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Gaps in knowledge for modern integrated protection in viticulture: lessons from controlling grape berry moths

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Abstract: Viticulture has an impressive range of progress for the future years concerning the use of integrated pest management. This can be illustrated by insect pest management for which several tools have been developed or could be developed rather soon for an integrated protection management. The present talk aims at presenting through the experience gained in on insect pest or vectors management gaps and potential progress that can be achieved. The European grapevine moth *Lobesia botrana* can serve as a case study to analyse the different possibilities that can be used in IPM. Few existing examples of IPM compatible techniques will be presented: use of behaviour modifying chemicals in push-pull strategies, monitoring techniques, mathematical models, biotechnical insecticides (*Bt*) and natural enemies.

The different advantages and limits are discussed, and we attempt to identify gaps where scientific or development efforts are required to progress.

Key words: Integrated pest management, monitoring traps, mating disruption, behaviour modifying chemicals, natural enemies, push-pull

Introduction

Integrated pest management (IPM) has received a tremendous number of different definitions since this concept appeared in crop protection. From those, IOBC defined it as follows: *Integrated control represents procedures (methods) which utilize all economically, ecologically and toxicologically acceptable methods for keeping the pests under a threshold of harmfulness with preferential and meaningful use of natural restricting factors.* One recent definition was given in 2004 by the late Ron Prokopy: '*… a decision-based process involving coordinated use of multiple tactics for optimizing the control of all classes of pest (insects, pathogens, weeds, vertebrates) in an ecologically and economically sound manner*'. IPM should also be acceptable by the current social trends. Recent policy decision in France (ECOPHYTO 2018) requesting that agriculture reduces by two times fold within the next ten years the use of pesticides are opportunities to develop the concept of IPM. In this context, viticulture has an impressive range of progress for the future years. This can be illustrated by insect pest management for which several tools have been developed or could be developed rather soon for an integrated protection management.

Here we aim at presenting through the experience gained in insect pests or vectors control several gaps and potential progresses that can be achieved. The grapevine moths *Lobesia botrana* (European grapevine moth, EGVM) *and Eupoecilia ambiguella* (Grape berry moth, GBM) will be taken as a case study to survey the different possibilities that can be used in IPM. Few existing examples of IPM compatible techniques will be presented: use of behaviour modifying chemicals which includes pheromones and kairomones that can be used in push-pull strategies (Pyke *et al.*, 2007; Cook *et al.*, 2007; Thiéry, 2008), biotechnical insecticides like *Bacillus thuringiensis* (Bt) and beneficial organisms mainly parasitoids (Thiéry, 2008;). Pest population dynamics survey using monitoring techniques either coupled or not with population dynamic models are also classical key tools for such an integrated strategy. In the present paper, we try to identify where bottlenecks could arise and attempt at identifying how to solve the bottlenecks. I will try to discuss gaps in knowledge that may occur in certain techniques or methods and to identify the scientific input or research and development requirements needed to progress. I also wished to present the different tool efficacies but also their limits of use, though limiting factors may be simply financial, or linked to variable efficiency, but also to vinegrowers traditions or cultural habits.

Pest population surveys and monitoring tools

Two main types of monitoring tools are used in viticulture. Those using behaviour modifying chemicals (semiochemicals), *i.e.* odourant traps, and mathematical models of population dynamics.

Odourant traps

In insects chemical communication plays an important role in most of the life cycle: pheromones, either sexual or epideictic *i.e.* regulating inter-individual distances like for example egg spacing or aggregation patterns; kairomones which are involved in host plant selection process (*e.g.* selection of an oviposition site or selection of food plant). Attraction by sexual partners or host plants is crucial in reproductive behaviours especially in phytophagous Lepidopterans. Attractive molecules or blend of molecules can thus be used to develop monitoring tools, for example as lures in trapping techniques. Two types of traps may be used against the grape berry moths: the pheromone traps attracting males and the food traps attracting both sexes but in majority the females, and depending upon the type of bait used a fairly important proportion of young females ready to oviposit or those that that just initiated.

Sexual traps

Several shapes of traps of different colours have been used against the grape berry moths, but no clear difference was obtained between these different types. The so called ‘delta trap’ of white colour provides good results and is widely used in France (Thiéry, 2008). A rubber caps can be either baited with synthetic pheromone. In France baits with the dose of 2µg or 1mg are used, the smaller dose cap being ideally replaced every 4 weeks.

Food traps

Food traps were probably with light traps the first traps to be used in vineyards, and they were recommended as mass traps to reduce populations especially against the EGVM at the beginning of the 20th century in the Bordeaux Vineyard. Several food sources can be used, either based on beer, wines eventually with sugar or vinegar, but also concentrated apple juice provides good results (Thiéry *et al*., 2006; Thiéry *et al*., unpublished data; Thiéry, 2008). When placed in foliage close to oviposition site, it may be used to efficiently monitor the egg-laying dynamics.

Coloured sticky traps

They are marginally used without odorant baits against moths. Coloured sticky traps are however used against leafhoppers like *Empoasca vitis* or *Scaphoideus titanus* or planthoppers like *Hyalestes obsoletus*.

Advantages and limits of use and gaps in knowledge for monitoring
Because trap is a seductive monitoring tool for insect population, it has also several limits of use that should be considered. First, odorant traps are very sensitive to climatic conditions. Wind may alter the odour diffusion but also the landing or targeting behaviour of the insect when arriving to the trap. Also temperature is a factor limiting flying activity of most insects which may hinder the trap efficacy. To our knowledge in berry moths no resistance of natural populations to the baits used in traps has been described to date. However, reduction in attractiveness of sex pheromone baits has been suspected during the last decade in several French or Italian vineyards. This hypothesis is however not confirmed.

Another limiting factor is the lack, to date, of mathematical relation between the insect captures and the egg or larval population on bunches. For this reason traps are thus mainly used to monitor the occurrence timing of males, females or eggs.

Probably, the main advantages of odorant traps are their convenience, facility of use and monitoring. Also the fact that the vinegrowers classically use them for long time and accept to adapt their decision to these tools is a real advantage. There is no doubt concerning the advantages of sex pheromone traps. The food trap against the EGVM has recently regain popularity in several French vineyards. Beside the good results in forecasting egg laying dynamics, it has also the advantage not to lose efficacy in mating disruption plots because its lure does not interfere with the cloud of sex pheromone. The other advantage is that it catches a majority of females, and especially young and mated ones (Thiéry *et al.* 2006; Reynaud & Thiéry, 2007), and is thus an interesting tool to monitor the beginning of each generation. Food traps, using this type of baits, seem to be less powerful in the GBM.

Behaviour modifying chemicals

Behaviour modifying chemicals may be efficiently used to control insect population especially those which influences the reproductive success. Mating and host plant selection (oviposition and feeding) are the main targets. We consider here semiochemicals used for modifying the pest behaviour itself but not those cueing natural enemies behaviour. In numerous species, and especially moths, mating is cued by volatile pheromones. Aside, all the steps leading to the host plant selection process (including attraction to the egg laying sites or to food sources, feeding activity regulation) concerns mainly females and larvae. It is cued by kairomones of plant origin.

These molecules can be used either as baits for trapping and monitoring (see above) but also to disrupt the different behaviours.

Mating disruption
Mating disruption has been developed against *L. botrana* and *E. ambiguella* since the 90's. Globally mating may be disrupted, but several fine behaviours are involved in mate research or mating and the exact mechanisms of action are not fully known. Currently, two types of dispensers are used in European vineyards, raks and ropes. The areas covered by this technique represents in France a bit less than 2% of the vineyard area, the proportion being higher in Swiss or German viticulture.

Limiting factors for mating disruption and gaps in knowledge
Two limiting factors are clearly the price of the technique. Raks cost around 0.40€ each (depending upon their type) and between 250 and 500 per ha could be needed for a control, in some vineyards with high pest populations, 750 or 1000 may be used per ha. Currently, ropes

are marginally cheaper. Relationships between efficacy and population level to control is also a limiting factor. One other additional factor which complicates its use is that it functions in a 'blind technique': no comparison with neighbouring untreated plots is hard and monitoring based on sex pheromone trap is not reliable.

The concentration in synthetic pheromone per volume of air above the vineyard needed for mating inhibition and the patterns of variation of concentration are yet not enough studied. More globally the synthetic pheromone cloud above a vineyard and its 'behaviour' for example as a function of wind should receive more investigation.

For example, interesting studies using the so-called 'field EAG' technique have been performed indicating important variations in concentration among seasons and that leaf cuticles could adsorb the pheromone like chemical traps and further act as secondary releasers (Karg & Sauer, 1995; 1997; Karg *et al.* 1994). One point on which progress could be obtained concerns the releasing sphere around a dispenser and its variation among the day as measured by accurate headspace techniques (Thiéry & Frérot, unpublished data). Also measuring the real inhibition of mating behaviour is hardly feasible except by placing from places to places net cages with couples of moths or by using the ancient technique of captive females.

Clearly, the development on large areas of mating disruption will be correlated to the price. Also, several progress could be done by coupling the technique to population reduction or example, in vineyards where first generation control is not predominant, dispensers could be hanged when summer starts for a higher concentration of pheromone during summer.

Oviposition disruption or misplacement

This approach has still to be developed and its efficacy to be verified in vineyards. This is a derived push-pull concept (Pyke *et al.*, 1987; Coock *et al.*, 2007). This principle could be adapted to the two species of grape berry moths (*L. botrana* and *E. ambiguella*) (Thiéry *et al.* 2002) because they naturally oviposit on fructiferous organs at the different bunch development stage (Thiéry, 2008) and because misplacement of the eggs will lead to an important mortality of the hatching larvae are short lived and have very low capacities to displace. *Lobesia botrana* produces oviposition deterring pheromones in its egg mucus (Thiéry & Gabel, 1993 a and b; Gabel & Thiéry, 1996), this also acting as kairomones by repelling oviposition in other species of tortricids like for example *E. ambiguella*.

Efficient and long lasting oviposition misplacement should however require attracting females to alternative oviposition sites. These alternative oviposition sites could be part of the plant to protect (*e.g.* leaves in grapes) or baited lures or plant surrogates. To date, poor results have been obtained with synthetic attractants isolated from grapes. Potentially, and because these moths have a polyphagous larva (Thiéry & Moreau, 2005) plants other than grapes can be investigated in search for attractants or oviposition stimulants, e.g., *Daphne gnidium,* tansy (Gabel & Thiéry, 1994), Rosemary (Katerinopoulos *et al.*, 2005) or *Drimia maritima.* As an example, strong oviposition stimulants being also produced by *D. gnidium* (Maher & Thiéry, 2006; Thiéry *et al.*, unpublished data). The limit of such techniques is that we still lack synthetic chemical structures to efficiently stimulate oviposition with baited plant surrogates or lures.

Biological agents or biotechnical products

Natural enemies

There are numerous beneficial organisms acting as predators or parasitoids known for long in vineyards and vineyard is far from being a 'no parasitoid's land'(Audouin, 1842; Jolicoeur, 1894; Marchesini & Dalla Montà, 1994; Thiéry *et al.*, 2001; Sentenac & Thiéry, 2008; Moreau *et al.*, 2010; but see Thiéry, 2008 for reviews). Also the efficacy of few species has been recognized for long. However, their biology is less known. Eggs and larvae (including pupae) are the main targets for efficient biological control, though predation of adults by birds may also occur.

Biological control may be obtained either by natural populations of predators or parasitoids but also by releasing natural enemies. Several attempts of releasing *Trichogramma* species have been done during the last decades in different European countries. Several species of *Trichogramma: T. brassicae* Bezdenko, *T. cacoeciae* Marchal (see Hommay et al. this issue), *T. dendrolimi* Matsumura or *T. minutum* Riley have for example been released with varying efficacies (Reda Abd el Monsef, 2004).

However the biology of potential efficient agents against berry moth larvae is probably not sufficiently studied even though recent progress attempted to solve this gap. For example recent laboratory and field studies have concerned efficient larval parasitoids that could be used in biological control, *Campoplex capitator* Auber, *Dibrachys cavus* Walker *and Phytomyptera nigrina* Meigen (Chuche *et al.* 2006; Xuéreb & Thiéry, 2006; Thiéry *et al.*, 2006; Moreau *et al.* 2010).

Biological control based on natural enemies against the grape berry moths will thus be challenging for the future years (see Thiéry et al. this issue), but both a better knowledge of the influence of environmental conditions on their biology and the development of mass rearing to release parasitoids will be needed.

Biotechnical products

We do not consider as biotechnical molecules those emanating directly from nature and being chemically modified to enhance their activity. Surprisingly the well known toxin of *Bt* is marginally used in European viticulture, and its use should probably developed. Several very active formulations exist, but the main limit of use is probably linked to the timing of application. These products have to be applied at egg stage, shortly before egg hatching, and because short persistence, the efficiency is directly related to an accurate monitoring of the egg laying dynamics.

Recent attempts are done to improve persistence, but also protection against UV radiation (e.g. French ANR ‘blanc’ research project named Ecophyto). Also as a toxin ingested by the larva, its efficiency depends on the larval feeding activity and thus on temperature which may be problematic during the spring generations of the EGVM and the GBM. In order to solve this problem, researches are for example conducted trying to incorporate feeding stimulants to the formulations, thus increasing the *Bt* intake.

Recent field or laboratory researches also concerns other families of biotechnical products, for example those acting as ecdysone like molecules. Azadirachtine (one of the active constituent of natural neem oil) and phytoecdysteroids may represent future good candidates against pests or even disease vectors. Recent laboratory interesting results have been obtained against *L. botrana*, showing egg laying inhibition but also food aversion by almost all larval instars in response to low doses of the synthetic phytoecdysteroid 20E (Callas *et al.*, 2006). These researches are however still far from application.

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