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Population Development and Infestation Rate of Codling Moth (*Cydia Pomonella* (Lepidoptera: Tortricidae)) In Apple Orchards in Northern Kyrgyzstan**

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ABSTRACT

The codling moth is a key and most widely distributed pest of apple orchards worldwide. The population development of *C. pomonella* was investigated using sex pheromone traps in different apple orchards between years of 2019 and 2020 in northern Kyrgyzstan. Flight of the codling moth males in apple orchards is characterized by instability, which is associated with temperature and other climatic factors. Trap captures of codling moth were positively correlated with temperature, but negatively correlated with relative humidity and altitude. Male moths started appearing in traps on April 10-14, 2019 and April 26-29, 2020 in Chui and Ysyk-Kol provinces. Analysis of seasonal trap catches from apple orchards over two years summarizes that the codling moth has 4 major peaks in Chui and 3 distinct peaks in Ysyk-Kol provinces. Codling moth damage per orchard ranged from 8.3% to 84.3% in Chui province and it was estimated per orchard from 1.4% to 27.2% in Ysyk-Kol province.

1. Introduction

Apple is one of the most widely produced and economically important fruit crops in temperate regions around the world. Cultivated apple (*Malus domestica* Borkh.), which is the oldest fruit crop used as a cultivated plant, has been domesticated from *Malus sieversii* in the Tian Shan Mountains for 4000–10,000 years and dispersed from Central Asia to West Europe along the Silk Road (Cornille et al, 2014; Duan et al., 2017). Since the homeland of the apple is Central Asia, it has been reported by the researchers that some pests and diseases of apple trees are unique to Central Asia, and it is still the subject of great interest for research (Luby et al., 2001; Mills, 2005).

Codling moth, *Cydia pomonella* L. (Lepidoptera: Tortricidae), originated from Central Asia is a key and most widely distributed pest of apple orchards worldwide (Barnes, 1991; Mills, 2005). Its host range is restricted mainly on apple, pear, crabapple, quince, hawthorn, and walnut, with one to four generations a year in the palearctic zone (Johnson, 2013). Codling moth adult females lay eggs on the fruit or leaf surface, hatched larvae mostly bore directly into the fruits and eats the seeds inside the fruits. There are five larval instars, at maturity, larvae usually leave the fruits and usually pupate under the bark. Codling moth overwinters as mature diapausing larvae in cocoons until climatic conditions are suitable for adults to fly (Welter, 2009).

Pest monitoring is a fundamental component of IPM programs and sex pheromones are the best tools to monitor the seasonal flight periods of pests, and they are widely used in a variety of ways in pest control programs in agricultural crops (Fadamiro, 2004). Sex pheromones are nontoxic and species-specific blends, which produced by adult females in order to attract males for mating (Baker and Heath, 2005). Captures in traps baited with synthetic pheromone lures accurately show whether a specific insect is present, provide reliable information about seasonal activity of pests and effective time of insecticide sprays (Witzgall, 2010). Numerous studies were conducted to determine the population development and infestation rate of *C. pomonella* in the different region of the world using sexual pheromones (Fadamiro, 2004; Mamay and Yanık, 2013; Zada et al., 2014; Aydoğan and Ünlü, 2019;)

In Kyrgyzstan, apple production is small (135 ths tons/year) and unstable due to yield and quality loss from key pests and diseases. Although *C. pomonella* is considered to be a key pest, no scientific studies have been conducted on this pest last 30 years and the present situation of the pest in the region is not known clearly. Studies conducted earlier than 1990 or during

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USSR time have mainly focused on determining the pest population with the help sum of effective temperatures or light traps (Vasilev and Pristavko, 1970; Mamaev, 1981). According to the information we obtained from the literature we could reach; the pest population development was not determined using sex pheromones at least in Kyrgyzstan. Consequently, there lack effective pest management programs against this pest for growers, and efforts to control the codling moth relies mostly intensive use of broad-spectrum insecticide sprays throughout the growing season, which has resulted in the development of insecticide resistance, and an increase in the abundance of secondary pests (Vreysen et al, 2010).

The aim of this study was: (1) to monitor population development, and (2) to estimate the damage of codling moth in apple-growing regions of northern Kyrgyzstan. We consider flight pattern information of pest and other observations obtained through this study will be useful in determining the control methods against this pest.

2. Materials and Methods

Population development

This study was conducted from April 2019 to October 2020 in three apple orchards in Chui province, and five in Ysyk-Kol province (YK), North Kyrgyzstan. Orchards' main characteristics and pest control informations are given in Table 1. Populations of adult codling moths were determined from the catches of male moths using delta-type pheromone traps for two years. In all traps, sticky trays were used for catching and counting, and species-specific pheromone capsules, which contain 1,5 mg E.E-8.10-dodecadien-1-ol, also known as codlemone (Russell IPM Ltd., Deeside, Flintshire, UK) used to attracting codling moth males to the traps. The traps were hung at 1.5-2 m high from the ground in the south direction of the trees and in the direction of the dominant wind. Trap visits were performed every day of week until the first adult was captured, and once a week after the first adult was captured, the number of captured adults were recorded. The pheromone capsules of the traps were replaced every six weeks and old capsules were removed from the orchards. The sticky trays in the traps were replaced with new ones as needed depending on the loss of the adhesive layer (Knight et al., 2009; Çelik and Ünlü, 2017).

Table 1
Location, main characteristics and pest control information's of apple orchards.

Name of orchard	Lat (°N)	Lon (°E)	Al (m)	Size (ha)	Age of trees (y.old)	Varieties	Insecticide application
2019							
Chui-1	42°54'16''	74°48'21''	731	0.7	12-15	Semerenko, Pre, R.d, G, İdared	(1) imidacloprid; (2) lambda-cyhalothrin
Chui-2	42°49'12''	74°38'21''	878	1.5	20-25	Aport, Pre, K.z	No ins. application
Chui-3	42°55'53''	74°49'42''	1313	5	35-40	Aport, Pre, K.z	No ins. application
YK-1	42°10'02''	77°37'02''	1696	0.5	15-20	Makintosh, K.z, Pre	thiacloprid
YK-2	42°18'27''	77°52'57''	1733	1.5	25-30	Pre, Aport	thiacloprid
YK-3	42°25'43''	78°12'11''	1760	1	20-25	Pre, Aport, K.z	dimethoate
YK-4	42°46'24''	77°43'57''	1780	0.6	25-30	Zolotoy Ranet, Pre, Aport	No ins. application
YK-5	42°45'10''	77°39'26''	1688	3	4	İ, Pre, G, Krimson	No ins. application
2020							
Chui-2	42°49'12''	74°38'21''	878	1.5	20-25	Aport, Pre, K.z	No ins. application
Chui-3	42°55'53''	74°49'42''	1313	5	35-40	Aport, Pre, K.z	No ins. application
YK-2	42°18'27''	77°52'57''	1733	1.5	25-30	Pre, Aport	lambda-cyhalothrin

Pre: Prevoshod, R.d: Red Delicious, G: Golden, I: Idared, K.z: Kirgizskiy Zimniy

Infestation rate and data analysis

To estimate the level of infestation, the damage to fruits caused by the codling moth was surveyed in July and September, in two consecutive years (2019, year 1; 2020, year 2). Different sampling methods can be used to determine the infestation rate of *C. pomonella*. Three different methods; 'Tree-Based', 'Fruit-Based' and 'Crate-Based', are commonly used to determine the codling moth infestation rates (Mamay and Yanık, 2013). In this study 'Fruit-Based' method was used to determine the infestation rate of the pest. In total, approximately 100 fruits were randomly collected from 5 trees in the center of each orchard each time and holes of codling moth larvae were determined from visual examination of each apple in a sample. Only apples that attached to the tree were assessed for larval infestation. The level of infestation (%) was calculated by the equation:

Level of Infestation (%) = (Ni / Nc) x 100

where Ni is the number of damaged fruits and Nc is the number of collected fruits in orchard.

Statistical analysis was conducted using SPSS v.22.0 (IBM, Armonk, NY, USA). The significance of altitude on the number of male catches in monitoring traps was determined by correlation (Pearson) and regression analysis at $P = 0.05$ for the multiple comparisons. The relationship between temperature with codling moth catches was evaluated using linear multiple regression analysis. T-test was used to compare the damage rates of apple orchards according to years, and

Kruskal-Wallis Test was conducted to examine the differences of damage rates between orchards and provinces.

3. Results and Discussion

Population development

Pheromone traps were installed at apple orchards and used to monitor *C. pomonella* populations in Chui and Ysyk-Kol provinces from April to October in 2019 (24 traps) and 2020 (9 traps) (Fig. 1; Fig. 2). Results from two-year study showed the detection of four major peaks (late April - early May, late May – early June, late June – early July, and early August – mid August) and three distinct peaks (late May – early June, late June – early July and late July – early August) of the pest in Chui and Ysyk-Kol provinces, respectively.

Chui province. In 2019, the first codling moth catch in Chui-1, Chui-2 and Chui-3 orchards were April 11th, April 13th, and April 14th, respectively. But, in 2020, moths started appearing in traps a week later than 2019, on April 21 and April 20 in Chui-2 and Chui-3 orchards, respectively. In Chui-1 orchard, a total of 259±12.6 (Mean±SE) males were caught in pheromone traps in 2019, with four peaks on April 14, May 15, June 19, and July 31 (Fig 1; Fig 2; Table 2). In 2020, monitoring has not carried out in this orchard due to regularly visiting problems. The total captured adult male moths' number were 1089±119.8 and 779±31.39 in Chui-2 orchard, in 2019 and 2020, respectively. According to trap data, four major peaks of the population were established in Chui-2 orchard, on May 5th, May 29th, June 22 and July 31 in 2019 and May 12, June 16, July 21, August 18 in 2020 (Fig 1; Fig 2; Table 2). The Chui-3 orchard has the highest pest population among all orchards, with four peaks on May 8, June 5, July 10 and August 14 in 2019 and May 12, June 23, July 28, and August 25 in 2020 (Fig 1; Fig 2; Table 2). The total captured moths were 1287±99.3 and 823±36.7 in 2019 and 2020, respectively.

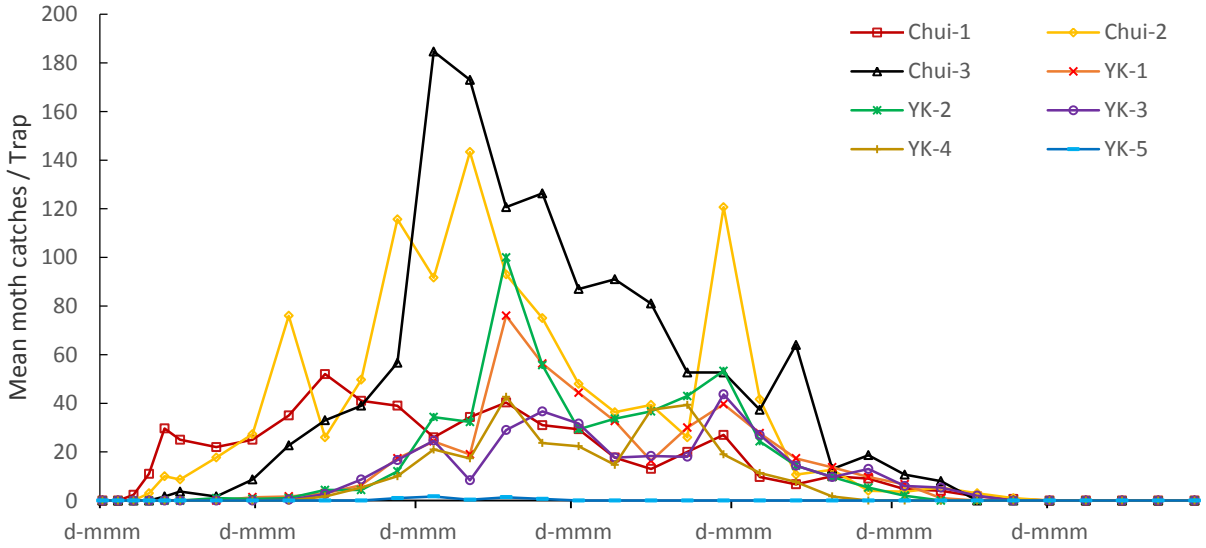

Figure 1
Population development of *Cydia pomonella* in apple orchards in Chui and Ysyk-Kol provinces in 2019. Each observation represents a mean of three replications.

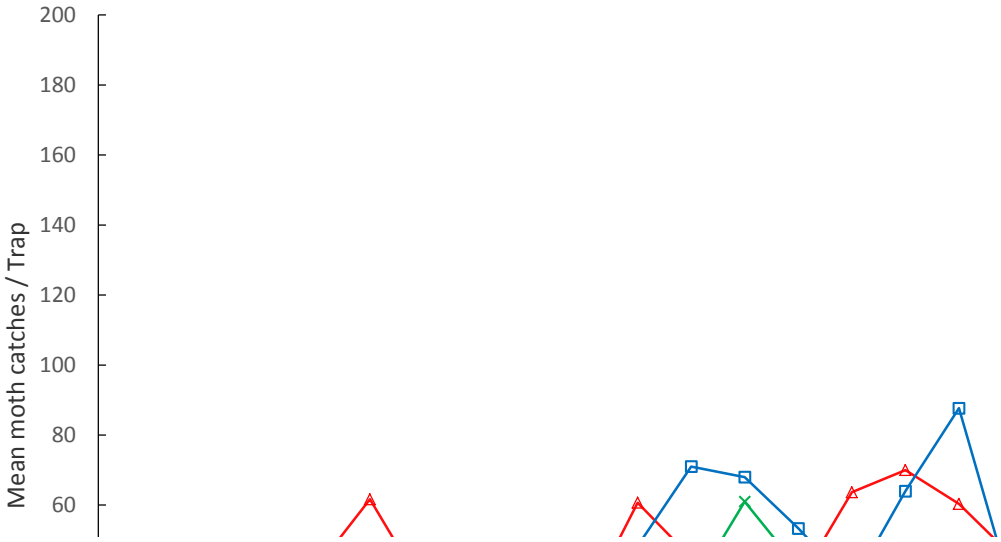

Figure 2
Population development of *Cydia pomonella* in apple orchards in Chui and Ysyk-Kol provinces in 2020. Each observation represents a mean of three replications.

Ysyk-Kol province. In 2019, population of codling moth monitored at 5 different orchard, and pest flight pattern was nearly similar in all orchards. The first codling moth catch in traps in YK-1, YK-2, YK-3, and YK-4 orchards were May 3, April 26, May 14, and May 18, respectively (Fig 1). The total captured adult male moths' number in YK-1, YK-2, YK-3, and YK-4 orchards were 444±36.7, 497±45.4, 333±18.2, and 275±15.9. In 2019, adults of codling moth were caught with the main and first peak on late of May and then undergone two more generations (late June – early July and late July – early August) in YK-1, YK-2, YK-3, and YK-4 orchards in Ysyk-Kol province (Fig 1; Table 2). In YK-5 orchard, a total of only 15 male codling moths were caught in three pheromone traps, starting from May 31 till June 22. The reason for this low population probably is due to the age of this orchard. In 2020, population monitoring was carried out in only one orchard (YK-2), because of codling moth flight pattern similarity in 2019 and regularly visiting problems due to global pandemic condition. Codling moth appeared from April 29 and showed three peaks until late August.

Table 2.
Population events (Mean±SD) of codling moth in apple orchards in Chui and Ysyk-Kol in 2019 and 2020.

Province	Orchard	Year	1st catch	1st peak	2nd peak	3rd peak	4th peak
Chui	Chui-1	2019	3.33±1.52	25.6±3.18	40.3±8.74	20±2.4	10.5±6.92
		2020	-	-	-	-	-
	Chui-2	2019	10±4.32	27.3±2.86	115.7±29.4	75±16.8	62.7±13.9
		2020	2.33±1.15	61.7±22±85	60.7±19.01	63.7±14.9	32.7±8.96
	Chui-3	2019	1.95±3.01	13.93±13.44	184.7±6.18	91±7.88	64.5±12.4
		2020	9.7±5.03	35±6	41.7±10.7	71±12.49	87.7±12.42
Ysyk-Kol	YK-1	2019	1.33±1.24	24.3±10.8	76±26.05	39.6±7.09	-
		2020	-	-	-	-	-
	YK-2	2019	4.3±3.24	34.3±5.50	100±7.93	53.3±13.61	-
		2020	3±1.73	43.4±7.09	61±11.1	46.7±10.1	-
	YK-3	2019	2.66±1.52	24.66±7.50	36.6±4.93	43.7±7.37	-
		2020	-	-	-	-	-
	YK-4	2019	5.33±3.05	21±10.44	42.7±13.31	39.3±4.16	-
		2020	-	-	-	-	-
	YK-5	2019	0.7±1.15	1.7±1.15	-	-	-
		2020	-	-	-	-	-

According to results, trap captures were positively correlated with temperature (r = 0.550; *P* = 0.001 in Chui and r = 0.558; *P* = 0.001 in Ysyk-Kol in 2019; r = 0.480; *P* = 0.001 in Chui and r = 0.228; *P* = 0.001 in Ysyk-Kol in 2020) and negatively correlated with relative humidity (r = -0.282; *P* = 0.001 in Chui and r = -0.359; *P* = 0.001 in Ysyk-Kol in 2019; r = - 0.270; *P* = 0.001 in Chui and r = - 0.288; *P* = 0.001 in Ysyk-Kol in 2020). Temperature data are given in Fig 3.

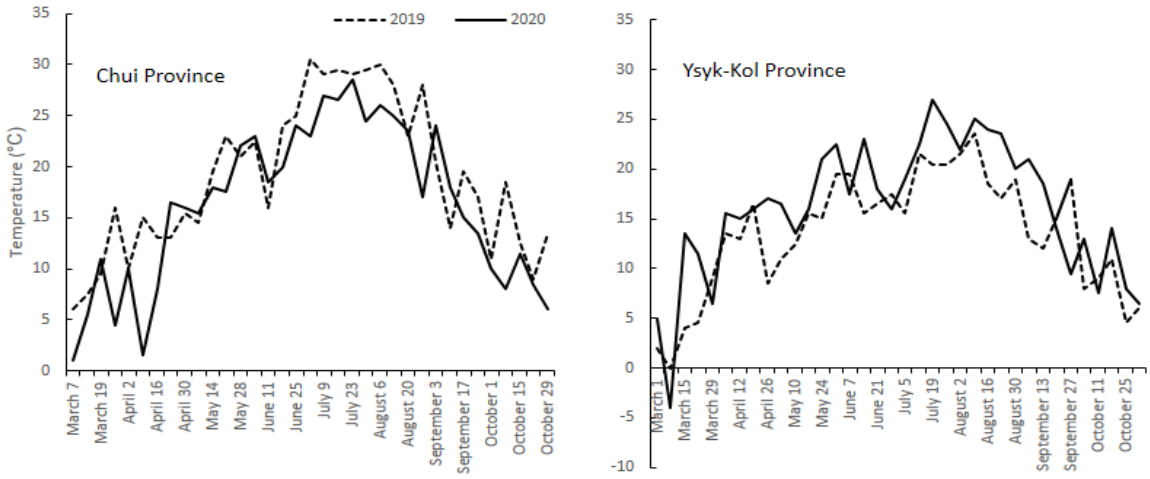

Figure 3
Temperature data of Chui and Ysyk-Kol from Bishkek and Cholpon-Ata Meteorological Station, 2019 and 2020.

Correlation studies revealed that codling moth adult catches had negative correlation with altitude in all orchards (r = -0.571; *P* = 0.013). The overall regression analysis was statistically significant (F=7.34, $p<0.006$, $R^2=0.50$). Detailed regression values are given in Table 3.

Table 3
Comparison of total mean moth catches of *Cydia pomonella* at different altitude using delta pheromone traps during 2019 and 2020.

Site / Year	Altitude (m a.s.l)	N	Monitoring Period	Total captured males (Mean ± SE)	Anova
Chui-2 / 19	878	3	March - November	1089.3±119.9	F=5.69, $p<.048$, $R^2=.049$
Chui-2 / 20	878	3	March - November	779±31.3	F=8.16, $p<.024$, $R^2=.054$
Chui-3 / 19	1313	3	March - November	1287.6±99.3	F=5.69, $p<.048$, $R^2=.049$
Chui-3 / 20	1313	3	March - November	823±36.6	F=8.16, $p<.024$, $R^2=.054$
YK-2 / 19	1733	3	April - November	497.3±45.4	F=5.69, $p<.048$, $R^2=.049$
YK-2 / 20	1733	3	April - November	535±35.3	F=8.16, $p<.024$, $R^2=.054$

N: number of replications

Infestation rate

Codling moth damage to apples was not significantly different between years (*df=26; t=-3.19; p = 0.531*), but it did vary significantly between orchards (*df=6; chi-square=18.488; p=0.005*) and provinces (*df=1; chi-square=7.350; p=0.007*) each year (Table 4). In Chui Province, CM damage per orchard ranged from 8.3% to 84.3% and from 15.4% to 77.1% in 2019 and 2020, respectively. But, in Ysyk-Kol province it was estimated per orchard from 1.4% to 20.6% and from 5.3% to 27.2% in 2019 and 2020, respectively. Damage, in general, was greater in Chui province (47.03%±26.01; mean ± SD) than in Ysyk-Kol (14.08%±8.64). Moreover, damage was higher in 2020 (31.15%±22.25; mean ± SD) than in 2019 (25.23%±26.75).

Table 4
Infestation rate of codling moth in apple orchards in North Kyrgyzstan.

Sampling Site	Infestation rate (%)			
	mid-July 2019	mid-September 2019	mid-July 2020	mid-September 2020
Chui-1	8,30	22,30	15,40	27,30
Chui-2	52,60	84,30	61,10	77,10
Chui-3	36,70	73,20	36,20	69,50
YK-1	7,90	15,10	14,10	25,10
YK-2	3,10	20,60	25,20	27,20
YK-3	1,40	16,40	5,30	23,10
YK-4	3,50	7,85	11,20	18,20

The most widespread and ubiquitous use of sex pheromones has been detection and population monitoring. In pest management programs, population monitoring using sex pheromone is necessary to determine thresholds, to schedule insect control applications on time (Baker and Heath, 2005). In this study, we monitored seasonal flight patterns of *C. pomonella* and es-

timated its damage status in apple orchards in northern Kyrgyzstan.

Our data on seasonal abundance indicated that the flight of the codling moth males in apple orchards is characterized by instability, which is associated with temperature and other climatic factors. Trap capture results showed 3-4 and 2-3 peaks of codling moth in Chui and Ysyk-Kol provinces. Thus, based on the above material, it can be noted that the codling moth developed in three and two generations in a year in Chui and Ysyk-Kol provinces, respectively. Similar results noted by Konurova et al, (2017) that codling moth able to develop three generations in Chui valley. Numerous reports have been published (Riedl and Croft, 1978; Blomefield et al., 1997; Reuveny and Cohen, 2004; Aydoğan and Ünlü, 2019) dealing with codling population under similar climate with Kyrgyzstan, which shows codling moth is essentially bivoltine with considerable yearly variability in third generation emergence. That the very low number of male codling moths caught in traps at YK-5, compared to the other orchards, is likely an indicator that the population of codling moth is not settled yet due to age of trees.

Some factors such as photoperiod and temperature are known to play a key role in codling moths' seasonal activity (Setyobudi, 1989). In our study, trap captures of codling moth were positively correlated with temperature, but negatively correlated with relative humidity and altitude. This is in agreement with Pitcairn et al., (1990) and Zada et al (2014), who reported weather parameters on codling moth population dynamics, but, in addition to other studies, here we investigated also the effect of altitude on the population.

Our study also points that the codling moth damage in orchards ranged from 1.4% to 84.3%, mostly it was around 15-25% at harvest time which show extremely high loss of yield. We consider, this high damage correlated with insufficient control against codling moth and other pests. As determined in the study, growers have applied only once or twice a year insecticide in their orchards. Here, we suggest that biological control or other environmentally friendly methods such as mating disruption or microbial control immediately should be implemented in apple orchards by growers, because only 1-3% of infestation by codling moth may tolerable in intensive production (Pajač et al., 2011).

Our results clearly showed the population fluctuation of the *C. pomonella* throughout the season in Kyrgyzstan and also give about the right time for spray application for the effective management of this pest. Successful future management of codling moth will require detailed researches using other models, such as degree day model (DD). Because, the DD model is also used to assess phenology and seasonal occurrence of the *C. pomonella* effectively.

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