Exclusion nets for orchards: manipulating mesh characteristics to improve net selectivity - with a focus on aphid's natural enemies

INSTITUT DE RECHERCHE ET DE DÉVELOPPEMENT EN AGROENVIRONNEMENT

Chouinard, Gerald*[1]; Pelletier, Francine[1]; Larose, Mikael[1]; Pouchet, Catherine[1]; Dumont, Marie-Josée[2] and Tavares, Jason Robert[3]

1. Research and Development Institute for the Agri-Environment (Saint-Bruno-de-Montarville, QC, Canada)
2. CREPEC, Polytechnique (Montréal, Canada) / 3. McGill University (Montréal, QC, Canada)

INTRODUCTION

- The vast majority of apple pests can be effectively controlled in northeastern North American orchards using exclusion nets instead of insecticides [1, 2, 3], but their use can be accompanied by increased population levels of some species of leafrollers and aphids, possibly due to the exclusion of some of their natural enemies [4, 5, 6, 7, 8].
- Smaller-sized meshes have generally been identified as the culprit, but mesh shape can also affect the composition and population of pests [9, 10, 11], and beneficial [12] species that can enter the netted environment.
- To improve exclusion systems currently being developed for fruit trees, the impacts of mesh size and shape on the exclusion of selected pest and beneficials was examined, both in laboratory and field conditions.

MATERIALS & METHODS

LABORATORY EXPERIMENTS

Test species:

- Three beneficials: the predatory midge *Aphidoletes aphidimyza* (Diptera: Cecidomyiidae), the parasitic wasps *Aphidius matricariae* (Hymenoptera: Braconidae) and *Aphelinus abdominalis* (Hymenoptera: Aphelinidae);
- Two pests: the apple maggot *Rhagholetis pomonella* (Diptera: Tephritidae) and the spotted wing drosophila *Drosophila suzukii* (Diptera: Drosophilidae).

Test material:

- Net samples of five geometric patterns (shapes): square, rectangle, triangle, rhombus and hexagon. All samples 3D-printed and shapes adjusted to the same discriminant size (area), selected for each species based on the average width of the thorax ;
- Cylindrical cage (Fig. 1) separated in two equal compartments by a section of net (mesh shape varying according to the treatment) with a yellow sticky trap suspended in the upper compartment.
- Introduction of 15 to 50 individuals (adults or mummies) according to the species, in the lower compartment.
- Devices placed vertically * and covered with aluminum foil (except the upper end)
  = Use of phototropism (+) and geotropism (-);
  * except for tests with *A. aphidimyza* which have been performed horizontally
- All tests (6 replicates) performed under controlled conditions (23ºC; 70% RH; 16:8 L:D).
- Recorded data: % individuals that crossed the net after 24 h (adults) or 6 days (mummies).

FIELD EXPERIMENTS

- 10-12 apple trees (cv Honeycrisp) covered with a row-by-row, complete exclusion system [1] in a pesticide-free experimental orchard (Fig. 2).
- 3 treatments : 1) Quebec's standard net (ProtekNet: 0.95 x 1.90 mm); 2) larger mesh net (Artes: 2.2 x 3.4 mm); 3) control (no nets) ; 5 replicates.
- Nets in place from bud break until harvest, opened for 2 days at bloom to ensure pollination.
- Apple shoots (120 - 180/treatment) randomly sampled twice in June.
- Aphid and ant density on each shoot was rated usind the following categories:
- 0=no aphids or ants; 1=1-5 ; 2=6-25 ; 3=26-50; 5=51-125; 5=more than 125.
- Number of predators or parasitoids (mummies) at any life stage were also noted.
- Aphid colonies of category 2 or more (exclusively *A. pomi*) were also selected, marked and monitored weekly from June 7 to September 12.
- 180 fruits/units were sampled from June to September to assess damage. All types of damage observed were identified, whether from insects and diseases, or from physiological or physical causes.

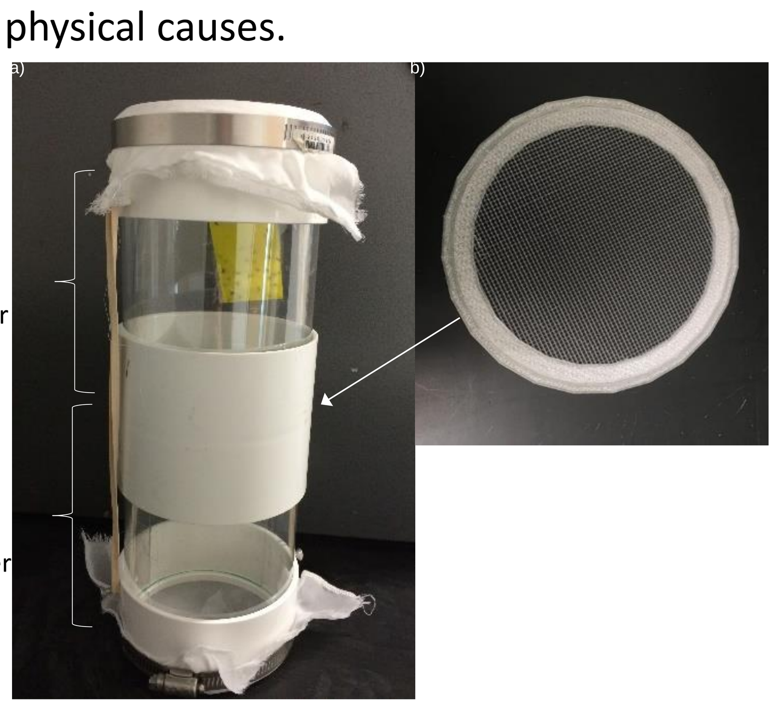

Fig. 1 Experimental setup used in the laboratory (a=cylindrical cage; b= net positioned inside a custom-printed double ring to tightly divide the cage into two enclosures)

Fig. 2. Complete exclusion system tested in the apple orchard.

RESULTS

- The physical and behavioral characteristics of the six studied species affected their ability to cross the nets.
- For an equal size (open area), the intrusion rate was generally greater through the square- and / or hexagonal-shaped meshes (Table 1).
- Rectangular-shaped apertures totally excluded the apple maggot in both laboratory and field trials, provided the mesh size did not exceed 1.9 mm (Table 1).

Table 1. Percentage of individuals of selected pest species (mean ± SEM) not crossing the nets of different geometric patterns with an equal aperture size (area). Different letters indicate significant differences (ANOVA (*R. pomonella*) or Kruskal-Wallis (*D. suzukii*), α = 0.05). a=height; b=width.

Mesh pattern	a (mm)	b (mm)	*R. pomonella* (females)	a (mm)	b (mm)	*D. suzukii* (females)	*D. suzukii* (males)
Hexagon	2.5	2.9	13.3 ± 9.4 a	1.4	1.6	32.1 ± 4.0 a	15.7 ± 6.4 a
Square	2.3	2.3	41.1 ± 3.6 ab	1.3	1.3	52.1 ± 12.4 ab	24.8 ± 9.5 a
Rhombus	2.5	4.3	69.9 ± 7.4 bc	1.4	2.4	79.0 ± 3.8 b	50.2 ± 6.2 a
Triangle	3.0	3.5	75.6 ± 9.5 cd	2.0	1.7	80.5 ± 5.6 b	40.8 ± 9.9 a
Rectangle	1.6	3.3	100.0 ± 0.0 d	0.9	1.8	100.0 ± 0.0 c	100.0 ± 0.0 b
Mesh pattern	**a (mm)**	**b (mm)**	***A. aphidimyza* (males and females)**	**a (mm)**	**b (mm)**	***A. matricariae* (males and females)**	***A. abdominalis* (males and females)**
Square	2.8	2.8	13.1 ± 3.3 a	0.7	0.7	16.1 ± 3.3 a	9.4 ± 2.7 a
Rhombus	3.0	5.2	29.4 ± 3.2 b	0.8	1.3	21.2 ± 3.2 a	7.0 ± 0.6 a
Triangle	3.7	4.3	34.1 ± 5.4 b	1.1	0.9	16.0 ± 5.4 a	5.7 ± 1.2 a
Rectangle	2.0	4.0	34.2 ± 4.8 b	0.5	1.0	31.7 ± 4.8 a	4.1 ± 2.3 a

- Field trials confirmed that more aphid predators (*A. aphidimyza*) colonized trees covered with larger mesh nets (2.3 x 3.4 mm), while still excluding the apple maggot (Table 2).
- Aphid density on the second assessment was significantly greater on trees covered with nets made of smaller-sized mesh (0.95 x 1.9 mm), compared to unnetted trees. The larger-sized mesh (2.2 x 3.4 mm) did not have an overall effect on aphids (compared to control plots). This pattern was also observed following the monitoring of the selected infested shoots (Table 2).
- Nets were not found to have an observable effect on the abundance of ants (Table 2).
- Damage from most insect pests was significantly reduced by nets, with almost no difference according to mesh size. Both mesh sizes almost totally excluded the apple maggot and the codling moth (Table 2).

Table 2. Mean density and or abundance (± SEM) of aphids, ants and aphid natural enemies on apple shoots and insect damage from trees covered with nets of different mesh sizes and from uncovered trees. Different letters indicate significant differences (α=0.05) among treatments (ANOVA (aphid density and insect damages) or Kruskal-Wallis (abundance on selected shoots).

	Large mesh (2,2 x 3,4 mm)	Small mesh (0,95 x 1,9 mm)	No net
Population density			
Early June			
D. plantaginae	0.53 ± 0.29 a	0.11 ± 0.07 a	0.92 ± 0.54 a
A. pomi	5.95 ± 3.76 a	2.78 ± 1.15 a	0.52 ± 0.24 a
Late June			
D. plantaginae	0 a	0.46 ± 0.31 a	0.06 ± 0.04 a
A. pomi	14.1 ± 3.94 ab	20.57 ± 6.13 a	8.08 ± 2.12 b
Abundance on selected infested shoots			
Aphids			
A. pomi	82.58 ± 3.66 b	97.71 ± 4.02 a	80.28 ± 4.21 b
Aphid allies			
Formicidae	3.20 ± 0.16 a	3.42 ± 0.20 a	3.52 ± 0.25 a
Natural enemies			
Cecidomyiidae	1.48 ± 0.21 a	0.48 ± 0.07 b	1.49 ± 0.17 a
Chamaemyiidae/Syrphidae	0.008 ± 0.004 b	0.003 ± 0.002 b	0.278 ± 0.073 a
Chrysopidae	0 a	0 a	0.004 ± 0.003 a
Coccinellidae	0 b	0 b	0.01 ± 0.003 a
Braconidae	0.002 ± 0.002 a	0.003 ± 0.002 a	0.01 ± 0.006 a
Insect damage at harvest			
Codling moth	0.1 ± 0.1 b	0 b	3.1 ± 0.8 a
Apple maggot	0.1 ± 0.1 b	0 b	12.9 ± 3.5 a
Plum curculio	12.3 ± 3.5 b	9.9 ± 3.9 b	26.8 ± 8.1 a
Tarnished plant bug	0.6 ± 0.3 b	0.8 ± 0.1 b	9.3 ± 6 a
Stink bugs	1.1 ± 0.4 a	0.3 ± 0.2 a	7.4 ± 3.3 a
Total hemipterans	3.1 ± 0.7 b	1.8 ± 0.3 b	25.8 ± 11.8 a
Spring feeding caterpillars	0.4 ± 0.3 a	0.2 ± 0.1 a	1.3 ± 0.8 a
Leafrollers	15.0 ± 1.8 ab	9.8 ± 2.6 b	18.3 ± 4.5 a

CONCLUSION

- The shape factor (height / width ratio) of the apertures affected net selectivity.
- For a similar aperture size (area), an elongated rectangular shaped mesh facilitated access for beneficials, while continuing to provide effective protection against apple pests.

ACKNOWLEDGEMENTS

The authors would like to thank the following persons for their involvement in field and/or lab work during the study: Jessica Champagne, Valérie Roy, Josiane Morrissette, Franz Vanoosthuyse, Audrey Charbonneau, Benoit Gadbois, Annabelle Firlej, Elisabeth Ménard, Kim Ostiguy, Éric Ménard, and many others.

RÉFÉRENCES

1. Chouinard G, Firlej A, Cormier D (2016) Going beyond sprays and killing agents: Exclusion, sterilization and disruption for insect pest control in pome and stone fruit orchards. Scientia Horticulturae 208:13–27.
2. Chouinard G, Veilleux J, Pelletier F, Larose M, Philion V, Cormier D (2017) Impact of exclusion netting row covers on arthropod presence and crop damage to Honeycrisp apple trees in North America: A five-year study. Crop protection 98:248–254.
3. Chouinard G, Veilleux J, Pelletier F, Larose M, Philion V, Joubert V, Cormier D (2019) Impact of exclusion netting row covers on Honeycrisp apple trees grown under northeastern North American conditions: Effects on photosynthesis and fruit quality. Insects 10:214.
4. Dib H, Sauphanor B, Capowiez Y (2010) Effect of codling moth exclusion nets on the rosy apple aphid, *Dysaphis plantaginea*, and its control by natural enemies. Crop Protection, 29:1502–1513.
Frechette B, Cormier D, Chouinard G, Vanoosthuyse F, Lucas E (2008) Apple aphid, *Aphis* spp. (Hemiptera: Aphididae), and predator populations in an apple orchard at the non-bearing stage: the impact of ground cover and cultivar. European Journal of Entomology 105:521–529.
5. Capowiez Y, Severac G, Sagnes JL, Alaphilippe A, Cros C, Parisi L et al. (2013) Impacts agronomiques et environnementaux d'une méthode de lutte permettant de réduire fortement l'usage des pesticides : les filets Alt'carpo en arboriculture. Dissertation, Agence de l'Environnement et de la Maîtrise de l'Énergie.
6. Romet L, Severac G, Warlop F (2010) Overview of "ALT'CARPO" concept and its development in France. Proceedings of the 14th International Conference on Organic Fruit-Growing, Hohenheim, Germany pp.176–182.
7. Marshall AT, Beers EH (2021) Efficacy and nontarget effects of net exclusion enclosures on apple pest management. Journal of Economic Entomology 114:1681–1689.
8. Marshall AT, Beers EH (2022) Exclusion netting affects apple arthropod communities. Biological Control 165:104805.
9. Bethke JA, Paine TD (1991) Screen hole size and barriers for exclusion of insect pests of glasshouse crops. Journal of Entomological Science 26:169–177.
10. Bethke J, Redak R, Paine T (1994) Screens deny specific pests entry to greenhouses. California Agriculture 48:37–40.
11. Alvarez AJ, Oliva RM (2015) Insect exclusion screens: The size of the holes from a three-dimensional perspective. In International Symposium on New Technologies and Management for Greenhouses-GreenSys2015 1170:1035–1042.
12. Hanafi A, Bouharroud R, Amouat S, Miftah S (2007) Efficiency of insect nets in excluding whitefies and their impact on some natural biological control agents. Acta Horticulturae 747:383–388.