Decision support systems and pest control – technological distraction or necessity?

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Abstract. Grapevine protection against tortrix moths has been a success over the last 35 years, noted primarily by the protagonists of mating disruption as the pest management technique. Data analysis published by official authorities as well as findings directly in the field provide clear and understandable indications that the reliability of sex pheromones as a monitoring system is currently questionable. Therefore, the concerns of growers about the confidence of the mating disruption method should be considered. Timing of phytosanitary action against Tortrix is typically based on determination of Biofix I date, where male's catches from pheromone traps are input data. Starting this date, the computing of the DD values takes place followed by the monitoring of the oviposition (searching for eggs). Based on that phytosanitary intervention is carried out when the embryonic stage - black head is present. With such concept of the decision process, it is necessary to take in consideration several sources of inaccuracies that significantly affect the timing: 1) reliability of the sex pheromone in relation to the local population, and consequently reliability of population dynamic data in real time; 2) ACV of males catches in relation to reproductive events in the vineyard; 3) error rate related with monitoring of eggs-laying compared to reality. VITIPORT digital platform not only simplifies decision of winegrower, but also allows him to save financial and human resources to be spent on monitoring. Our DSS is based on original algorithms, the accuracy of which has been verified over the last 5 years by professional authorities and winegrowers within the EU. Precise timing in eco/organic farming is crucial, as bio pesticides have a significantly shorter period of effectiveness. In addition to computing males and females eclosion, VITIPORT also indicate very precisely oviposition and larvae hatching. That makes possible to inform the grower a week in advance when insecticide treatment is needed - WITHOUT searching for eggs on the plants! Currently, the DSS also indicates the timing of new phytosanitary tool Pheromark, which acts as a host-marking pheromone with an oviposition deterrent effect. The advantage of VITIPORT is its universality, regardless of geographical location in both hemispheres, atypical weather patterns, correct prediction of population development even in years with spring frosts, as well as in zones with specific variety features that modify the development cycle of the pest, e.g. variety Uni blanc and Cognac region.

1 Introduction

In agriculture, perhaps more often than in other sectors of human activity, we find periodically recurring ideas of the ''final solutio'' to a biological problem, forgetting the fact that in nature there are neither victories nor defeats - there are only consequences. It is particularly striking in the development of crop protection methods, where after a certain time (roughly after 20 years) we observe/note/conclude a reduced effectiveness or ineffectiveness of the latest solutions to phytosanitary problems. This applies not only to classic synthetic pesticides, modern plant protection products with eco/bio attributes, but also to phytosanitary methods themselves, e.g. targeted release of predators, parasites, sterile or genetically modified individuals...etc. Situation is no different in the case of the use of sex pheromones, whether as a monitoring tool (protection signaling according to pheromone traps), or as a crop protection method (mating disruption).

2 Monitoring of tortrix moths

The deployment of sexual pheromones in agricultural practice was the result of successive steps in the search for a suitable method of detecting pest presence in the vegetation during the growing season. Operability, laboriousness, cost and relevance of data with regard to

changes in the cenosis, these were the main criteria applied in this search process by generations of researchers.
One of the first methods was catching butterflies in bait traps of various shapes and types, filled with old beer or wine with the addition of sugar or vinegar. The goal was to capture as many butterflies as possible, especially females, to prevent the oviposition process. This method of ‘‘mechanical’’ combat with tortrix pest was commonly used in the years 1908-1916. Despite the thousands of butterflies caught, no significant decrease in attack was detected [1], therefore the aforementioned method of combat was gradually abandoned and the method of "Stellwaag" glass containers [2] began to be used to capture the course of the butterflies' flight [3]. The date of oviposition and hatching of the larvae, and therefore also the possible date of insecticide intervention, was subsequently deduced from the catching data. Almost at the same time as the bait traps, experiments began in the vineyards with the use of the positive reaction of the tortrix pest to the light source [4]. From oil, carbide and kerosene lamps, there was a gradual transition to electric light traps of various shapes and designs [5]. Up until the mid-1970s, light traps were commonly used to determine flight dynamics, and based on that spraying dates were signaled [6-8].

2.1 Sexual pheromones as monitoring tool

Already in 1913, French experts found that cages with live females of the European grapevine moth (EGVM) intensively attract the opposite sex [9]. Later, the German researcher Bruno Götz [10] addressed the question of whether live female moths are able to attract a sufficient number of males to prevent mass fertilization by trapping them.

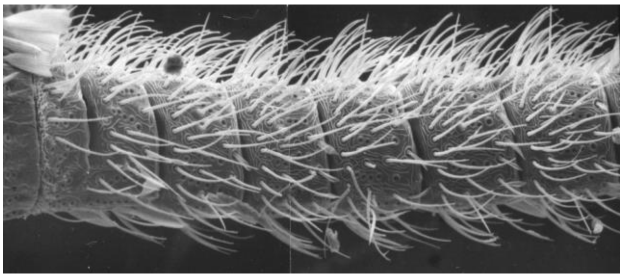

Figure 1. The antennae of EGVM males are responsible for the detection of sex pheromone and search for an odor trail in the agrocenosis. The detector itself is the *sensilla trichodea.*

In his opinion, capturing males with traps will be of practical importance in the fight against grapevine moths only if the attractant produced in the back of the female's body is identified and subsequently synthesized (Fig. 1).

The sex pheromone EGVM (Lobesia botrana) was identified only in 1973 [11]. The main component of the sex pheromone was identified as (E)-7, (Z)-9 dodecadienyl acetate, while the result of synthesis and subsequent purification by preparative gas chromatography was a mixture of isomers, namely: 90% (E)-7, (Z)-9 and 10% (E)-7, (E)-9 dodecadienyl acetate. It should be noted that the identification of sex pheromones at that time was conditioned both by the development of chemical-analytical methods, but also by the development of artificial breeding methods, which had to ensure a sufficient number of individuals of the target pest species for analytical purposes. The multiplication of a geographically limited sample of individuals, which served as the starting material for the establishment of laboratory breeding on a synthetic medium, could have been a source of inaccuracies at the very beginning of the research with regard to the variability of the natural population, which will manifest itself later especially when extrapolating the results of chemical analyzes in industrial production and subsequently in the case of application of pheromones as a method of protection (mating disruption).

The French drew attention to the ‘‘remarkable’’ feature of the wild, natural population of EGVM in the second half of the 1970s [12]. Under natural conditions, they compared the baiting efficiency of two isomers of dodecadienyl acetate and monoethylene acetate. They found that monoethylene acetate did not appear as an attractant in any experiment, the activity of the mentioned isomers was unequal in two consecutive years. In later works [13] even attraction differences between the aforementioned isomers were found not only in individual years, but also between individual generations within one growing season. The genetic heterogeneity of the population in terms of the communication signal contained in the sexual pheromone was identified as the cause of this imbalance.

An updated 1999 identification of the EGVM sex pheromone [14] revealed that it is a mixture of three major components (E)-7,(Z)-9 dodecadienyl acetate, (E)-7,(Z)-9 dodecadien-1- ol acetate and (Z)-9 dodecenyl acetate with a ratio of 94:5:1, further two unsaturated acetates with biological activity when searching for a mating partner and 5 saturated acetates with hitherto unknown biological activity.

What was designated by French researchers in 1976 as a ‘‘remarkable’’ property of the wild population [12] is actually a normal distribution of the probability of occurrence of the examined biological property within the population, which is expressed by the Gaussian curve of the probability distribution of a continuous random variable. In our case, it is the frequency of occurrence of different communication signals materialized through the chemical composition of the sexual pheromone.

If the pest population was heterogeneous in terms of the production and reception of the odorous components of the sex pheromone, and the results of the observations confirmed that it is heterogeneous [12-13], then the incorrect assessment of the attractant in the case of a confusing effect would lead to the unwanted selection of the population and the emergence of resistance to the used pheromone [15]. Intraspecific variation of sexual communication was also detected in other species of tortrix pests. By extracting pheromone glands of individual codling moth (Cydia pomonella) females from a laboratory population in Canada and from apple orchard populations in Spain and Italy, significant between- and within-population variation was found [16]. Overall, the intraspecific variation observed shows the potential for a shift in female sexual signal when selection pressure is high, as is the case with continuous use of mating disruption.

2.2 Catches and mating disruption

The beginnings of sex pheromones' use in viticulture were accompanied by euphoria and exaggerated expectations, as even the scientific community assumed that winegrowers had gotten their hands on a reliable tool for controlling the population density of an economically important pest - EGVM. However, few people were aware of the fact that capture data from traps is only an **information derivative**, which primarily speaks about the suitability of abiotic conditions for the sexual flight of males, about the suitability or unsuitability of the physical and chemical parameters of the monitoring system itself, and only secondarily, unquantifiably reflects the facts associated with pest development cycle and population dynamics.

Pheromone traps of various types and colors captured males with varying intensity, agronomists drew capture curves, various DD values determining flight peaks were calculated, from which the term of laying eggs and hatching of caterpillars was subsequently derived. The overestimation of pheromones as a monitoring tool even led to efforts to determine the population density of the pest according to the number of captured males and, based on such estimate, to predict the necessity of phytosanitary intervention.

The entire concept of predictions of insecticide treatment was based on the evaluation of capture data from pheromone traps in real time and the subsequent application of one of the following key formulations. Apply spraying: a) immediately after reaching the flight peak, or b) 1 week after reaching it; c) 3-4 or. 4-5 days after finding the flight maximum; d) at the time of the maximum raid of males,...etc. Difficulty or the impossibility of determining the flight peak in real time is clearly documented by Fig. 2.

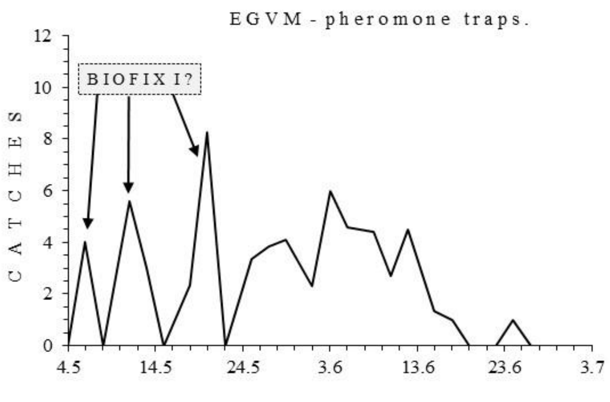

Figure 2. EGVM overwintering population flight according to pheromone traps (Zoecon corp., USA). Small Carpathian wine-growing region (Slovakia), year 1987.

At the same time, the widespread deployment of sex pheromones in the form of plastic diffusers hung in the vineyard was introduced into the viticultural practice in order to mask release of sex pheromone by live female moths. It seems that more than 25 years of widespread deployment of sex pheromones in the vineyards of Europe has led to the selection of that part of the natural population that is located on both ''tails'' of the Gaussian curve, even though we have successfully eliminated the main part of the population from the reproductive process for several decades .

In recent years, we have come across a common practice that recommends to install multiple food traps in vineyards protected by the mating disruption method, so that the grower and the agrochemical company can be sure that the formulation of the sex pheromone in the commercial product will ensure the protection of the vineyard. It is the most costly method of grapevine protection against tortrix moths. Available data points to a high risk of a widespread failure of effectiveness, provided that the producers do not change the formulation of the synthetic pheromone based on the analysis of the current communication means of the natural population. The problem is all the more complicated because it may not be one and the same formulation valid for the global population of moths in different geographical zones, as the selection pressure caused by the use of the confusion method may not be chemically manifested a priori in the same way in local populations.

2.3 Sexual pheromones - recent performance

Clues about reduced effectivness of the current commercial sex pheromone formulation for EGVM can be found in the official documents of the agricultural regional structures in France, which are responsible for the edition of BSV information bulletins for the needs of winegrowers.

BSV from 2017 [17] states that the cumulative weekly capture of males from more than 50 monitored locations during the flight peak of the 1st generation (May 8-14) represents an average of 16 butterflies, while in food traps it was twice as many. In the following week (May 15-21), pheromone traps caught an average of 14 and food traps 420 butterflies. The ratio of 14:420 is really surprising.

A year later [18], the notified data of the BSV surprised again in terms of quantitative disproportion. For the entire flight period, the maximum value of average catches per day in the case of pheromone traps was 2 individuals, while in food traps it was 52. For the period 28.05.- 05.06. an average of 266 butterflies were caught in the food traps, while 2 butterflies were caught in the pheromone traps, i.e. a ratio of 2:266.

In both mentioned years (2017-2018) there is a significant, quantitative discrepancy between the monitoring tools: pheromone versus food traps, not to mention a significant time shifts if we look for flight peaks and then consider the optimal time of application.

However, the disproportion between the capture data at the beginning of the use of sex pheromones in viticultural practice was not detected (Fig. 3).

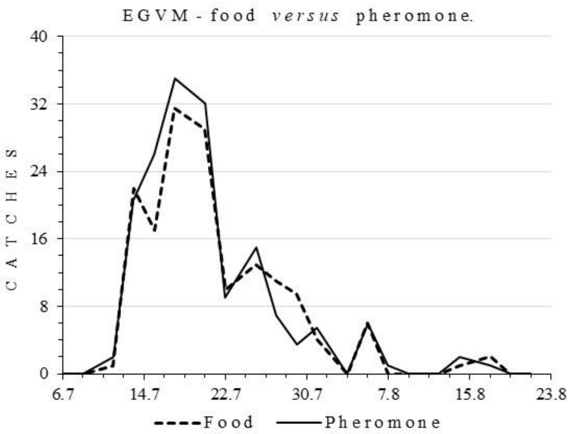

Figure 3. Flight of the second generation EGVM according to food and pheromone traps (INRA, France). Wine-growing region Modra (Slovakia), year 1987.

IFV (Institut Français de la Vigne et du Vin) specialists carried out comparative tests in 2022 with a new type of EGVM population control agent – Pheromark. It is a host marking pheromone, which is applied before eggs laying. They simultaneously placed pheromone and food traps in a ratio of 1:3 on the experimental plots, while the comparison of captures at the end of the season was again surprising (Fig. 4).

The ratio of the total number of individuals caught for the whole season 4:238 (pheromone/food traps) confirms already published findings from previous years [17, 18]. It is obvious that to time the phytosanitary intervention against EGVM only on the basis of capture data exposes the grower to the risk of inefficiency, increased costs and increase in pest population density with all the consequences for the quality of the harvest.

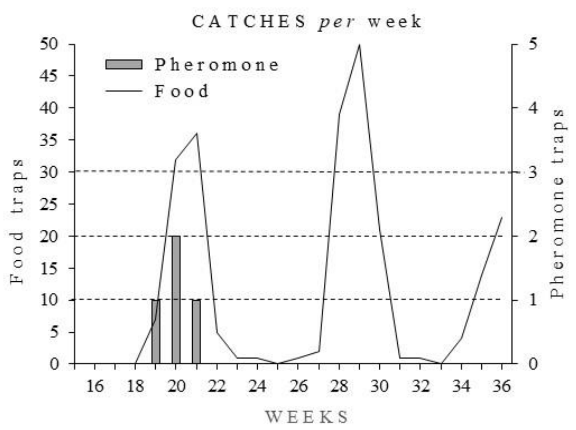

Figure 4. EGVM flight in region Cognac, campaign 2022. Cumulative catches per week are expressed.

3 DSS – unquestionable necessity

In order for the viticultural public to be able to respond effectively to the EU regulatory changes regarding pesticide use, it is necessary to provide innovative solutions to winegrowers. The essence of the problem in terms of the long-term sustainability of agricultural production stands and falls on two simple questions: when and what. The word WHEN expresses the correct timing of the phytosanitary intervention, if it is necessary at all. Put into practice, this represents reduction in toxicological load, reduction in the carbon footprint, an increase in the effectiveness of phytosanitary interventions and reduction in infection risks. The word WHAT points to innovative, preferably eco-friendly product with intelligent strategy for its use based on comprehensive knowledge of the bionomy of the target pest.

3.1 WHEN

Over the last two decades, with the development of digital and IT technologies, we increasingly find more or less complex advisory systems with varying degrees of complexity in the product offerings of commercial companies. However, few people are aware of the fact that the backbone of every production of agricultural crops, be it integrated, ecological or bio-production, must be perfectly mastered phytosanitary protection. The goal should be to reduce the toxicological load in the vineyard, but at the same time guarantee the economic profitability of winegrower. In order to achieve these goals, it is necessary to enter the decision-making process when applying phytosanitary products with accurate, up-to-date and comprehensive information that is addressed to the given vineyard. If DSS products have not mastered this aspect, then everything else is just variations on an old theme, technical improvements, updates of existing production processes.

Many agrochemical producers realize the need for DSS to accurately guide the application timing of their biosolutions to ensure their commercial success. The period of effectiveness of currently registered bio-phytosanitary products is generally shorter than what farmers were used to in previous years, so a change in application habits is inevitable.

It is clear from the above that the decision-making process based on the evaluation of information derivatives (data from traps) is cumbersome, unpredictable, with a high risk of inaccurate decisions in real time. Therefore, mathematical models appear to be a necessity, which, however, would not use data from the monitoring of biological events in the field as a ‘‘fixed point’’ for calculation, which is a priori imprecise, labor-intensive and financially demanding.

In the era of climate change and atypical weather patterns, prediction algorithms based on statistical analysis of abiotic and biotic factors from local 20-30 year databases are inaccurate, requiring an annual update after the end of the growing season. The word universality should be forgotten in this case.

VITIPORT’s software is based on algorithms and mathematical models that integrate the results of more than 20 years of experiments aimed at determining the key parameters of the life cycle of target pathogens.

Critical values of these parameters obtained from experiments in laboratory as well as in natural conditions, by entering in the form of coefficients and constants in mathematical equations, make Vitiport a unique, globally operating tool, built on causal mathematical models. The platform is built as a SaaS solution (software as a service) using CLOUD architecture.

Starting from the first phenological stages at the beginning of the growing season until the harvest, the winegrower's decision-making process on the implementation of phytosanitary treatments is guided on the basis of forecasts of the infectious risks of key pathogens (powdery mildew, downy mildew, downy mildew) and forecasts of the development cycles of pests (tortrix moths). for a given vineyard, identified via GPS coordinates. The information for the end user is clear, concise, comprehensible, but above all personalized.

The accuracy of VITIPORT predictions has been positively evaluated by specialists from several EU wine-growing countries since 2015. Cooperation with the IFV in 2022, aimed at verifying the biological effectiveness of the new concept of grapevine protection against tortrix moths, has raised, at first glance, contradictory conceptual challenges within the DSS: the concept of universality (abiotic factor) and locality (biotic factor). Example of a challenge: the Cognac region with its specific Uni blanc variety. According to growers feedback, have not come across reliable prediction models in the Cognac region. The problem is related to two aspects: abiotic - spring frosts and biotic - variety.

Unpredictable spring frosts result in developmental chaos, both in relation to the plant and the pest population.

Table 1. Prediction of phenological stages in the Cognac region in 2022 after correction of vine development due to spring frosts. The deviation between the DSS prediction and the findings in the field is expressed in days.

Phenological stages - BBCH	Monitoring	DSS	Delta
05 - Bourgeon dans le cotton	08.04.	06.04.	-2
09 - Pointe verte	19.04.	14.04.	-5
9/13 - Trois feuilles étalées	02.05.	27.04.	-5
12/17 - Sept feuilles étallées	09.05.	06.05.	-3
12/19 - Neuf feuilles étalées	16.05.	16.05.	0
61 - début floraison	30.05.	25.05.	-5
69 - fin floraison	07.06.	06.06.	-1
73 - Grain de plomb	13.06.	15.06.	2

The vine itself, with respect to duration and intensity, starts the physiological process of regeneration of vegetative and generative organs after the end of spring frosts, so we are witnessing a partial reset of the plant's development. In practice, this means that the algorithm must correct in real time the calculations of the onset of individual phenological stages, the determination of which is important for the prediction of some mandatory phytosanitary interventions. According to the data from the terrestrial meteorological stations, spring frosts hit the Cognac region in April in two waves: 03-04. and 09.-10. Vines were hit in the BBCH 05-07 stage. If the calculation did not take into account the negative impact of spring frosts on the development of the vine, the error rate of the calculation of the following phenological stages would reach 12-14 days. After correcting the energy values, which determine the onset speed of each individual phenological stage, very satisfactory prediction results were achieved during the entire vegetation period after the end of the spring frost period (Table 1).

In the case of EGVM, a wave of minus temperatures after the end of the diapause stage and the onset of the first generation causes elimination of all juvenile stages (eggs and larvae), as their internal structures are not protected by ‘‘antifreeze’’ as in the case of wintering pupae. If there was no correction of the calculation of the development cycle of EGVM after the wave of spring frosts, compared to the reality in the field, the error rate of the description of the subsequent development stages of the pest is so great that the DSS loses its credibility and the meaning of the word forecast must be replaced by the term guessing (Table 2).

Table 2. The difference between EGVM life cycle modeling without correction and after correction of the effect of spring frosts on the development of the pest. The deviation is expressed in the number of days. G1 – first generation, G2 – second generation.

	DSS - predictions				
	Frost correction	Males	Females	Eggs	Larvae
		Δ	Δ	Δ	Δ
G1	With Without	27	13	13	9
G2	With Without	7	6	6	6

Questions related to the different sensitivity of grape varieties to Tortrix attack have occupied whole generations of researchers for more than 100 years [19-21]. In the case of polyphagous insects, this is a very complex problem, while the ‘‘specificity of the variety’’ in relation to attack can have several causes: plant's nutritional status, morphological, anatomical features, secondary substances or, more likely, a combination of these factors (22) and one very important aspect - timing of infestation related to plant phenological stage in real time. At which phenological stage the neonatal larvae of the first generation attack the vine is crucial from the point of view of the abundance of subsequent generations. Semi-field conditions experiments on 6 varieties, in two geographically different regions, clearly demonstrated that vines in the BBCH 65-71 stage are generally an unsuitable food substrate for neonatal larvae [23], which was also confirmed by later chemical analyzes generative organs [unpublished data]. At the same time, the finding that the characteristics of the grape host plant affect the emergence phenology of L. botrana [24] must be taken into account.

When correcting the algorithm for the Cognac region, in addition to the reset of the development cycle of the first generation EGVM due to sub-zero temperatures, it is also necessary to take into account the change in the length of larval development caused by the change in the phenological stage of the vine, which is available to neonatal larvae after the frost period. The result is a modified algorithm for the Cognac region, which takes into account both the change of abiotic and biotic factors, which is crucial for the description of the development cycle and the prediction of phytosanitary measures (Table 3).

Table 3. Vitiport predictions with a modified algorithm for the Cognac region, third generation EGVM versus observations of IFV specialists. Food traps catches (F/t), monitoring data – searching for eggs (Mt).

	DSS-G3	IFV	DSS-G3	IFV
	Females	F/t	Eggs	Mt
Q 1	05.07.	08.07.	08.07.	08.07.
Q 10	09.07.		13.07.	18.07.
Q 30	13.07.		16.07.	
Q 50	17.07.	18.07.	20.07.	25.07.
Q 70	22.07.	22.07.	25.07.	
Q 90	28.07.		31.07.	

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