Controlling codling moth with different netting structures and their influence on crop yield and quality

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Abstract

In most pome fruit growing areas, the codling moth (Cydia pomonella) is the major pest. In warm climates, the insect has 2 or more generations per year. Notwithstanding intensive spray schedules, in organic farming codling moth control is challenging due to the limited number of products available, and sometimes organic pome fruit growing becomes almost impossible due to high yield losses. An additional tool for suppressing codling moth consists in enclosing trees with net. In 2008 and 2009, different netting structures were compared at the Research Centre VZ-Laimburg, Auer, Italy. Promising results were obtained especially with single-row netting structures, which gave efficacy values in reducing codling moth damage of almost 100 %. Pome fruit growers in Northern Italy showed great interest in these trials.

Keywords: apple, codling moth, hail net, netting structures

Introduction

Different products and technical tools for the control of codling moth (henceforth CM) are available in organic farming. Foremost, mating disruption must be mentioned, which has been used for many years. However, in warm climate areas and under conditions of high pest pressure, its efficacy is not satisfactory (Boscheri et al., 1992). This applies also to *Cydia pomonella* Granulovirus (CpGV): despite intensive spray schedules of up to 5 applications per generation, organic growers frequently are not able to prevent considerable fruit damage. In addition, field resistance of CM populations to the Mexican isolate of CpGV, the active substance of almost all CpGV-based products available on the market, has been confirmed in several locations (Jehle et al. 2006). New products based on novel resistance-breaking CpGV isolates are under development, but at the moment registration is still pending in most European countries. Recent studies showed that also autumn applications of entomopathogenic nematodes (*Steinernema carpocapsae and S. feltiae*) against overwintering larvae are a valuable tool to suppress CM: 1st generation damage the following spring was reduced by approximately 50%, while effects on the following generations were less evident (Curto et al., 2008, Kienzle et al., 2008). In 2008, the active substance Spinosad was included into Annex II of Regulations 834/2007 and 889/2008, the list of active substances allowed in organic farming. In order to avoid resistance development, the manufacturer of Spinosad recommends not to make more than 2-3 applications per year, and up to now the German Associations of Organic Farming were against the use of Spinosad due to residue issues.

An interesting approach for CM control was tested in France. Sêvêrac and Romet (2008) were able to completely suppress CM without the use of mating disruption and/or any additional insecticide spray by enclosing single rows in hail net. The behaviour of the pest in the presence of conventional hail net structures is described in Tasin et al. (2007, 2008): the reproductive behaviour of CM seems to be impaired to a varying extent depending on hail net type and netting structure. This may be exploited for CM control.

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In our trials we investigated the effects of different hail net types, netting structures (single row, entire block), and timing of net deployment on phytosanitary state, yield and quality of the crop.

Material and Methods

The trials were conducted in 2008 and 2009 in experimental orchards of the Research Centre VZ-Laimburg (Auer, South Tyrol, Italy). In all study orchards, which were cultivated according to either organic or integrated pest management guidelines, high CM pest pressure had been recorded the previous year. In order to provide for high pest pressure also in the study year, no mating disruption was applied to any of the study orchards. Furthermore, only in Trial SR3, a CpGV-based product was applied against the 1st CM generation, while no additional insecticides were applied in any of the other trials from beginning of flowering on.

Two different netting structures were tested. The first structure consisted in enclosing single rows in net (henceforth SR; Fig. 1): several trees along one single row were covered with net from top to ground, and the net was then closed by pegging it to the ground. In the SR trials, 3 to 4 replications per treatment were used, each plot consisting of at least 10 trees. Not netted trees acted as untreated control. The second system, tested in 2009, consisted in entirely enclosing two large plots of 50 m in length and 5 rows in width in net (henceforth EB; Fig. 2): a conventional hail netting structure was used to cover the tree canopy, and the, usually open sides were also closed with hail net. Two additional uncovered plots of the same size were used as untreated control plots. The plots used in these trials were located in the immediate surroundings of an orchard, heavily infested by CM. In 2008, an intensive insecticide spray programme was applied to all EB study plots (both treated and untreated) in order to reduce pest pressure to the minimum. Different topics were addressed in the various trials.

In 2008, only the single-row netting structure was tested (Trial SR1), but, to cover the trees, two different types of net were used: normal black hail net with a mesh size of 3 x 8 mm and a close-meshed white cultivation net (mesh size: 1 x 1 mm).

In 2009, the single-row netting structure was evaluated in three additional trials. In one trial (henceforth Trial SR2), conducted in an apple cv Braeburn orchard, the conventional black hail net with mesh size 3 x 8 mm was compared to black hail net with mesh size 2 x 6 mm, and to white net with mesh size 1 x 1 mm. In order to investigate the possible effects of netting on fruit set, the 3 x 8 mm mesh size hail net and the 1 x 1 mm mesh size white net were deployed already before flowering. On all fruits within each plot, the following values were then assessed: percent 1st and 2nd generation CM fruit damage, number of fruits per tree, percent red colour skin coverage of fruits, and any additional fruit damage of biotic and abiotic origin (apple bitter pit percentage, etc.).

The second trial (henceforth Trial SR3) was conducted in an apple cv GoldRush orchard. To assess the effects of delayed net deployment, the trees were covered with black hail net with mesh size 2 x 6 mm at the beginning of the flight of the 2nd CM generation (20.07.09), while CpGV was used to control the 1st generation. The CM fruit damage level at the starting point was estimated on fruit samples, while fruit damage at the end of the 2nd generation was established on all fruits within each plot.

In an additional trial (henceforth Trial SR4), conducted in an apple cv Braeburn orchard, trees were covered with black hail net with mesh size 2 x 6 mm at the beginning of the flight of the 2nd CM generation to investigate the effect of delayed net deployment timing. The CM fruit damage level at the starting point (end of 1st generation) was estimated on samples of fruits, while fruit damage at the end of the 2nd generation was evaluated on all fruits within each plot.

In 2009, also the entire-block netting structure was tested in two trials. One trial (henceforth Trial EB1) was carried out in an apple cv Kanzi orchard, while the other trial (henceforth Trial EB2) was conducted in an apple cv Braeburn orchard. Fruit damage assessments were made at the end of the 1st CM generation.

In the trials with more than 2 treatments, percent fruit damage values and any additional recorded value were compared across treatments using 1-way ANOVAs followed by Student-Newman-Keuls' test for post hoc comparisons of means. In the trials with 2 treatments, instead, the percentages of fruits damaged by CM were compared between treatments using T-test for independent samples. To improve homoschedasticity, data were acrsinradq(x/100))-transformed. All statistical analyses were performed with the statistics programme PASW 17.

Figure 1: Single-row netting structure (SR) (black hail net with mesh size 2 x 6 mm)

Fig. 2: Entire-block netting structure (EB) (black hail net with mesh size 3 x 8 mm)

Results

Trial SR1, single-row netting structure (2008)

Table 1: Trial SR1, mean CM fruit damage (%) at the end of the 2nd generation. Different letters indicate statistically significant differences (Student-Newman-Keuls'-test: $P<0.05$).

Treatment	Net colour	Mesh size	% damaged fruits	stat
cultivation net	white	1 x 1 mm	0.5	ab
hail net	black	3 x 8 mm	0.1	a
control	-	-	1.0	b

In the first trial year, significant differences among treatments were recorded notwithstanding the low pest pressure (1% fruit damage in the untreated control): on trees enclosed in black hail net fruit damage was significantly lower than on untreated control trees, while damage levels on trees enclosed in white net were intermediate, and did not differ significantly from those recorded for the other two treatments (Table 1).

Trial SR2, single-row netting structure (2009)

Table 2: Trial SR2, mean CM fruit damage (%) at the end of the 1st and 2nd generation. Different letters within the same column indicate statistically significant differences (Student-Newman-Keuls'-test: P<0.05).

Treatment	Net colour	Mesh size	% damaged fruits 1st gen.	stat	% damaged fruits 2nd gen.	stat
hail net	black	3 x 8 mm	0.2	a	3.3	a
hail net	black	2 x 6 mm	0.3	a	0.8	a
net	white	1 x 1 mm	0.2	a	5.2	a
control	-	-	17.7	b	46.6	b

In the second study year, pest pressure was extremely high already at the end of the 1st CM generation (17.7% 1st generation and 46.6% 2nd generation CM fruit damage in the untreated control). Fruit damage in treated plots was negligible (below 0.3%) at the end of the 1st generation, and ranged from 0.8 to 5.2% at the end of the 2nd generation. Fruit damage levels were always significantly lower in treated than in untreated control plots, with differences among treated plots and thus net types not being significant (Table 2).

Table 3: Trial SR2, mean number of fruits/tree, and mean percentage of apple bitter pit and red colour skin coverage in the different treatments. Different letters within the same column indicate statistically significant differences (Student-Newman-Keuls'-test: P<0.05).

treatment	covering date	fruits/ tree	stat	% bitter pit	stat	% red colour	stat
Black hailnet (3 x 8 mm)	before blossom	44,6	a	8,4	b	35,3	ab
Black hailnet (2 x 6 mm)	after blossom	58,9	b	1,5	a	38,1	ab
White hailnet (1 x 1 mm)	before blossom	43,6	a	10,7	b	32,7	a
control		57,5	b	0,8	a	41,8	b

In Trial SR2, in addition to CM fruit damage we also recorded fruit yield (no. of fruits per tree), percent red colour skin coverage of fruits, percent deformed fruits due to inadequate pollination, and any other fruit damage of biotic and abiotic origin. The number of fruits per tree was significantly lower and percent apple bitter pit significantly higher in plots that had been enclosed in net before flowering than in those that had been covered with net after flowering and in untreated control plots (Table 3), while no significant differences among treatments in the percentage of deformed fruits emerged (data not reported). The percentage of red colour skin coverage was highest in the untreated control, intermediate in the black hail net treatments, and lowest in the white net treatment (Table 3). Sporadically we also observed other symptoms of fruit damage, such as damage caused by rosy apple aphid, rot pathogens, summer fruit tortrix moth, etc., but differences failed significance (data not reported).

Trial SR3, single row netting structure (2009)

Table 4: Trial SR3, mean CM fruit damage (%) at the end of the 2nd generation. Different letters indicate statistically significant differences (T-test: P<0.05).

Treatment	Net colour	Mesh size	% damaged fruits	stat
hail net	black	2 x 6 mm	6.8	a
control	-	-	9.1	a

In this trial, the single row netting structures were not deployed until after the flight of the 1st CM generation. A CpGV-based product was used for the control of the 1st generation in all plots. Before net deployment, percent CM fruit damage amounted to 6%, but most of it was superficial damage (stopped due to CpGV), while active fruit damage (damaged fruits with living larvae) was extremely low. At the end of the 2nd generation, fruit damage was not significantly differing between the netted and the untreated control plots (Table 4). Also the percent fruit damage increase from the 1st to the 2nd generation (data not reported) was not significantly differing between treatments.

Trial SR4, single row netting structure (2009)

Table 5: Trial SR4, mean CM fruit damage (%) at the end of the 2nd generation. Different letters indicate statistically significant differences (T-test: P<0.05).

Treatment	Net colour	Mesh size	% damaged fruits	stat
hail net	black	2 x 6 mm	38,5	a
control	-	-	48,7	b

Also in this trial, the single row netting structures were installed between the flight of the 1st and 2nd CM generation, but no additional treatments against CM were applied to any of the plots before net deployment. Mean 1st generation CM fruit damage amounted to 17%, and approximately 60% of the damaged fruits contained living larvae. At the end of the 2nd generation, fruit damage increased to 48.7% in the untreated control plots, and to 38.5% in the plots covered with hail net. Both percent fruit damage increase from the 1st to the 2nd generation (data not reported) and percent fruit damage in the two treatments at the end of the 2nd generation (Table 5) were significantly differing.

Trial EB1, entire block netting structure (2009)

Table 6: Trial EB1, mean CM fruit damage (%) at the end of the 1st generation. Different letters indicate statistically significant differences (T-test: P<0.05).

Treatment	Colour	Mesh size	% damaged fruits	stat
hail net	black	3 x 8 mm	2.0	a
control	-	-	3.3	a

At the end of the 1st CM generation, fruit damage levels in the plots enclosed in hail net were comparable to those in the untreated control plots (2.0 versus 3.3%, respectively; Table 6).

Trial EB2, entire block netting structure (2009)

Table 7: Trial EB2, mean CM fruit damage (%) at the end of the 1st generation. Different letters indicate statistically significant differences (T-test: P<0.05).

Treatment	Net colour	Mesh size	% damaged fruits	stat
hail net	black	3 x 8 mm	2,0	a
control	-	-	8,8	b

At the end of the 1st generation, percent CM fruit damage was significantly lower in the plots enclosed in hail net than in the untreated control plots (2.0 versus 8.8%, respectively; Table 7).

Discussion

Our results confirm those obtained in previous studies (Sêvêrac & Romet 2008): single row netting structures, deployed before flowering (Trial SR1 and SR2), resulted in a highly significant reduction of CM fruit damage also under conditions of high pest pressure. This is unexpected, because CM overwinters in crevices on tree trunks (Kienzle et. al 2008), and undoubtedly the following spring CM adults should thus be present underneath the netting structures. At the moment no scientific explanation for these results exists, and presumptions diverge widely from disruption of male flight towards calling females underneath the netting structures to accumulation of pheromone released by unmated females, etc. In previous different studies we had placed a large number of diapausing larvae underneath netting structures, and CM fruit damage had actually reached high levels (unpublished data). Therefore, a relation between the number of overwintering larvae underneath the netting structure and CM damage progression may exist. However, in some cases CM fruit damage underneath the netting structures was not negligible. This may be due to the fact that not all netting structures were full exclusion nettings. In some cases it was impossible to hermetically seal the nets.

With regard to net deployment timing, it must be mentioned that in both Trial SR3 and SR4 netting structures were deployed at the beginning of the 2nd CM generation, but trial conditions differed considerably. In Trial SR3, CpGV had been applied against the 1st CM generation, and thus pest pressure was considerably reduced. In fact, at the end of the 2nd generation no increase in CM fruit damage was observed in the plots covered with net and only a slight increase was registered in the untreated control plots. In Trial SR4, instead, no treatments had been applied against the 1st generation in any of the plots, and, in fact, fruit damage increased noticeably over time both in plots with netting structure and in untreated control plots. However, this increase was significantly lower in treated than in untreated plots.

In Trial SR2 we also investigated the effects of the netting structure on fruit yield and quality. Netting before flowering resulted in a reduction of the number of fruits per tree of approximately 20%, but fruit set was low also in untreated plots (mean no. fruits/tree: 58). The increase in the percentage of fruits with apple bitter pit in the plots enclosed in net is probably due to the low fruit set. Further studies are warranted to evaluate whether netting structures could be a valuable tool also for fruit set regulation. Pollination requirements and thus fruit set vary considerably among years and varieties. In principle, considering the full exclusion of pollinating insects a valuable tool for fruit set control would be in complete contrast with the efforts of all those growers that place honey bee hives in their orchards to improve pollination. The netting structures negatively affected red colour skin coverage, while no significant increase in the occurrence of rot pathogens and any other damage of biotic or abiotic origin was observed. To consider the results on the efficacy against CM and the possible side effects of single row netting structures under South Tyrol growing conditions as conclusive, they should be confirmed in additional studies.

To avoid the occurrence of a high damage in the orchard, the trials with entire block netting structures (Trial EB1 and EB2) were concluded at the end of the 1st CM generation. No significant differences between treated and untreated plots emerged in Trial EB1, but according to the farm manager the netting structures had not been sealed hermetically. In Trial EB2, instead, fruit damage at the end of the 1st generation was significantly lower in the netted plots than in the untreated control plots. Also in this case, in order to make a clear statement about the efficacy of entire block netting structures in suppressing CM, further studies are deemed necessary.

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