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Dynamics of codling moth larvae (*Cydia pomonella* L.) in three varieties of apple (*Malus domestica* Borkh.) in the region of Aït Sbaa (Morocco)

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Abstract

Codling moth (*Cydia pomonella* L.) is a serious pest of apple in worldwide orchards. Despite their negative impact over the environment, chemical pesticides are the main control method against the codling moth. *Cydia pomonella* Larvae are responsible of codling moth apple infestations. Thus, the study of codling moth larvae dynamics might contribute to developing alternative codling moth control methods. We studied codling moth larvae dynamics considering canopy aspect (north, east, south, and west) and canopy height (bottom, middle, and top) in three apple varieties in the region of Aït Sbaa (Morocco). First generation codling moth larvae infestation was higher in Golden delicious apple variety. We recorded high second generation codling moth larvae infestation in Royal gala variety. Moreover, first and second generation codling moth larvae infestation was influenced by canopy aspect and canopy height of apple trees belonging to Golden delicious and Starking delicious varieties.

1. Introduction

The codling moth (*Cydia pomonella* L.) is the main insect pest of apples in worldwide orchards [1,2]. this pest has huge impact over apple cultivars. it can cause up to 80% of production loss [3].

Cydia pomonella larvae are responsible of codling moth infestation [4]. Apple fruits drop from apple trees due to codling moth larvae which dig deep tunnels into the fruits in order to reach the seeds [5].

To face this problem, chemical control is mostly used [6]. This method is cheaper and more efficient [7]. Nevertheless, chemical control can lead to serious human health and environmental problems [8]. Therefore, there is an increasing interest in alternative codling moth control methods and developing such methods should be based on the study of codling moth host choice.

Several studies were interested in codling moth larvae dynamics [9-11]. Many factors such as temperature, humidity, tree height and size influence codling moth larvae distribution in apple trees. The most important codling moth infestation rate is recorded in orchard borders [12].

In this work, we study the codling moth population dynamics in three apple varieties (*Malus domestica* Borkh.). We are specifically interested in understanding the factors behind codling moth larvae infestation in apple varieties.

2. Material and Methods

2.1. Plant material

The studied apple tree varieties are Golden delicious, Royal gala and Starking delicious. They are located in the Middle Atlas at 1155 m of altitude, in the region of Aït Sbaa (Morocco) and 30 Km away of Fez (33 ° 46'41.7 "N 5 ° 00'42.6" W). The studied orchard is 10 ha wide with 67 apple trees. The trees are arranged in 88 lines and oriented N - S. The distance between tree lines is 3.5 m. There is 3.5 m between same line trees. The apple trees are 2.5 - 4 m high.

2.2. Codling moth survey

The survey was performed in 2015. Apples attached to the tree were counted. Codling moth first generation survey was conducted during the first week of June. Second generation codling moth were surveyed during the last week of July [13]. Apple fruits were surveyed according to tree bottom, middle and top (canopy height) and tree north, east, south, and west sides (canopy aspect). Apples with frass-filled holes were considered infested by codling moth larvae.

2.3. Statistical analysis

We performed statistical analysis on the percentage of apple fruits damaged by codling moth larvae in Golden delicious, Royal gala and Starking delicious apple varieties depending on canopy aspect and canopy height of the apple trees. We used the software IBM SPSS Statistics 20 (SPSS, Inc.,Chicago, IL) to conduct the statistical analysis.

3. Results and discussion

3.1. Codling moth larval infestation

3.1.1. Infestation by first generation larvae

According to ANOVA test results, a significant correlation was found between infestation by codling moth first generation larvae and apple variety ($P < 0.001$; $F = 54.677$). Golden delicious seems the most infested variety followed by Royal gala and Starking delicious (Figure 1).

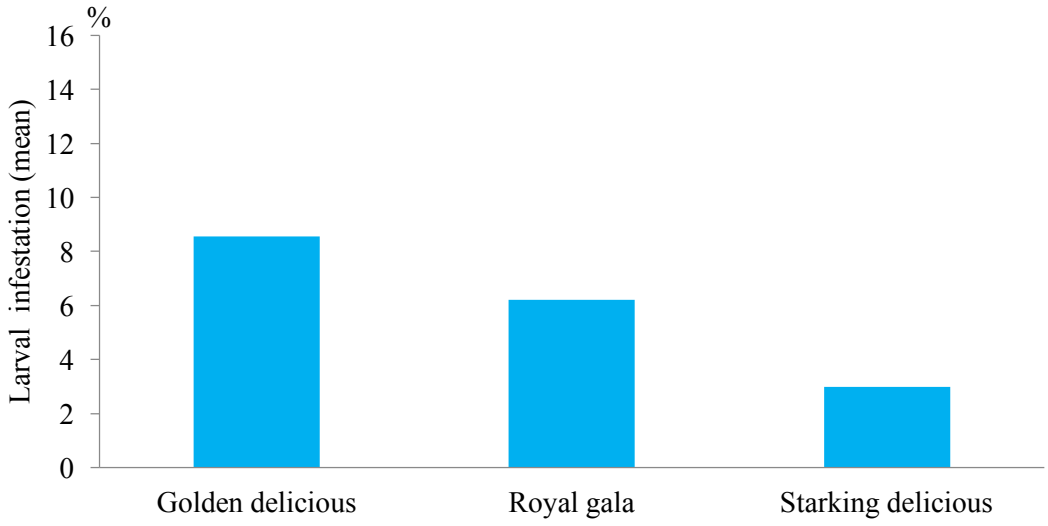

Figure 1 : Percentage of infestation by *Cydia pomonella* first generation in Golden delicious, Royal gala and Starking delicious apple varieties

The codling moth larvae occurence in a variety of apple is related to the egg laying choice of codling moth females. This behaviour is mainly influenced by the host plant characteristics. A previous study claims that the Golden delicious apple variety is prefered by codling moth females to lay their eggs since this apple tree variety has high quantity of fruits by Bush [14]. According to some studies, α-farnesene in fruits influences female egg laying behaviour through their olfactory system [15,16]. Golden delicious is rich many polyols and sugars which attracts females to lay eggs in this apple variety [17].

3.1.2 Infestation by second generation larvae

Results of ANOVA revealed that there is a significant correlation between infestation by codling moth larvae of second generation and apple variety ($P < 0.001$; $F = 33.663$). Figure 2 shows that the two varieties Golden delicious and Royal gala are equally infested by second generation larvae. Nevertheless, Starking delicious variety is the least infested either by larvae of first generation or larvae of second generation.

The fruits organoleptic character can explain the second generation codling moth larvae choice towards Royal gala and Golden delicious apple varieties. Golden delicious and Royal gala belong to the fondant and little

crunchy fruits organoleptic category [19]. Codling moth larvae may prefer Royal gala and Golden delicious apple varieties because of they have low concentration of polyphenols compared to Starking delicious [20]. Second generation codling moth larvae choice is influenced by apple fruit volatil compounds and primary metabolites such as amino acids, sugars, lipids, etc. [15-18].

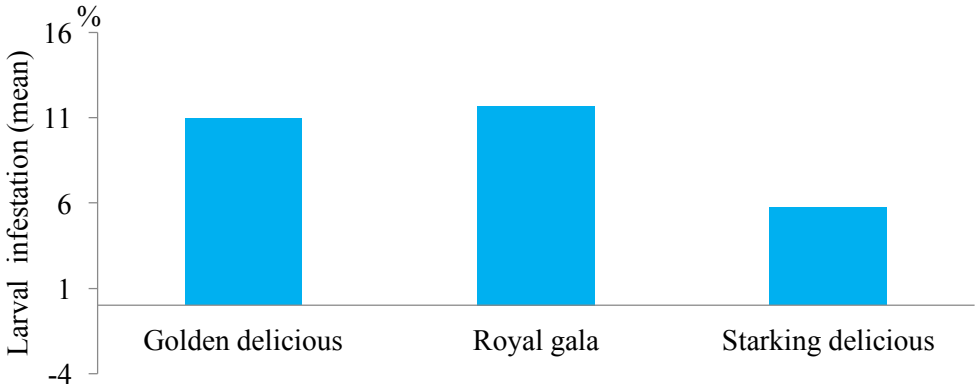

Figure 2 : Percentage of infestation by *Cydia pomonella* second generation in Golden delicious, Royal gala and Starking delicious apple varieties

3.2. Canopy aspect

3.2.1 Infestation by first generation larvae

Temperature, apple cultivars, light interception, wind and rainfall are some of several factors that influence the codling moth population dynamics [14-21,22]. The first generation larvae infestation was significantly influenced by canopy aspect of the trees belonging to the Starking delicious variety (Friedman test, P = 0.008). During their first generation, codling moth larvae cause more damage in Golden delicious apple. First generation codling moth attack rate is 8.52% in Golden delicious, 5.56% in Royal gala and 2.83% in Starking delicious.

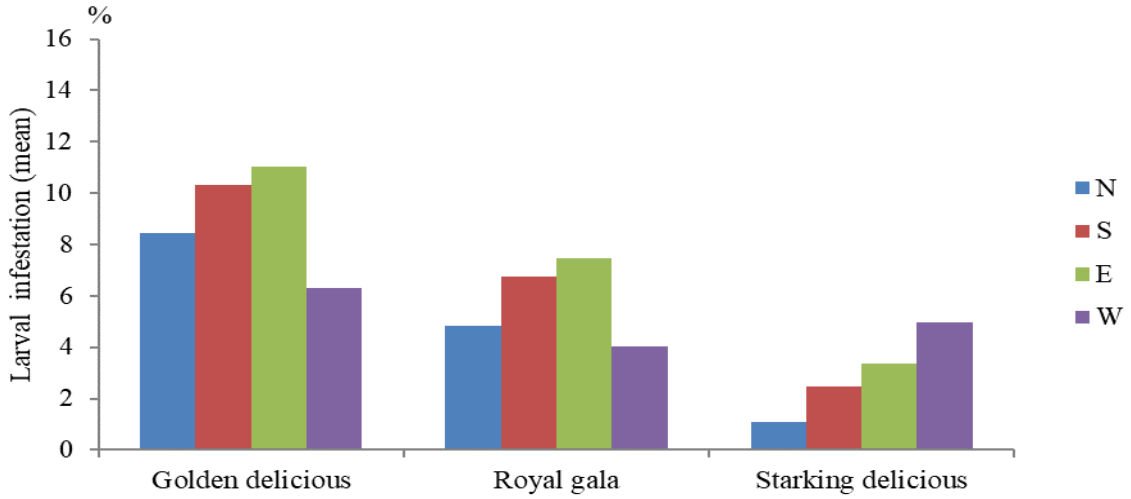

Figure 3 : Effect of canopy aspect (N, north; E, east; S, south; and W, west) on infestation by *Cydia pomonella* first generation in Golden delicious, Royal gala and Starking delicious apple varieties

In Golden delicious variety, the east side is the most infested followed by the south side and finally, both north and west sides are the least infested. In Royal gala, the east and south sides of the trees are more infested compared to the north and west sides. In Starking delicious variety, the west side of the trees is the most infested follow by south side and finally the north side is the least infested (Figure 3). Previous works inflield showed that the codling moth females oviposition behaviour is influenced by canopy aspects [23,24]. also, codling moth females avoid to lay eggs in low temperature areas under lab conditions [22]. the north side of apple trees, where low teperature is registred, is the least damaged by the lfirst generation codling moth larvae [25].

3.2.1 Infestation by second generation larvae

In figure 4 below, the apple fruits of Royal gala variety are the most infested by the second generation codling moth larvae with an infestation percentage of 12.8%. Followed by, Golden delicious with 10.54% of infestation. Finally, Starking delicious apple fruits with 6.36% of infestation.

The west and south sides of the trees belonging to Golden delicious apple variety are more damaged by second generation codling moth larvae in comparaison with the north and east sides of this apple tree variety. The west side of the Royal gala apple tree is the most attacked by codling moth larvae of second generation. It comes ahead of the south side, east side then the north side. Low infestation rate was registred in the west side of Starking delicious. The highet rate of infestation is observed in the west side of this apple variety.

Codling moth second generation larvae are sensible to the hot east side of the apple trees. Also, this side faces hot eastern winds during summer. Furthermore, Wind direction and temperature influence codling moth behaviour towards apple [22]. The infestation by larvae of the second generation with Golden delicious is highly influenced by the canopy aspect of the trees (Friedman test, P = 0.008).

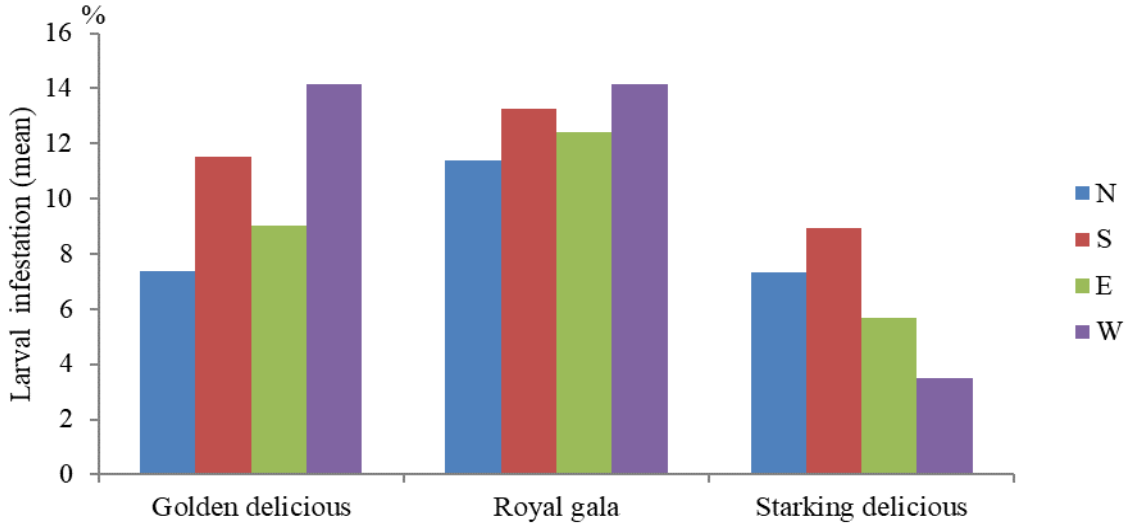

Figure 4 : Effect of canopy aspect (N, north; E, east; S, south; and W, west) on infestation by *Cydia pomonella* second generation in Golden delicious, Royal gala and Starking delicious apple varieties

3.3. Canopy height

3.3.1 Infestation by first generation larvae

According to Friedman test, canopy height influences first generation larvae infestation in Golden delicious (P = 0.017) and Starking delicious (P = 0.035).

The highest infestation rate of apple fruits by first generation codling moth larvae is recorded in the middle level of the trees. It is 11.6%, 8.2% and 4.6% in the three varieties Golden delicious, Royal gala and Starking delicious respectively. Besides, the bottom level of the trees is the least infested by first generation larvae. The percentage of infestation is about 8.6% in Golden delicious, 6% in Royal gala and 1.8% in Starking delicious. In the top level of the apple trees, the infestation rate of the Golden delicious, Royal gala and Starking delicious varieties are respectively 12%, 10.7% and 7% (Figure 5). Infested fruits have the same distribution in apple trees during either the first or second generation of codling moth. Such behaviour could be related to lots of factors as light, temperature and humidity. The top and middle heights of the tree are the most exposed to sun light. Like other insects, the codling moth search the tree parts exposed to fresh wind and sunlight and escape high humidity parts of the tree [26]. A recent work claims that the middle height of apple trees are the most infested by larvae of codling moth [25]. However, earlier studies state that the top height of apple trees have the highest rate of codling moth eggs [27,28].

3.2.1 Infestation by second generation larvae

The infestation by the second generation larvae is highly influenced by canopy height in Golden delicious (Friedman test, P = 0.008).

Figure 6 shows that the middle level of apple trees belonging to Golden delicious and Royal gala varieties are the most infested by second generation larvae by 14.2% and 12.6% respectively. In Starking delicious, the top level is the most attacked with 7% of the apple fruits.

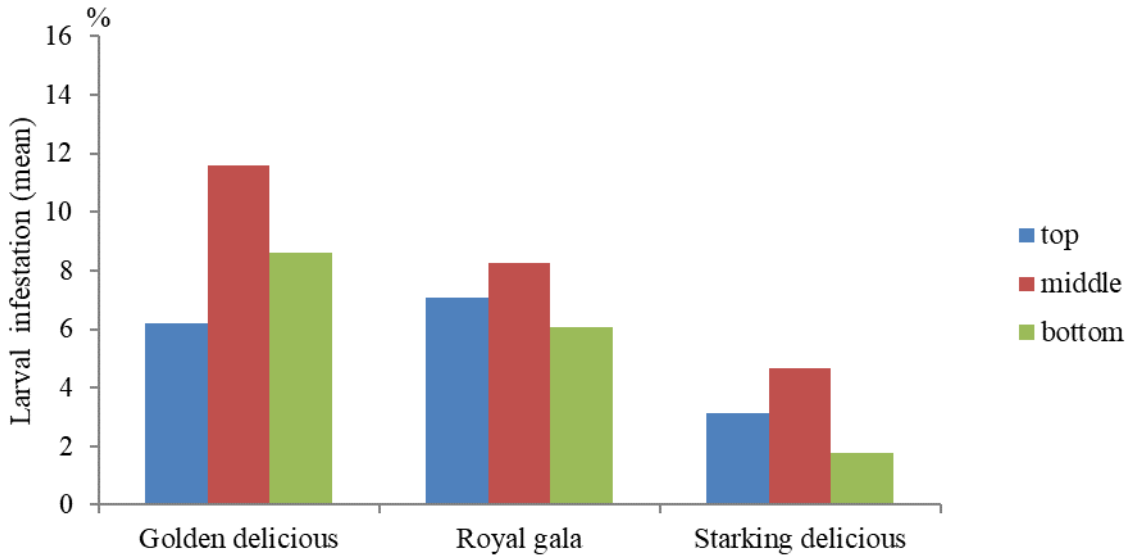

Figure 5 : Effect of canopy height (bottom, middle, and top) on infestation by *Cydia pomonella* first generation in Golden delicious, Royal gala and Starking delicious apple varieties

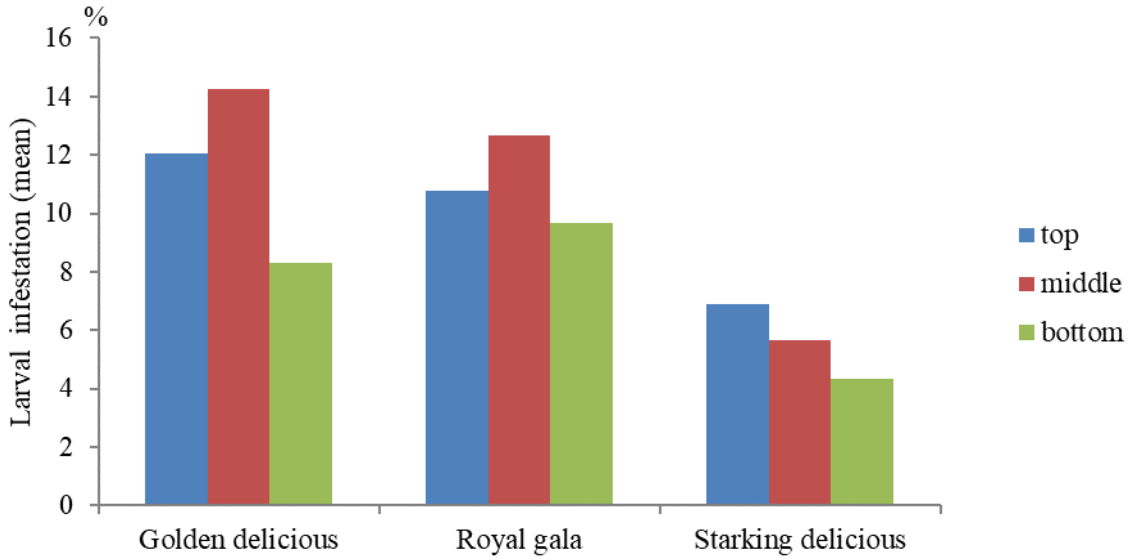

Figure 6 : Effect of canopy height (bottom, middle, and top) on infestation by *Cydia pomonella* second generation in Golden delicious, Royal gala and Starking delicious apple varieties

The bottom level of the trees is the least infested by second generation larvae in the three studied varieties. The infested apples rate is 8.3% in Golden delicious, 9.6% in Royal gala and 4.3% in Starking delicious.

In the region of Laanoucer (Morocco), codling moth first and second generation larvae prefer the Golden delicious more than Royal gala and Starking delicious apple varieties [29]. This codling moth larval behavior is similar in the region of Aït Sbaa (Morocco) concerning larval infestation as well as canopy height. The middle level of the trees is the most damaged by codling moth first and second generation larvae. Nevertheless, codling moth larval infestation differs between this two regions depending on canopy aspect. While the North side is the least infested by codling moth first and second generation larvae in both regions, the west side of the trees is the most infested by the first generation of codling moth in the region of Laanoucer in comparaison with the region of Aït Sbaa where codling moth first generation larvae prefer east and south sides of the trees. The second generation codling moth larvae damage highly the west side of the trees in the region of Aït Sbaa while the south the mosted attacked by codling moth second generation larvae in the region of Laanoucer.

Conclusion

Golden delicious, Royal gala and Starking delicious apple varieties were vulnerable to codling moth attacks. Codling moth larval infestation was higher in Golden delicious variety. Golden delicious sugars may stimulate larval infestation as it stimulates *Cydia pomonella* oviposition [18]. Royal gala was slightly attacked by *Cydia pomonella* larvae. However, larval infestation rate was the lowest in Starking delicious. Starking delicious has higher antioxidant capacity and polyphenol concentration [20]. This may have a repellent effect over codling moth.

Larval infestation occurance depends on canopy aspect. The east side was highly infested by first generation codling moth larvae. However, larval infestation rate was lower at the trees north side. High temperatures may promote larvae development during this low temperature period of the year. On the contrary, in summer, second generation larvae tend to avoid the trees east side which encounters high temperatures during this season. The trees east side faces more sun rays in comparison with north, west and south sides of trees.

Similarly, the middle part of the trees was highly attacked by codling moth larvae. The sun exposure of this tree part is moderate. Nonetheless, during summer, the tree top part has high sun exposure while the bottom part temperature is lower.

All in all, codling moth larval infestation depends on many factors including apple variety, the tree sun exposure as well as the fruit position depending on canopy aspect and canopy height. The variation of larval infestation rate among Golden delicious, Royal gala and Starking delicious apple varieties enabled us to determine codling moth larvae dynamic which is highly influenced by sun exposure, fruit position on the tree and apple variety.

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