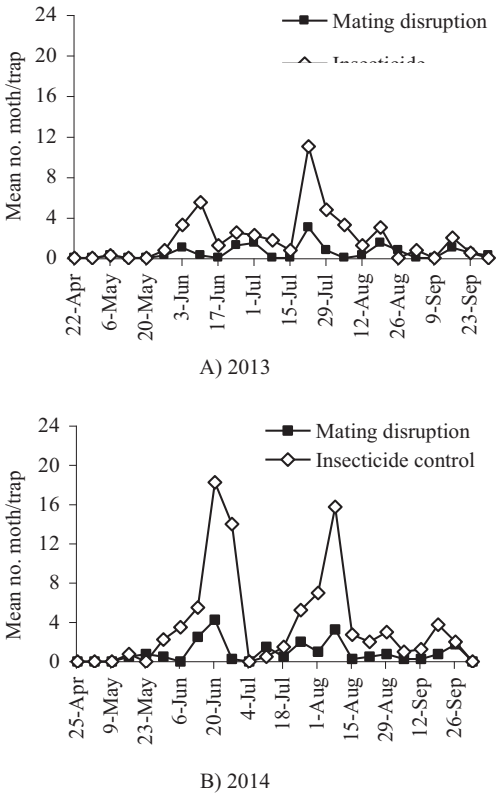

Figure 1. Mean codling moth catch in pheromone traps averaged across cultivars in mating disruption and insecticide plots in 2013 and 2014 in Bursa, Turkey

Depending on the years and cultivars, a total of four to 10 sprays was eliminated in the mating disruption plots. Insecticide applications for codling moth were reduced from three to six in the conventional programme to one in the mating disruption programme.

There were significant cost differences between conventional control and mating disruption in terms of materials, labour, and machinery (Table 2).

Table 1. Number of insecticide applications for all insect and mite pests of cvs. 'Gala' and 'Fuji' apples in mating disruption and insecticide plots in 2013 and 2014 in Bursa, Turkey

Variety	Insect pests[1]	2013			2014		
		Insecticide	Mating disruption	Difference	Insecticide	Mating disruption	Difference
'Gala'	Apple sawfly	1	1	0	2	2	0
	Aphids	2	1	1	2	1	1
	Budworm moths	0	0	0	0	0	0
	Codling moth	3	1	2	4	1	3
	San Jose scale	1	1	0	2	0	2
	Spider mites	2	1	1	2	1	1
	Total	9	5	4	12	5	7
'Fuji'	Apple sawfly	2	1	1	1	2	-1
	Aphids	4	3	1	5	3	2
	Budworm moths	1	1	0	1	0	1
	Codling moth	5	1	4	6	1	5
	San Jose scale	2	2	0	2	1	1
	Spider mites	4	3	1	3	1	2
	Total	18	11	7	18	8	10

[1]Apple sawfly = *Hoplocampa testudinea* (Klug); Aphids = *Dysaphis plantaginea* (Pass.), *D. devecta* (Walker), and *Eriosoma lanigerum* (Hausmann); Budworm moths = *Spilonota ocellana* (Den. & Schiff.) and *Hedya nubiferana* (Haworth); Codling moth = *Cydia pomonella* (L.); San Jose scale = *Quadraspidiotus perniciosus* (Comstock); Spider mites = *Panonychus ulmi* (Koch), *Tetranychus urticae* Koch, and *T. viennensis* Zacher

Table 2. Cost of materials, labour and machinery per ha compared between mating disruption and insecticide treatments consisting of cvs. 'Gala' and Fuji apples in 2013 and 2014 in Bursa, Turkey

Year	Cultivar	Treatment	Total no. applications[1]	Materials ($/ha)	Labour ($/ha)	Machinery ($/ha)	Total	Difference	Break-even analysis ($/dispenser)
2013	'Gala'	Insecticide	9	202.50	19.80	47.00	278.30		
	'Gala'	Mating disruption	6	420.00	31.00	15.00	472.00	-193.70	-0.19
	'Fuji'	Insecticide	18	382.50	39.60	150.00	590.10		
	'Fuji'	Mating disruption	12	532.50	44.20	61.00	649.70	-59.60	-0.06
2014	'Gala'	Insecticide	12	300.00	26.40	76.00	414.40		
	'Gala'	Mating disruption	6	368.00	31.00	19.00	424.00	-9.60	-0.01
	'Fuji'	Insecticide	18	397.50	39.60	170.00	625.10		
	'Fuji'	Mating disruption	9	442.50	37.60	40.00	529.10	96.00	*[2]

[1] Mating disruption treatments included one pheromone dispenser application plus insecticide applications.
[2] Since mating disruption was more cost-effective, there was no need to calculate a decrease in dispenser.

Mating disruption treatments lowered insecticide and machinery costs but increased labour costs compared with conventional treatments. Our findings are in agreement with those of Williamson et al. (1996).

Savings in insecticide expenditures varied from $ 120.00 in cv. 'Gala' to $ 255.00 in cv. 'Fuji'. Inconsistent with our results, Elkins et al. (2005) reported an average savings of $ 99 per ha in pesticide costs per year in pear orchards treated with pheromone puffers for control of codling moth. However, material costs in mating disruption plots were higher than insecticide plots due to the high cost of pheromone dispensers. The time-consuming installation procedure of pheromone dispensers caused a slight increase in labour costs in mating disruption blocks in most cases except for cv. 'Fuji' in 2014. Therefore, the cost of mating disruption ranged from $ 193.70 higher than the conventional treatment in 'Gala' in 2013 to $ 96.00 less than the conventional treatment in 'Fuji' in 2014. Similar to our cost calculations with cv. 'Gala' in 2013, Williamson et al. (1996) found in 'Red Delicious' apple orchards that codling moth mating disruption was $ 188.22 per ha more costly than conventional control on average. The cost difference could be perceived as the price of switching from conventional chemical control to mating disruption. Apparently,

management costs change from crop to crop, cultivar to cultivar, and year to year. Brumfield et al. (2004) demonstrated a lower of cost mating disruption for Oriental fruit moth, *Grapholita molesta* (Busck), in peach orchards containing cv. 'Redhaven', 'John Boy' and 'Encore', but not in those with cv. 'Bounty'. However, it is important to note that the researchers did not calculate machinery costs and labour in their study. Codling moth damage and cullage data were analyzed to compare the cost differences between the two treatments. The percent total culls in 2013 were 27.40% and 30.80% in insecticide and mating disruption plots, respectively, while they increased to 35.10% and 36.00% in 2014 in the same order. In apples, codling moth is responsible for about 10% of cullage, with an average of 2-3% damage (Hansen and Schievelbein, 2002). In fact, levels of percentage damage by codling moth larvae in traditional insecticide plots were 0.90% and 1.50% in 2013 and 2014, respectively (Table 3). On the other hand, percent larval damage was higher than the economic threshold of 2% for codling moth (Kovanci et al., 2010) in mating disruption plots with 2.20% and 3.70% infestation recorded on apples in 2013 and 2014, respectively. Our results showed that mating disruption did not cause any significant increase in cullage.

Table 3. Mean percent fruit damage by codling moth larvae averaged over cultivars in mating disruption and insecticide plots in Bursa, Turkey in 2013 and 2014.

		Damage[b](%)			
Year	Treatment	Sting	Entry	Larvae	Total
2013	Mating disruption	0.5 a	0.9 a	0.8 a	2.2 a
	Insecticide	0.5 a	0.3 a	0.1 a	0.9 a
2014	Mating disruption	1.5 a	1.1 a	1.1 a	3.7 a
	Insecticide	0.8 a	0.4 a	0.3 a	1.5 a

A break-even analysis was made based on the difference in costs between mating disruption and insecticide applications. To determine a break-even situation, cost differences for each cultivar and year were divided by the number of pheromone dispensers applied (1000/ha). Our findings indicated that about 22.22% price decrease in pheromone dispensers was needed to convince growers to use mating disruption in cv. 'Gala' apples in 2013. Even higher price reduction of up to 70.37% was necessary to achieve a break-even situation in cv. 'Fuji' apples in the same year. These results confirm the previous break-even analysis by Williamson et al. (1996), who suggested a 30-73% decrease in pheromone dispenser prices to 'Red Delicious' apple growers. To promote mating disruption, Turkish government offer subsidies of $ 125 per ha to encourage growers. However, there was no need for decrease in pheromone dispenser prices in 2014 because mating disruption programme was as cost-effective as insecticide programme.

This favourable change in costs of the two management programmes between years may have been caused by an increase in beneficial insects in apple orchards (Calkins, 1996). Evidently, the aphidophagous seven-spotted lady beetle, *Coccinella septempunctata* L., and *Typhlodromus athiasae* Porath and Swirski, the important predator of the European red mite, were more abundant in pheromone-treated orchards. In contrast, mating disruption may increase the risk of damage by some pests such as apple sawfly, *Hoplocampa testudinea* (Klug), which was previously suppressed by cover sprays. For example, two sprays were applied to control this pest in cv. 'Fuji' apples in mating disruption plots in 2014, while only one spray was applied in insecticide plots.

CONCLUSIONS

Based on partial budgeting analysis, mating disruption treatments lowered insecticide and machinery costs but increased labour costs compared with conventional treatments.

Codling moth mating disruption reduced the overall amount of insecticides used for managing apple pest complex. Despite these savings, the cost of mating disruption for codling moth averaged about $ 126.55 more than traditional insecticide applications in apple orchards in 2013.

A break-even analysis for the same year showed that a mean price decrease of 46.30% for pheromone dispensers would be required to convince growers to use mating disruption.

However, on average, mating disruption programme cost $ 43.20 less than a conventional insecticide programme in 2014.

Cost differences between years could be explained by varying codling moth populations, and different number of insecticide sprays.
The decrease in initial pest density, accompanied by enhanced biological control, may help us to develop more cost-effective mating disruption programmes in subsequent years.

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