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Abstract: Climate change will probably induce changes in the use of virus-based biocontrol agents at various levels. Climatic changes will affect host development, indirectly modifying virus behaviour. Invasive species will constitute potential new niches for virus populations, but also may reduce their traditional hosts. Introduction of new viruses adapted to such invasive species in their new geographic areas might be an appropriate strategy. Variation in UV radiation, in rain or wind will directly affect the survival or the availability of the virus for the appropriate hosts. Variation in temperatures influence insect host development, but also plant development, and will indirectly affect virus/host relationships.

Instructions of use, timing and doses should be re-evaluated in function of new climate parameters. In addition, formulation changes might be required to optimise the persistence of virus-based products in new environmental conditions.

Key words: pests, diseases, integrated control, climatic change, adaptation

Introduction

Climate change is now well established and is affecting us in many different ways. Abundant literature has been devoted to the effects of climate changes on agriculture, mainly concentrating on the ability of crops to cope with increasing temperatures, or with drought, and the ways to avoid production losses, by changing varieties or crop species by others more adapted to the new climatic conditions. These adaptations often imply changes in the pest affecting the crops, and thus, in the way to control them.

Another consequence of the climate change is the colonisation of new areas by invassive species, that might acquire the pest status in the new area. Fighting these invasive species may require the adaptation of native pathogens or predators. Alternatively, a solution could be the introduction of the agents that regulate the invader in its original distribution area, where often it does not represent a problem.

In temperate regions, increasing the temperature will accelerate the development of insects, leading to a higher generation number in multivoltine insect species in temperate regions. Similarly, increasing the period of appropriate temperature will have similar consequences. This effect will of cours have an upper limit that is the maximal temperature supported by the insect.

However, the most limiting factor for larvae survival seems to be the lowest temperature that larvae can stand during diapause. The work by Causse (1976) showed that the density of first generation is clearly influenced by the lowest temperature during the winter. Climatic changes, by inducing higher extreme might also have this effect.

Whatever situation, climatic change will affect the life cycle of the insect host, and thus, that of the virus pathogen. From an agronomic perspective, that probably means adapting the treatments, maybe having more treatment per season.

When adressing specifically the virus based biocontrol agents, all these concerns should be taken into account. In addition, there are other points to consider, due to the specificity of the virus. In this work we will adress more specifically the insect pathogenic viruses that are or could be used to control insect pests. Even if at the present time baculovirus are almost the only virus group used for as biocontrol agents, I'll try to depinct a more general view, that could be applied to other virus families.

Invasive insect species: adaptation of virus populations

Adaptation of a virus to a new host species has been described both in laboratory conditions and in fields. Determination of baculovirus host range determinants was a hot reseach topic in the 90's. Using the model baculoviruses AcMNPV and BmNPV, Maeda's group in Japan and Croizier's group in France demonstrate that AcMNPV could be adapted to replicate in silkworm and silkworm cells by modifying the virus helicase gene (Kondo and Maeda, 1991; Crozier et al., 1994; Argaud et al., 1998). Other works revealed that there was often possible to adapt(baculo)viruses to new hosts, but that the genes involved are not allways the same, preventing a systematic approach (Thiem and Cheng, 2009; Williams et al., 2022).

Field observations confirm the ability of a local virus population to adapt to a new host. The guatemale tuber moth, *Tecia solanivora* progressively invaded south America and recently was found in the Canary Islands (Puillandre et al., 2008). This pest displaced the potato tuber moth, *Phthorimaea operculella*, but the two species coexist in many locations. The Phthorimaea operculella granulovirus is found associated to all *P. operculella* populations. The isolates of this virus collected were or when no *T. solanivora* is present do not replicate in this species. However, soon after invasion, granuloviruses able to replicate in *T. solanivora* larvae were isolated in Venezuela (Niño de Gualdron and Notz, 2000). The process of invassion of *T. solanivora* in Colombia has been analysed in the 2000's (Zeddam et al., 2013). Sampling for viruses was carried out and revealed that the genetic composition of virus isolates changed to adapt to the presence of this new potential host (and probably to the reduction of the original host). This adaptation process will probably take place for every invassion, although the succes cannot be granted.

A complementary or alternative way is the introduction of a virus already adapted to this species. This approach has often been taken both for invassive species or for already established pests. As exemple, the mexican isolate of Cydia pomonella granulovirus (CpGV-M), the first discovered, was used for developping virus based insecticides to control codling moth in european orchards.

Sensibility to environmental conditions

The primary infection is a key point that may be heavily affected by climatic change. Tranmission will not be affected for viruses that are propagated by close contact of individuals. This can be the situation for social insects living in colonies (bees, termites, …), gregarious insects, or those in high density situation. A well know exemple is Oryctes virus used for the control of the rynoceros beetle, *Oryctes rhynoceros* (Huger, 2005). Two main ways of contamination have been proposed. Virus replicate actively in the midgut epithelium, and particles are released in high numbers on the feces, contaminating feeding burrows of palm crows. The Oryctes virus is a non occluded virus, whos particle and replication remembers that of baculoviruses. It was classified as a "non occluded baculovirus" before an independent family was proposed in the 2000's. This virus is highly susceptible to environnmental

conditions, heat and UV radiation, but the hughe amounts released and the shield offered by palm leaf certainly attenuate such limitations. In addition, the second way of transmission of the infection, that is supposed to be the most important, is by direct contact during mating or coocupation of the same palm. In such circunstances, the delai on the external environment is very reduced. The same constraints will apply to other viruses with similar transmission strategies.

Viruses that need to survive into the environment between infection cycles will be affected by changes in climate. If the virus is supposed to survive in the environment between infections, variation in the climatic conditions may affect its persistance. Increasing temperature is probably not a direct limiting factor for survival of these viruses. Baculovirus OBs can stand temperatures up to 50 °C without significantly loosing infectivity (McLeod et al., 1977). The same applies for other occluded insect viruses, like cytoplasmic polyhedrosis viruses (Reoviridae) (Tanada and Chang, 1968). Baculovirus can survive as OBs to low temperatures without significantly loosing pathogenicity. Accordingly, stronger or mildler winter temperatures should not greatly influence the virus survival. However, when transmission between years is mainly dependent on a diapausing stage, like in vertical transmission, or in chronically infecting viruses, the survival of the insect may be affected, and indirectly, that of the virus. In addition, increasing the average temperatures will induce faster insect development, and thus an increasing number of generations per year. From an agronomic perspective, this means expanding the treatment period.

Increasing the sun light irradiance implies a higher UV dosis, that affects virus survival. Increasing rainfall intensity may result on virus wash off from the aerial parts of the plant. Similarly, strong winds may also affect the disponibility of the virus to the insect pest. Baculovirus inactivation by UV light has been studied both in laboratory and in field conditions. It is one of the key point that limit the development of this crop protection biocontrol agents in the actual climatic conditions. To increase the survival time, commercial products include UV protection, like flurescent brigtners or other UV protective substances (Çakmak et al., 2021). If the changes on UV radiation are significant, it may be necessary to reevaluate the level of UV protection required, by increasing the concentration of UV protector, or by changing the substance used.

Brassel and Bentz (1979) repported a 5.6 increase in the resistance to UV inactivation on CPGV after selection. In their work they do not specify which isolate they used, but it was probably the CpGV-M, that is know to contain extremely low genetic diversity, which may explain the relatively low response to the selection process. Similar approaches were taken for other baculoviruses, confirming a genetic variability for the resistance to UV light, that could be exploited when developping biocontrol agents, and that the virus could mobilize for its adaptation to evolving climatic conditions.

In Chrysodeixis chalcites nucleopolyhedrovirus, two genes homologous to photolyases were found by when sequencing the entire virus genome, phr1 and phr2. The DNA repair activity was demostrated for phr2, but not for phr1 (van Oers et al., 2008). However, homology searches have detected homologous genes in group II alphabaculoviruses infecting plusiine insects (Xu, 2008), but not in other baculoviruses.

Overexpression of the Bm65 virus gene results in a higher UV tolerance. Bm65, homologous to Ac79, is predicted to be an endonuclease, that could be involved in UV-induced DNA repair (Tang et al., 2015). Tang et al. (2019) observed that BmN cells infected with BmNPV show higher resistance to high UV radiation than non infected cells, suggesting than the baculovirus activate UV repearing pathways, either by producing UV repair enzymes or by complementing cellular pathways.

Other virus families also encode photolyases. The activity of the Amsacta moorei entomopoxvirus gene 25 (AMV025) is able to rescue photolyase deficient *E. coli* cells, confirming its ativity as a functional photolyase (Nalcacioglu et al., 2010).

A recent paper by a sudafrican team (Mwanza et al., 2022), describes selection for UV resistance on a betabaculovirus local isolate, the Cryptophlebia Leucotreta Granulovirus-SA. These authors obtain a more than 1000 fold improved pathogenicity after only five passages on insects after UV exposure. The authors did not conclude on the genes involved in UV tolerance or resistance, but address the point that UV resistance probably has a fitness cost, as it is not generally distributed in the virus population.

As increasing the resistance to UV radiation in baculovirus is a key point in the development of biocontrol agents, research was done by inserting DNA repair enzymes from other viruses (Petrick et al., 2003). These authors did not obtain a significant decrease in the inactivation rate for OBs.

Increasing rainfall or wind intensity will wash off the virus from the leaves, but may also mobilize the virus present in the soil. Most probably, the adhesion of the virus particle to a surface is a pasive mechanism. Crude virus preparations of Heliothis zea nucleopolyhedrovirus strongly adhere to surfaces (Ignoffo et al., 1997), probably due to the soluble components of the dead larva tissues, but this does not seem to be a general feature. Virus-based insecticides can be supplemented with adjuvants that increase the adhesion of particles to the surfaces. Soil is a reservoir for virus, protecting it from UV. If the target passes trhough soil, it can be contaminated. Alternatively, heavy rain or wind can transport virus from the soil to the aerial parts of plants (Jacques, 1985).

Tritrophic interactions

Andrews and Sikorovski (1973), cite in Jacques, 1985, noted that deposits of HNPV on cotton leaves were inactivated during the night when dew caused the deposits to be wet. Plants secrete substances that degrade the virus, maybe combined with humidity. Secretion is a response to stress, that can be climatic (higher temperatures, lower water availability), and accordingly, it might be neccesary to adjust formulations to varying exterior temperatures. A more subtle interaction is the response of plants by making the upper parts of the leaves thicker, and sclerotised, and thus, not eateble to larvae. If the virus is located on this upper part, the probability of ingestion will be lower.

Conclusion

Climatic change will affect the use of viruses as biocontrol agents for the regulation of insect pests. It will offer opportunities to develop new approaches, but direct transposition from what we know to work in one place could not be done to new locations. A careful analysis of the local climate will be necessary. If introduction of a imported virus is the preferred solution, the similarity of climatic conditions between the virus original region and the intended location should be taken into account.

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